Lake Vermont Meadowbrook Project

Stygofauna Assessment

Prepared by

Stygoecologia

Armidale, NSW,

Email: stygoeco@gmail.com

Prepared for

Bowen Basin Coal Pty Ltd

Level 7, 12 Creek Street, Brisbane Queensland (Qld) 4000

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Executive Summary

Bowen Basin Coal Pty Ltd proposes to develop the Lake Vermont Meadowbrook Project, an extension to the existing Lake Vermont Mine located approximately 25 km northeast of Dysart and approximately 160 km southwest of Mackay, within central east, Queensland. The Project comprises underground longwall mining and open cut coal mining of coal seams. On 26 August 2019 the Department of Environment and Science approved an application for Bowen Basin Coal Pty Ltd to voluntarily prepare an EIS under the EP Act, for the proposed project. The controlling provisions are sections 18 and 18A (listed threatened species and communities), sections 20 and 20A (listed migratory species), and sections 24D and 24E (a water resource, in relation to coal seam gas development and large coal mining development). Stygoecologia was commissioned to prepare a Stygofauna Assessment for the Environmental Impact Statement (EIS) for the proposed mine.

This report specifically assesses whether subterranean groundwater dependent ecosystems occur within the area of the Project and if they exist, whether the Project is likely to have a significant impact on them. This assessment includes a baseline aquifer ecosystem evaluation of stygofauna and provides a risk assessment of the proposed development to this ecosystem.

The survey of bores in and adjacent to the area of the proposed operations found a depauperate community of stygofauna, stygophiles and stygoxenes associated with the alluvial aquifer (Tertiary sediments) adjacent to the Boomerang Creek. Although the community is depauperate, it is likely that they are present across a wider area within and adjacent to the study area but restricted in distribution to the close proximity of the riverine alluvial corridor due to the fine-grained nature of the sediments and the poor water quality in the surrounding catchment. The low diversity and abundance are likely to be influenced by the fine-grained nature of the sediments. The groundwater fauna found in the phreatic zone of the shallow groundwater of the aquifer consist predominantly of the Oligochaeta (aquatic worms) and Cyclopoid Copepoda (Crustacea).

A total of nine bores (12 samples) were sampled for stygofauna and water quality using rapid assessment techniques. These sites were selected from each of the major geological units. The fine-grained nature of the geology and soils/sediments and poor water quality, at least in the Quaternary alluvium and coal seams, appears to be the limiting factors.

The results showed stygofauna exist in small, isolated populations within the Study Area. A total of eight taxa and 11 individuals were collected from 5 bores during the 2 surveys. The taxa were divided into species of terrestrial (n=6) in origin (stygoxenes and edaphobites) that were collected in 4 bores and true stygofauna (n=2) that were collected from 2 bores. Each true stygofauna species was collected once from separate bores. The depauperate, sporadic and highly localised nature of the community across this Project are assessed as having a low ecological value based on the community composition and number of taxa for the sites surveyed.

While stygofauna are present within a small number of the shallow, alluvial piezometers, they were not collected from the deeper coal seam aquifers. The community composition included eight orders. This included one crustacean, one order of Oligochaeta, one order of mite and five families of insects (including the Collembola and the Diplura). There were no listed threatened species collected, however, as is the case for most assessments in this emerging field, some groundwater species are likely to be new to science. The biological and water quality data indicates that the stygofauna is associated with the Tertiary sediments and the others are associated with the quaternary alluvial aquifers. There were no stygofauna recorded for the coal measures. The shallow aquifers are composed of fine sediments with relatively low electrical conductivity and relatively neutral pH water quality whereas the other aquifers have very high electrical conductivity and relatively more acidic pH. The low numbers and inconsistent nature of the community composition within the bores that recorded stygofauna across the Project Area is an indication of low connectivity within the shallow alluvial aquifers due to the fine-grained nature of the sediments. For this reason, the shallow alluvial aquifer was assessed as having a low ecological value for the purpose of this project. The fine-grained nature of the coal measure and of the alluvial soils on the hill slopes and alluvial sediments as well as the high electrical conductivity of the coal measures are suggested as reasons for the lack fauna in the other sites.

The results of the current survey indicate that the ecosystem condition within Tertiary sediments and the Quaternary Alluvium Aquifer is currently stable along this subcatchment as indicated by the relatively consistent water levels and water chemistry.

Stygofauna are potentially threatened by activities that change the quality or quantity of groundwater, disrupt connectivity between the surface and aquifer, or remove living space. Aquifer drawdown and possible water chemistry changes are identified as the main risks to stygofauna associated with the future proposed Lake Vermont Meadowbank mine. The potential impacts include changes to:

- water table levels.
- aquifer flow paths.
- aquifer discharge volume to off-site GDEs.
- the frequency/timing of water table level fluctuations.
- natural groundwater chemistry; and
- groundwater salinity levels.

The stygofauna recorded are assessed as having a low ecological value and a low risk of mining related impacts based on the modelled drawdown to the Tertiary Sediments and Quaternary alluvial aquifers from water extraction and the connected, loosing nature of the alluvials groundwater to the underlying coal seams. A risk assessment ranked ecological risk to sites where stygofauna were present as Class G (low value/low risk). The remaining bores which did not record stygofauna were also ranked as Class G (low value/low risk). The short-term management actions as outlined in the GDE Risk Assessment Guidelines (Serov et al, 2012) to these risk ratings include continuing the ongoing risk monitoring of physicochemical parameters such as water level and water chemistry; periodic biological survey monitoring for the identified hot spot sites; and the exploration of more appropriate monitoring locations. This is suggested within a long-term adaptive management and monitoring program.

1. Introduction

The uniqueness of Australia's biodiversity is encapsulated and magnified tenfold by its groundwater dependent biodiversity. Groundwater in an aquifer is a body of underground water but it is not isolated or stationary. Neither is it devoid of life or an inexhaustible supply of clean water. It flows in much the same way as a river from its surface recharge zone to its surface discharge areas and will transport impacts such as pollutants or reductions of quantity throughout the subsurface environments to the surface land and waters. Therefore, there is always a flow-on effect from one point of impact on the groundwater quantity or quality to the rest of the landscape (Serov & Kuginis 2017). The parameters that make groundwater environments a separate entity to many surface water environments and have contributed to the development of many specialised, highly endemic ecosystems, communities, and species, is the relatively consistent nature of its flow, pressure, level, and water chemistry.

Bowen Basin Coal Pty Ltd (Bowen Basin Coal) proposes to extend the existing Lake Vermont Mine by developing the Lake Vermont Meadowbrook Project (the Project), which comprises underground longwall mining and open cut coal mining of coal seams to the immediate north of the existing Lake Vermont Mine. The Lake Vermont Mine and the associated Meadowbrook Project is located approximately 25 km northeast of Dysart and 160 km southwest of Mackay in the Bowen Basin region of central Queensland (Figure 1).

1.1. Purpose of this Report

The primary objectives of this study are to:

1) Determine whether any substantial stygofauna communities exist within the Project area and surrounds.

2) Determine the species ranges if stygofauna exist and identify conservation values such as short-range endemics.

3) Determine the factors influencing stygofauna distribution such as water quality (DO, pH, conductivity, temperature), aquifer structure, and connectivity to rivers.

4) Assess the potential impacts of the Project on stygofauna and if appropriate, recommend future work programs to potentially investigate and/or monitor this ecosystem over time.

1.2. Impact Assessment Objectives

The aim of the stygofauna baseline surveys and impact assessment is to determine the presence of stygofauna within the area of the proposed future development and to assess the potential impacts of the proposed development on groundwater including aquatic threatened species, populations, communities, or their habitats that are dependent on groundwater. Although it is never possible to be completely exhaustive in such an investigation due to the complexity of geologies, habitat formation, habitat availability and the hydrogeological flow paths, the following process ensures the results will be as comprehensive and reliable as possible. The assessment addresses the impacts of the mining operations on any stygofauna communities that may be present within the associated aquifers. This assessment includes a baseline aquifer ecosystem evaluation for stygofauna across the study area and provides a risk assessment of the proposed development to this ecosystem.

The specific objectives of this study are to:

- Describe the natural/pre- development characteristics of the groundwater ecology through quantitative and qualitative monitoring of stygofauna, water chemistry and water levels.
- Identify or determine the likelihood of occurrence of threatened stygofauna species, populations, habitat and/or communities within the study area.
- Determine if the mining of coal could affect groundwater ecology.
- Assess the likelihood that any identified potential impacts will cause significant adverse effects to groundwater ecology using a risk-based assessment designed specifically for Groundwater Dependent Ecosystems and Stygofauna; and
- Determine whether these impacts will significantly impair any identified threatened species, populations, habitat, or communities.

1.3 Project Overview

The Project is situated in the Bowen Basin of Central Eastern Queensland, Australia, on tenure adjoining the northern boundary of the existing Lake Vermont Mine. The Lake Vermont Mine is an operation producing primarily hard coking coal and low volatile PCI coal.

The Project represents an extension of mining activities at the existing Lake Vermont Mine and involves underground longwall mining and open cut mining activities within the Mining Lease Application (MLA) area and supporting infrastructure (Figure 1 and Figure 2).

The key components of the Project include:

- underground longwall mining of the Leichardt Lower Seam and Vermont Lower Seam; the depth and thickness of the coal seams in the Project area means the coal resource can be extracted using underground mining methods.

- an open cut pit to mine the Leichardt Lower Seam, Vermont Seam, and Vermont Lower Seam.
- development of a new infrastructure corridor linking the new mining area to existing infrastructure at the Lake Vermont Mine.
- development of a Mine Infrastructure Area.
- construction of a drift and shafts to provide access to underground operations; and
- development of other supportingg infrastructure and associated activities.

The Project addresses the forecast reduction in coal production that will occur at the Lake Vermont Mine by combining output from the existing open cut operations and the Project extension.

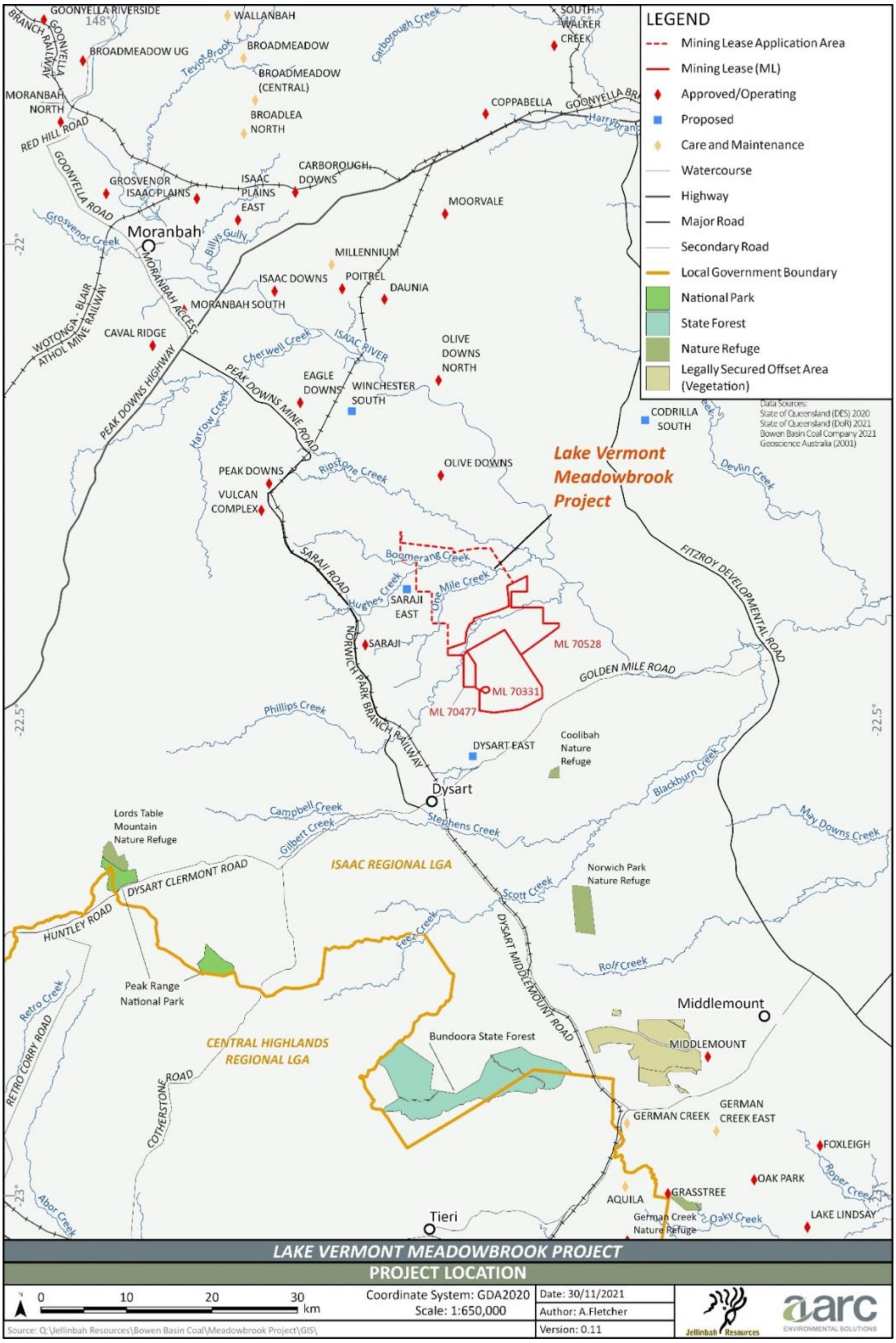

Figure 1. Project Location

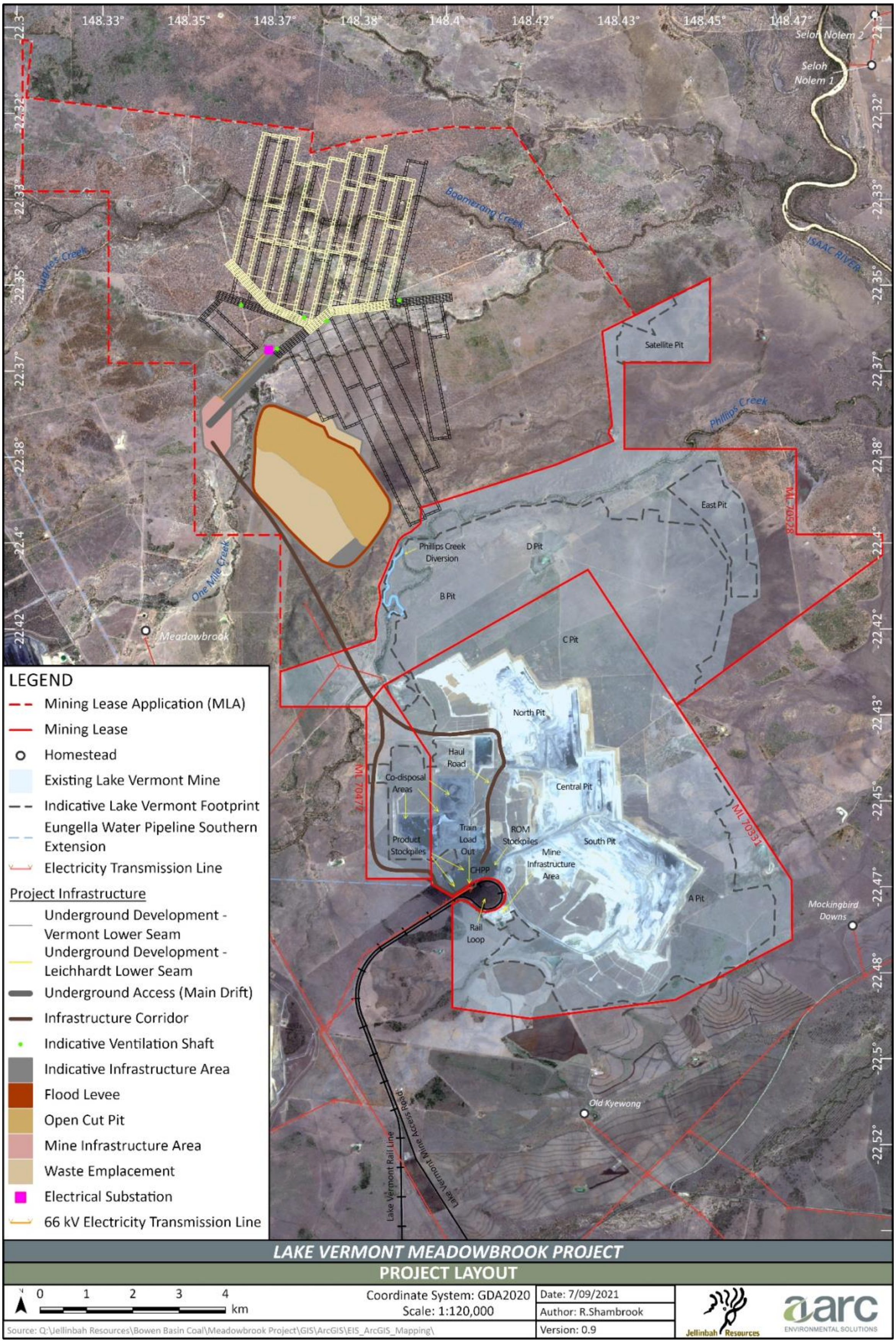

Figure 2. Project Layout.

The Bowen Basin contains numerous mining operations (Figure 2), with a number directly bordering the Project site; including BHP Mitsubishi Alliance's (BMAs) Saraji Mine and proposed Saraji East Project to the west; the recently approved Pembroke 'Olive Downs Coking Coal Project' to the north and east; Whitehaven Coal's 'Winchester South Project' and Aquilla Resources' 'Eagle Downs South Project' both to the north-east and the existing Lake Vermont Mine to the south (Figure 2). The Lake Vermont Mine operates on Mining Lease (ML) 70331, ML 70477 and ML 70528 under the approval of Environmental Authority (EA) Permit No. EPML00659513. The proposed Project lies on Mineral Development Licence (MDL) 303 and MDL 429.

1.4 Critical Matters Relevant to this Study

Groundwater ecosystem dependence is an increasingly important component of surface and groundwater impact assessment initiatives in Queensland. The Project is subject to an MLA process pursuant to Qld's *Mineral Resources Act 1989* (MR Act). The Project activities are also required to be authorized under an EA, pursuant to Qld's EP Act.

The Project will also be assessed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which requires assessment by an EIS process accredited under the environmental assessment Bilateral Agreement (section 45 of the EPBC Act). As such, the EIS must address the 'controlling provisions and all matters relating to them. The controlling provisions for the Project, with regard to its potential impacts on matters of national environmental significance (MNES) are:

- listed threatened species and communities (sections 18 and 18A).
- listed migratory species (Sections 20 and 20A); and
- water resources (24D and 24E).

This study has been conducted to address the Project Terms of Reference that are relevant to the investigation of the subterranean groundwater dependent ecosystem known as Stygofauna.

1.5. Stygofauna Ecology

Stygofauna are animals that live in underground water. They are generally comprised of invertebrates including crustaceans and other invertebrate groups such as worms, snails, mites, and even blind insects. Stygofauna are animals that spend their entire lives in groundwater and due to their specific habitat requirements, the species are generally highly endemic. As such, these organisms have highly specialised adaptations to survive in relatively resource-poor aquifers, where there is limited light, space, and food supply (Humphreys 2008).

Stygofauna are blind, colourless, have slow metabolisms, reduced body size, specialised anatomies, and low reproduction rates (Coineau 2000). As there is no photosynthesis below ground, these groundwater environments rely on inputs of organic matter from the surface to provide the basis of the food web on which stygofauna depend. Despite their small size, the cumulative effect of stygofauna activity plays an important part in maintaining groundwater quality. This process is evident in alluvial aquifers where water flowing though sediment particles is cleaned during transit by stygofauna, in much the same way as water moving through slow sand filters or trickle filters in water and sewage treatment (Hancock et al. 2005). Stygofauna therefore play a functional role in aquifers and are also considered a direct and sensitive indicator of the quality of an underground water source.

1.5.1. Stygofauna Ecological Requirements

Stygofauna are intricately linked both ecologically and physiologically to the aquifer environment and are adapted to the relative stability of their surroundings. Compared to surface environments, groundwater fluctuates less both in level and physico-chemical variables such as electrical conductivity, temperature, and pH (Hancock et al. 2005). Groundwater is also generally lower in dissolved oxygen and has less readily available organic matter than surface water environments (Humphreys 2002). As there is no direct photosynthesis in aquifers, stygofauna rely on connections to the land surface to provide them with food. These connections may be hydrological, with infiltrating water bringing dissolved or particulate organic matter to form the basis of subterranean food webs, or it may be more direct, with tree roots that extend below the water table providing leachates, organic carbon, or fine rootlets for food (Hancock et al. 2005). Generally, stygofauna biodiversity is highest near the water table and declines with depth (Datry et al. 2005).

Stygofauna biodiversity is also higher in areas of recharge where the water table is close (< 20 m) to the land surface (Humphreys 2001, Hancock and Boulton 2008). This is because the water table is likely to have the highest concentration of oxygen and organic matter. Stygofauna can occur at considerable depth below the water table, but are fewer in number, have lower diversity, and may change in community composition (Datry et al. 2005).

In Australia, stygofauna are known from alluvial, limestone, fractured rock, and calcrete aquifers (Hancock et al. 2005; Humphreys 2008). Most aquifers occur as confined aquifers and as such have very low dissolved oxygen, high salinity and have a general lack of connectivity with surface environments. Stygofauna require space to live, which is dependent on the porosity of the sediments, degree of fracturing, or extent of cavity development. These requirements must be sufficient to enable fauna to move through the substrate.

The most biodiverse subterranean ecosystems in Australia are recognised to occur within the alluvial aquifers. Alluvial aquifers are unconsolidated aquifers consisting of particles of gravel, sand, silt, or clay (Tomlinson & Boulton, 2008). Within alluvial aquifers, groundwater is stored in the pore spaces in the unconsolidated floodplain material. Shallow alluvial groundwater systems are associated with coastal rivers and the higher reaches of rivers west of the Great Dividing Range. These groundwater systems are often in direct connection with surface water bodies such as rivers and wetlands. Alluvial aquifers are generally shallower than sedimentary and fractured rock aquifers. Due to their shallow and unconfined nature, alluvial aquifers are highly susceptible to contamination/pollution and excessive drawdown of the water table from pumping.

Research in Australia on these stygofauna communities have until recently, been concentrated within Western Australia (Humphreys, 2002) with far less attention being given to the stygofauna of Eastern Australia. However, surveys conducted by government agencies (NSW Office of Water, DECCW), Universities (University of New England, NSW Institute of Technology, Sydney University and Macquarie University) as well as individual researchers and consultancies (Eberhard et al., 1991, Eberhard and Spate, 1995; Serov, 2002; Thurgate et al, 2001; Tomlinson et al., 2007; Tomlinson & Boulton 2008) have found that eastern Australia, and in particular Qld and NSW, is at least as diverse as the regions previously recognised as biodiversity hotspots or centres of high stygofauna biodiversity such as Western Australia.

The findings have found that the most significant and potentially sensitive groundwater organisms are those in aquifers and cave Groundwater Dependent Ecosystems (GDEs) (i.e., those that are totally dependent on groundwater). These invertebrate communities are intrinsically adapted to these very specialised environments.

These ecosystems and organisms have many values including the following:

- A majority are rare or unique.
- Retain phylogenetic and distributional relictual[1] species and communities.
- The ecosystems surviving in aquifers and caves are amongst the oldest surviving on earth.
- High proportion of short-range endemics.

[1] Relictual species are species that exist as a remnant of past geological ages.

- Develop or retain narrow range habitat requirements (i.e., narrow range endemic species). To survive, these species and communities continue to rely on the continuance of certain groundwater levels/pressure and water chemistry.
- Develop specialised morphological and/or physiological adaptations to survive in groundwater environments.
- They have water quality functions, biodiversity value and add to the ecological diversity in a region.

The other important characteristic of alluvial aquifer communities is that their dispersal capabilities are entirely dependent on the subsurface hydrological connectivity of the alluvial aquifer with other aquifers and have narrow physiological tolerance ranges in water chemistry. As this community is adapted with specialized morphological features, narrow environmental tolerances and have no desiccation tolerant life stages (i.e., they cannot disperse via surface rivers and streams or via aerial dispersal of eggs) they are solely restricted to this habitat (Gibert et al. 1994; Gibert & Deharveng, 2002; Marmonier et al, 1993; Rouch and Danielopol, 1997; Sket 1999b; Danielopol et al., 2000; Serov, 2002; Tomlinson & Boulton, 2008). Tomlinson & Boulton (2008) outline the characteristics of subsurface aquifer communities. These communities can be isolated by a few barriers including geological, hydrogeological, climatic and differences in water chemistry. Due to these barriers to dispersal, subterranean communities in general have a high potential for speciation and very short-range endemism and are highly vulnerable to habitat change resulting in local or total extinction of species.

Stygofauna surveys in Queensland, and more specifically within and around the Bowen Basin have identified the karst or carbonate aquifers as well as the alluvial aquifers as the main aquifer types to contain a stygofauna community. A literature review conducted by Glanville et al. (2016) indicates that while stygofauna has been recorded in hypersaline groundwaters, there is a general negative trend between stygofauna richness and EC. with the average EC values in which stygofauna have been recorded were less than 4,000 µS/cm (3D Environmental, 2018).

1.5.2. Processes that Threaten Stygofauna

There are three critical factors that are essential requirements for stygofauna communities in aquifers. These include:

1) Stable water quality/physicochemical parameters.

Many groundwater species have evolved under strict physiochemical constraints and require a level of stability of these parameters for their continued existence. Stygofauna can tolerate natural fluctuations in water parameters such as groundwater level, electrical conductivity, and temperature. This has been demonstrated experimentally (Tomlinson et al. 2007) for stygofauna such as amphipods, copepods, and syncarids. However, changes outside the natural range of water quality, water chemistry and levels such as rapid drawdown or changes to water chemistry such as a pollution plume is likely to have significant impacts on the community composition, biodiversity, and overall sustainability of the community.

2) Surface connectivity.

Groundwater communities require links to the surface environment to provide organic matter and oxygen. If that linkage is broken or disrupted, the stygofauna community in the area affected could decline over time.

3) Subterranean connectivity.

The third critical factor is subterranean connectivity and dispersal capability. Stygofauna typically have a high degree of endemicity (Humphreys 2008) that is controlled by the animal's ability to move through and along hydrologically connected environments. Unlike many surface-dwelling aquatic invertebrates, stygofauna do not have aerially dispersing life stages. To migrate between areas, stygofauna must be able to swim or crawl through the aquifer matrix. However, as aquifers are not homogenous in porosity and change over geological time, natural hydrological barriers within the matrix restrict their movement. Over time, these natural barriers encourage genetic isolation and ultimately, speciation. Barriers, however, can also be created rapidly by changes in water levels or water chemistry/quality such as an area of lower porosity and sections of poor water quality. If any area is impacted by a disturbance that results in a loss of biodiversity, these new barriers to dispersal may prevent recolonization of the habitat.

Many species of stygofauna are restricted to small geographical areas. This is particularly the case in non-alluvial aquifers such as some of the limestone karsts of NSW (Eberhard & Spate 1995; Thurgate et al. 2001), and calcrete aquifers in Western Australia, where one or more species are known only from a single aquifer, or part of an aquifer (Humphreys 2002). This means that any process that threatens the aquifer, potentially threatens an entire species and community. There is also a high degree of endemism in alluvial aquifers, even between adjacent systems (Hancock and Boulton 2008). However, providing there is sufficient hydrological connectivity within the aquifer, and physico-chemical conditions are suitable, the distribution of species will not be restricted to small parts of an aquifer.

1.5.3. Potential Impacts of Mining on Stygofauna

Mining operations may incorporate a range of activities in their operations that may result in impacts on water resources and subsequently, stygofauna communities, including, but not limited to, some or all the following (Serov et al. 2012):

- ❑ Below water table mining.
- ❑ Water supply development (e.g., groundwater, dewatering, surface water).
- ❑ Desalination for potable supply (with subsequent brine disposal).
- ❑ Dust suppression.
- ❑ Tailing's disposal.
- ❑ Overburden storages.
- ❑ Backfilling and rehabilitation works.
- ❑ Water diversions and surface sealing.
- ❑ Hazardous and dangerous goods storage.
- ❑ Water storages including wastewater ponds; and
- ❑ Disturbance/removal of terrestrial vegetation.

In recognition of the above mining activities, potential direct effects on GDEs may be as follows:

- ❑ Quantity (changes in groundwater levels, pressures, and fluxes).
- ❑ Quality (changes outside of natural ranges, concentrations of salts, heavy metals, and other toxic water quality constituents).
- ❑ Groundwater interactions (changes in interactions between groundwater systems and between groundwater and surface systems); and

❑ Physical disruption of aquifers (excavation of mining pits and underground workings, compaction of aquifer matrix through dewatering, increase in porosity by blasting, or overburden compaction).

The existence and extent of these water affecting activities, and their potential impact on local to regional scale groundwater resources will depend largely on the scale of the mining operation, mining method, and process water requirements, as well as the climatic and geological setting.

1.5.4. Other studies

The National Water Commission (NWC) reported (RPS 2011) that extensive gaps exist in our knowledge of the distribution, composition, and biodiversity value of Australian stygofauna. Despite this incomplete inventory it is apparent that stygofauna are present across a variety of Australian subsurface environments and are generally characterised by high diversity and local scale endemicity.

In Australia, at least 750 stygofauna species have been described (Humphreys 2008). However, more than 66 % of known species come from just two regions of Western Australia, which suggests that the total continental biodiversity is much higher (Humphreys 2008) and large parts of Australia remain un-surveyed.

In Southern Queensland around Baralaba, the fauna consisted of both Cyclopoida Copepoda and Bathynellacea Syncarida which were collected exclusively from the alluvial aquifers. In the broader regional context of the Bowen Basin, stygofauna are known from the alluvial aquifer Devlin Creek (ALS 2011), the Bowen River (GHD 2012), and Mackenzie River (ELA unpublished), and are likely to occur in many alluvial aquifers present in the Basin (4T Consultants 2012). The fauna generally, consists of cyclopoid and harpacticoid copepods, as well as Bathynellacea (GHD 2012). Amphipoda have been collected from northern aquifers with coarse sediments and high hydraulic conductivity (GHD 2012). Stygofauna have also been recorded in a shallow sandstone seam in the Galilee Basin (4T Consultants 2012).

There has been no previous sampling for stygofauna conducted within the study area, however stygofauna surveys have been conducted for nearby areas including the Olive Downs Coking Coal Project (DPM EnviroScience's, 2018), Isaac Downs Coal Mine (FRC Environmental, 2019), Vulcan Coal Project (FRC Environmental, 2020) and Winchester South Project (Ecological Service Professionals, 2021) and did not record any specific stygofauna.

1.6. Terminology Used in This Report

Stygofauna is an all-encompassing term for animals that occur in subsurface waters (Ward et al. 2000). They are classified by the degree to which they are dependent on groundwater. Those that are completely dependent on groundwater are termed stygobites or phreatobites and consist predominantly of crustaceans, Oligochaetes (worms) and a small number of insects. Those that rely on groundwater to a lesser extent and can live in mixed surface and groundwater are termed stygoxenes or stygophiles depending on their adaptation to the subterranean environment (Marmonier et al. 1993). The distinction is often ambiguous because it is difficult to know the degree of surface/groundwater mixing in an aquifer, and the classifications are regularly disputed (Sket 2010). However, classifications based on affiliation to groundwater can be useful when assessing the conservation status of species and their vulnerability to potential impacts. In this report we adopt the following definitions:

Stygoxenes - organisms that have no affinities with groundwater systems but regularly occur by accident in caves and the near surface, shallow alluvial sediments. Some planktonic groups (e.g., Calanoida Copepoda) and a variety of benthic crustacean and insect species (e.g., fly larvae, Caenidae Mayflies) may passively infiltrate alluvial sediments (Gibert et al.1994).

Stygophiles - organisms that have greater affinities with the groundwater environment than stygoxenes because they appear to actively exploit resources in the groundwater system and/or actively seek protection from unfavourable surface water conditions and are associated with the riverine hyporheic zone. Stygophiles can be divided into occasional/temporary hyporheos and permanent hyporheos as well as edaphobites or soil fauna.

Stygobites - obligate subterranean species, restricted to the shallower subterranean environments such as shallow alluvial aquifers and typically possessing specialised character traits related to a subterranean existence (troglomorphisms), such as reduced or absent eyes and pigmentation, and enhanced non-optic sensory structures.

Phreatobites - stygobites that are restricted to the deep groundwater substrata of deep alluvial and fractured rock aquifers (phreatic waters). All species within this classification have specialised morphological and physiological adaptations (Gibert et al 1994).

1.7. Assumptions and Limitations

This report is a baseline assessment, which focuses on identifying the presence and biodiversity of stygofauna within the study area. The study area has been assessed using monitoring and insitu field information and will serve as a baseline for impact assessment.

Groundwater bores sampled are assumed to be representative of the aquifer types and groundwater ecosystems present across the study area. Every effort was given to maximize the representativeness of the aquifer types across the study area with each of the major aquifers and geology types surveyed.

2. Study Area and Sampling Sites

The study area for the purposes of this report encompasses the Lake Vermont Meadowbrook Project area and surrounds (refer to Figures 1-5, and Figure 9).

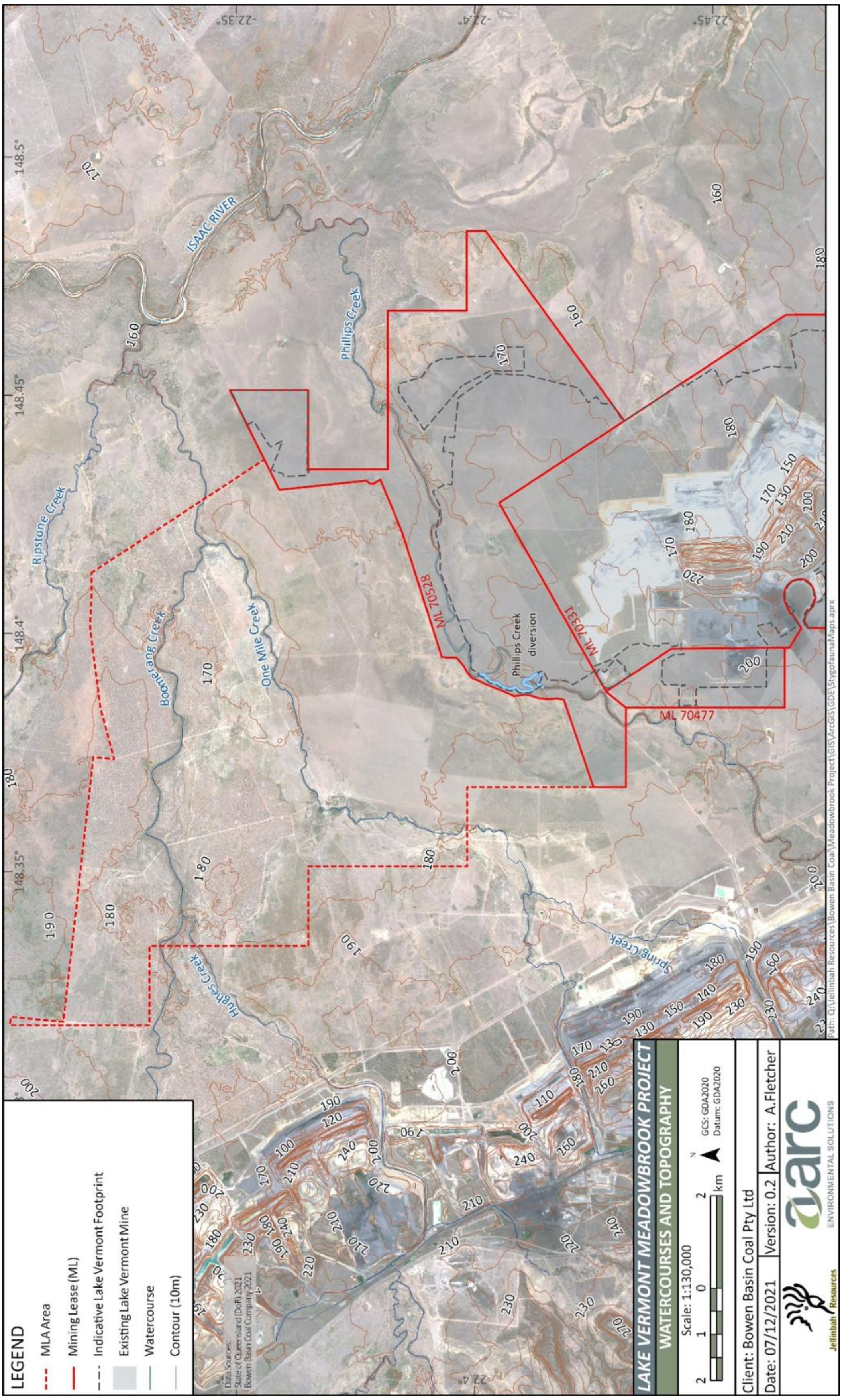

Figure 3. Watercourses and Topography

2.1. General Description

The study area is situated within the Bowen Basin of Central Qld (Figure 1 and 2) and covers Lake Vermont Meadowbrook Project area and surrounding lands and is located within the catchment of five water sources that are tributaries of Isaac River. These are ordered from north to south and include: Ripstone Creek (third order stream), Boomerang Creek (fifth order stream), Hughes Creek (fourth order stream and tributary of Boomerang Creek), One Mile Creek (third order stream) and Phillips Creek (fourth order stream) (Figure 4).

The current land use of the study area is agricultural with the primary industry being beef production and for exploration activities. As described above, several mining operations or projects occur to the north and west of the study area and the Project represents an extension of mining activities at the existing Lake Vermont Mine located to the immediate south (Figure 2).

Boomerang Creek, One Mile Creek, and Hughes Creek flow through the neighbouring BMA leases (Saraji Mine, Saraji East Project) upstream of the Project. Ripstone Creek and its tributaries crosses the northern sections of MDL 429. Ripstone Creek flows through both the BMA leases and the recently approved Olive Downs Coking Coal Project, before joining with Boomerang Creek and flowing into the Isaac River. Phillips Creek flows through both the BMA leases and other Lake Vermont Mine tenements (AARC, 2019). Streamflow in the region is highly variable, with periods of flow (typically during December to April) interspersed with long dry spells (AARC, 2019).

2.1.1. Geology and Geomorphology

The topography of the study area is dominated by the floodplains of Boomerang Creek and One Mile Creek. The area is relatively flat with only slight undulation, with ground elevations ranging between 166-187 m Australian Height Datum (AHD) (Figure 4).

<table>
<tr><th rowspan="2">Age</th><th rowspan="2">Group</th><th colspan="2">Formation</th></tr>
<tr><th>Southern Bowen Basin</th><th>Northern Bowen Basin</th></tr>
<tr><td>Quaternary</td><td></td><td>Alluvium</td><td>Alluvium</td></tr>
<tr><td rowspan="3">Tertiary</td><td rowspan="3"></td><td>Alluvium</td><td>Alluvium</td></tr>
<tr><td>Main Range Basalt</td><td>Main Range Basalt</td></tr>
<tr><td>Duaringa Formation</td><td>Duaringa Formation</td></tr>
<tr><td rowspan="2">Triassic</td><td rowspan="2">Rewan Group</td><td>Arcadia Formation</td><td>Arcadia Formation</td></tr>
<tr><td>Sagittarius Sandstone</td><td>Sagittarius Sandstone</td></tr>
<tr><td rowspan="5">Late Permian</td><td rowspan="5">Blackwater Group</td><td>Rangal Coal Measures</td><td>Rangal Coal Measures</td></tr>
<tr><td>Burngrove Formation</td><td rowspan="2">Fort Cooper Coal Measures</td></tr>
<tr><td>Fairhill Formation</td></tr>
<tr><td>MacMillan Formation</td><td rowspan="2">Moranbah Coal Measures</td></tr>
<tr><td>German Creek Formation</td></tr>
<tr><td>Middle Permian</td><td>Back Creek Group</td><td>Ingelara Formation</td><td>Blenheim Formation</td></tr>
</table>

Table 1. Geological units within the proposed mining area.

The Project is dominated by the three major regional geological formations:

1. Cainozoic sediments - The surface geology and the alluvial sediments across most of the Project area is Cainozoic and includes a combination of Quaternary and Tertiary sediments. These are composed of fine sands, silt, clay, and minor gravel. The depth of this formation is highly variable ranging from 2 to 80 m and averaging 26 m. The formation gradually thickens through the southern part of the area to the south of Boomerang Creek) to 35 – 45 m. In the area to the north of Boomerang Creek, the Cainozoic thickness is more than 60 m, with the area of greatest thickness associated with a topographic high (Minserve 2017, JBT Consulting 2022). The Quaternary alluvial sediments generally overlaying the sandier Tertiary sediments. The watertable is generally developed in the Tertiary sediments below the base of alluvium, and the alluvium is likely to be seasonally saturated following direct rainfall recharge and especially following flow events in Boomerang Creek that will provide more direct recharge to the alluvium.

2. Rewan Group – which is an early to mid-Triassic sandstone, mudstone, and conglomerates. The Triassic Sagittarius Sandstone occurs beneath Cainozoic sediments and is the basal formation of the Rewan Group. The unit is up to 300 m thick and is differentiated from the underlying Permian Rangal Coal Measures by a 1 to 3 m thick mudstone, which acts as a regional stratigraphic marker for the base of Rewan (Minserve 2017).

2. Permian Overburden (the Fairhill Formation / Fort Cooper Coal Measures) – which are Permian Age sandstones, conglomerates, mudstones, carbonaceous shales, coal, and cherty tuff (AARC, 2019). Fort Cooper Coal Measures. The Late Permian Fort Cooper Coal Measures stratigraphically underlie the Rangal Coal Measures with the unit sub cropping beneath Tertiary

sediments within the western area of the Project area due to either the dip of the strata or due to faulting (e.g., east of the Isaac Fault) (JBT Consulting 2022).

2.1.2. Groundwater

The aquifers sampled during the stygofauna assessment includes the alluvial sediments of the Quaternary and Tertiary sediments, the Permian overburden, the Rewan Group and two Permian coal measures including the Girrah 1 Seam and the Vermont Seam.

Geological and hydrogeological units within the area are as follows.

Alluvial Aquifers

Quaternary Alluvial Aquifers

Quaternary alluvium is of limited lateral extent, relatively thin and has not been observed during prior site investigations or geological exploration data, to contain groundwater. It is conceptualised that this is a shallow, ephemeral, losing groundwater system that does not typically contain permanent groundwater as the alluvial flow seeps downwards into the underlying Tertiary sediments (JBT Consulting 2022). The modelled data (JBT Consulting 2022) suggests the only location where the alluvium is permanently saturated is the Isaac River alluvium (SLR 2021a). The alluvium, however, may be of importance as a source of groundwater recharge to underlying units which could explain the predominance of bores in areas beneath surface drainage lines (AARC, 2019).

Tertiary Sedimentary Aquifer

Tertiary sediments consist of a sub-horizontal blanket and have been previously observed from both exploration and groundwater drilling to be generally dry. However, the basal sand and gravel deposits have been noted to contain localised pockets of groundwater in some instances. The occurrence of these deposits is sporadic, and the continuity of the deposits is not mappable (AARC, 2019). These pockets of groundwater along Boomerang Creek are potentially biological hotspots.

Triassic Sedimentary (Rewan Group) Aquifer

The Triassic Rewan Group occurs as a discrete lens that is fault-bound to the east by the Isaac Fault and forms the recognised basal confining unit of the hydrogeological Great Artesian Basin and normally conceptualised as being a regional aquitard. The unit is known to contain structures or sandstone lenses that can provide locally useable volumes of water for stock supply. However, in the surrounding region there are no registered bores constructed within Rewan Group sediments. This observation, combined with observations from prior drilling nearby, supports a conceptualisation of this unit as low permeability not forming significant regional groundwater units, and likely unimportant as a potential source of groundwater (AARC, 2019).

Coal Seam Aquifers

Permian Sedimentary Aquifers

Within the Bowen Basin it is generally accepted that coal seams are more permeable relative to the Permian overburden and interburden material. Bores are often drilled dry until a water-bearing coal seam is encountered, with water rising along the borehole, indicating confined conditions within the coal (AARC, 2019). Due to the low permeability of the coal measures, groundwater residence time is often long, resulting in occurrences of highly saline groundwater in some areas. It is often the case however, that the coal measures are the first unit where useable volumes of groundwater are encountered.

2.1.3. GDEs

Terrestrial groundwater dependent ecosystems have been mapped across the Project area and are illustrated in Figure 5. The GDE mapping is based on the National Atlas of GDEs (BoM 2021) and is a combined assessment including groundwater modelling, surface vegetation mapping and research into terrestrial vegetation species rooting depths. This mapping does not include subterranean ecosystems; however, it does give an indication of the likely presence of suitable subterranean groundwater resources that could harbour subterranean communities. The mapping identifies:

- A large proportion of the area of land within the study area as having either no, or a low, potential for groundwater.
- areas of 'Moderate potential terrestrial GDEs' associated with riparian vegetation of Boomerang Creek, Hughes Creek and the eastern section of One Mile Creek, and their associated watercourses; and
- Phillips Creek, the lower reaches of Ripstone Creek and the Isaac River as having a high potential for groundwater interaction.

A Groundwater Dependent Ecosystem Assessment has been conducted for the Project by 3D Environmental (2022). The study conducted in parallel with this stygofauna assessment found that there that two types of (surface) GDEs present within the Project Area being:

1. GDE Type 1: Includes drainage features with developed alluvial landforms that host variable groundwater volumes and are seasonally recharged via surface flows and flooding. This includes Phillips Creek, Hughes Creek, and the Isaac River (3D Environmental (2022)).
2. GDE Type 2: This represents a conceptualized perched groundwater lens that lies below GDE Assessment Site 3 (a mapped as an HES wetland). Percolation of groundwater through the alluvial soils occurs when surface water is recharged, and the infiltrating surface water is captured above an aquitard at the alluvial unconformity. Tree roots of river red gum and coolibah are utilizing this freshwater lens, which possibly only remains viable for several months following rainfall. The perched freshwater lens is inferred to be >6m below the surface of the wetland (3D Environmental (2022)).

2.2. Site Data

Nine bores (12 samples) were selected as representatives of each of the major habitats and aquifers (Table 1, Figures 4 and 5). Two stygofauna surveys (one autumn and one spring) were conducted of these bores on 26^{the} May 2021 and 14th September 2021.

All groundwater bores have been monitored monthly for water quality and water level since October 2020, with monitoring continuing. All bores had been installed at least six months prior to sampling to reflect guideline requirements. This report describes the predevelopment/natural water quality and level data collected over a year up to September 2021. All sites sampled are shallow monitoring piezometers of less than 100 m, and accessed groundwater situated in either the quaternary alluvial sediments, tertiary sediments, or deeper coal seams. The design of the sampling regime also considered the direction of the shallow groundwater flow which, as described earlier flows in an easterly direction to the Isaac River.

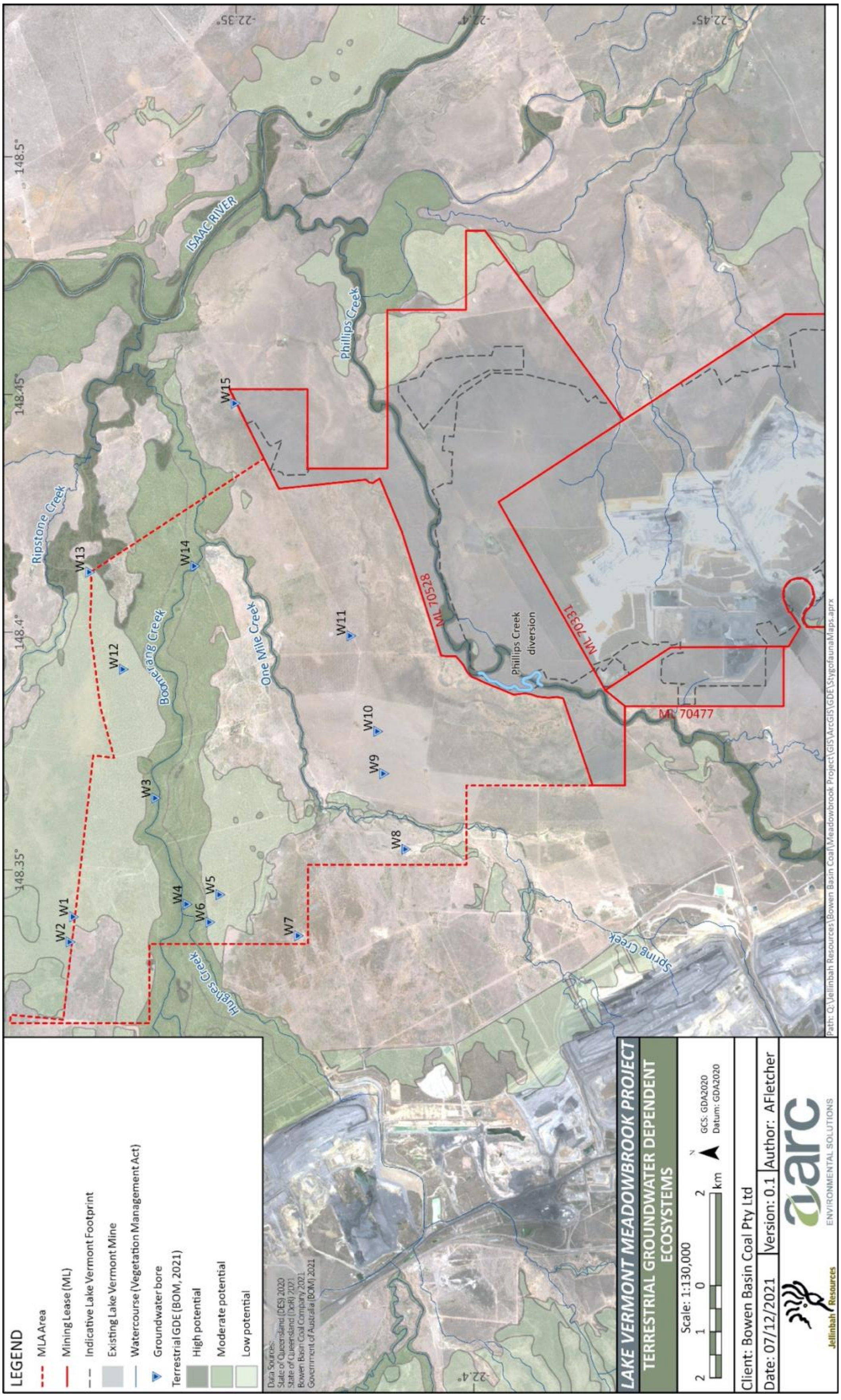

Figure 4. Terrestrial Groundwater Dependent Ecosystems (Bureau of Meteorology, 2021)

Bore ID	Groundwater Unit	Easting (AGD84)	Northing (AGD84)	Collar RL (mAHD)	Casing Stickup (m)	Bore Depth (m)	Slotted (mbgl)
W1_MB1	Tertiary sediments	637914	7531373	187.09	0.60	45.5	42.6-45.1
W1_MB3	Vermont Seam	637919	7531372	187.18	0.60	124	121.5-124
W2_MB1	Tertiary sediments	637368	7531452	187.92	0.60	42	33-40
W2_MB2	Girrah 1 Seam	637370	7531452	187.93	0.60	110	103-110
W3_MB1	Quaternary alluvium	640470	7529435	176.80	0.60	12	9-12
W3_MB2	Tertiary sediments	640468	7529435	176.20	0.60	41	34-41
W4_MB1	Quaternary alluvium	638172	7528735	179.00	0.60	12	9-12
W5_MB1	Rewan Group	638387	7527823	181.15	0.60	50	43-50
W6_MB1	Permian overburden	637758	7527892	179.85	0.60	56	49-56
W11_MB1	Rewan Group	643941	7524860	174.42	0.60	120	113-120
W12_MB1	Tertiary sediments	643268	7530165	166.80	0.60	60	53- 60
W14_MB1	Tertiary sediments	645373	7528515	166.80	0.60	20	14.6-18.6

Table 2. Bore details. The highlight shows the sites that recorded stygofauna. Blue represents stygobites, green represents Stygoxenes/stygophiles, white represents no fauna.

2.2.1. Groundwater Levels

Water levels and bore depths are illustrated in Figure 6. Hydrographs for the bores show very consistent water levels over the period of monitoring with a negligible response to rainfall. The bores with the shallowest groundwater levels are those in proximity to the Boomerang Creek (i.e., W3 MB1, W3 MB2, W4 MB1 W5 MB1, W14 MB1). Groundwater levels within the alluvium decrease with distance from Boomerang Creek, indicating potential recharge to the alluvium i.e., the stream is losing to the groundwater along this section of the stream. Bore W11-MB1 recorded a significant decline in groundwater levels from December 2020 to August 2021, compared to the very stable nature of the other bores. The decline in standing water level would suggest an active pumping event as opposed to natural causes such as a reduction in rainfall due to the rapid decline and gradual recharge. The gradual recovery over a length period would also suggest a low transmissivity for the aquifer.

The groundwater characteristics of the Tertiary Alluvium bores that recorded stygofauna have a surface water level between 17.3 – 15 mbgl, which varied little over time (Table 3 Figure 5). The sediments within the profile are predominantly fine sands with muddy silts and minor clays.

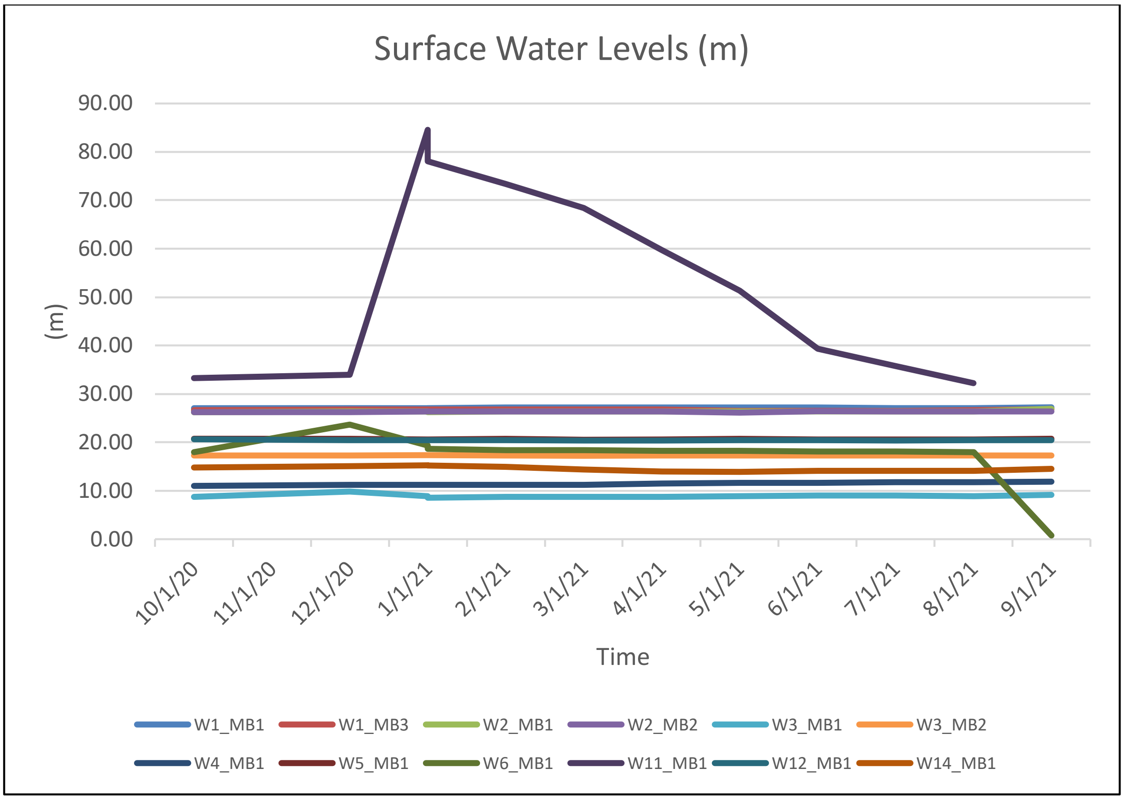

Figure 5. Surface water levels (SWL) depths recorded at each bore over time.

Bores	Groundwater Unit	Total Depth (m)	20/10/20	9/12/20	15/01/2021	26/1/21	16/2/21	24/3/21	14/4/21	26/5/21	29/6/21	26/7/21	24/8/21	14/9/21
W1_MB1	Tertiary sediments	45.5	27.06	27.08	27.06	27.13	27.17	27.16	27.16	27.23	27.15	27.13	27.12	27.24
W1_MB3	Vermont Seam	124	26.65	26.73	26.74	26.75	26.77	26.77	26.77	26.53	26.58	26.49	26.65	26.86
W2_MB1	Tertiary sediments	42	26.21	26.33	26.34	26.31	26.34	26.38	26.33	26.36	26.36	26.36	26.37	26.93
W2_MB2	Girrah 1 Seam	110	26.27	26.27	26.33	26.34	26.37	26.37	26.37	26.14	26.43	26.32	26.41	26.39
W3_MB1	Quaternary alluviun	12	8.68	9.84	8.84	8.56	8.70	8.75	8.81	8.92	9.01	9.02	8.89	9.13
W3_MB2	Tertiary sediments	41	17.33	17.30	17.36	17.36	17.28	17.23	17.28	17.33	17.34	17.29	17.33	17.31
W4_MB1	Quaternary alluviun	12	11.01	11.17	11.21	11.24	11.25	11.24	11.53	11.63	11.70	11.76	11.78	11.88
W5_MB1	Rewan Group	50	20.75	20.74	20.58	20.55	20.69	20.54	20.61	20.69	20.65	20.55	20.58	20.75
W6_MB1	Permian overburden	56	18.01	23.67	19.33	18.61	18.40	18.36	18.25	18.27	18.11	18.16	18.03	18:15
W11_MB1	Rewan Group	120	33.27	34.00	84.56	78.05	73.44	68.35	59.74	51.26	39.30	35.72	32.23	
W12_MB1	Tertiary sediments	60	20.65	20.47	20.48	20.43	20.45	20.38	20.38	20.41	20.41	20.38	20.45	20.5
W14_MB1	Tertiary sediments	20	14.84	15.04	15.26	15.16	14.94	14.38	13.96	13.90	14.17	14.14	14.15	14.49

Table 3. Surface water level (m) data from each site collected. Blue rows represent stygobites, green represents Stygoxenes/stygophiles, white represents no fauna.

2.2.2. Groundwater Water Quality

Overall, the available data (Tables 4-5 for groundwater quality show that:

- groundwater within the Tertiary Alluvium has a range of electrical conductivities (Table 4 Figure 6) that are moderately saline ranging from 7,311-19,966 µS/cm (Bore W3 MB2) to fresh/brackish (178.8-1,202 µS/cm) (Bore W14 MB1) for the bores adjacent to the Boomerang Creek and up to hyposaline (39,283 µS/cm) for more distant bores.

- The pH (Table 5 Figure 7) is generally mildly acidic to neutral across the floodplain ranging from pH 5.77 to 7.05 with an average pH of 6.62. The values in each bore were very consistent over time with no significant connection with rainfall. There was no significant difference between the bores that recorded stygofauna and those that did not, except for Bore W14 MB1 which consistently recorded the lowest pH (and EC) values of all the bores with average of pH 6.03.

Bores	Groundwater Unit	Total Depth (m)	20/10/20	9/12/20	15/1/21	26/1/21	16/2/21	24/3/21	14/4/21	26/5/21	29/6/21	26/7/21	24/8/21	14/9/21
W1_MB1	Tertiary sediments	45.5	500	8817	17339	27524	24171	27160	24503	23665	28371	27454	26085	26115
W1_MB3	Vermont Seam	124	37668	36478	39283	38115	39149	39256	37221	35390	38303	36966	37109	37160
W2_MB1	Tertiary sediments	42	38079	12004	19500	25411	26933	29328	26882	27320	23776	29704	29997	30059
W2_MB2	Girrah 1 Seam	110	2121	39511	36823	39221	39618	39487	38558	38612	40032	34666	38334	39323
W3_MB1	Quaternary alluvium	12												
W3_MB2	Tertiary sediments	41	11685	11400	15749	17618	12118	19463	18547	7311	12116	19177	19523	19966
W4_MB1	Quaternary alluvium	12												
W5_MB1	Rewan Group	50	21254	22528	23363	23500	22776	22511	18810	22009	22151	20293	22606	23409
W6_MB1	Permian overburden	56	12370	14486	14692	15060	15425	15334	15624	15880	16918	17385	17433	17720
W11_MB1	Rewan Group	120	21523	23743	23667	23911	23870	23898	24120	24298	24573	24653	23911	24289
W12_MB1	Tertiary sediments	60	20531	21685	23609	22395	23249	22982	21757	20716	23395	20900	21990	22315
W14_MB1	Tertiary sediments	20	178.8	491		1202	1099	999	963	842	893	889	903	955

Table 4. Electrical Conductivity (µS/cm) data from each site collected. Blue rows represent stygobites, green represents Stygoxenes/stygophiles, white represents no fauna.

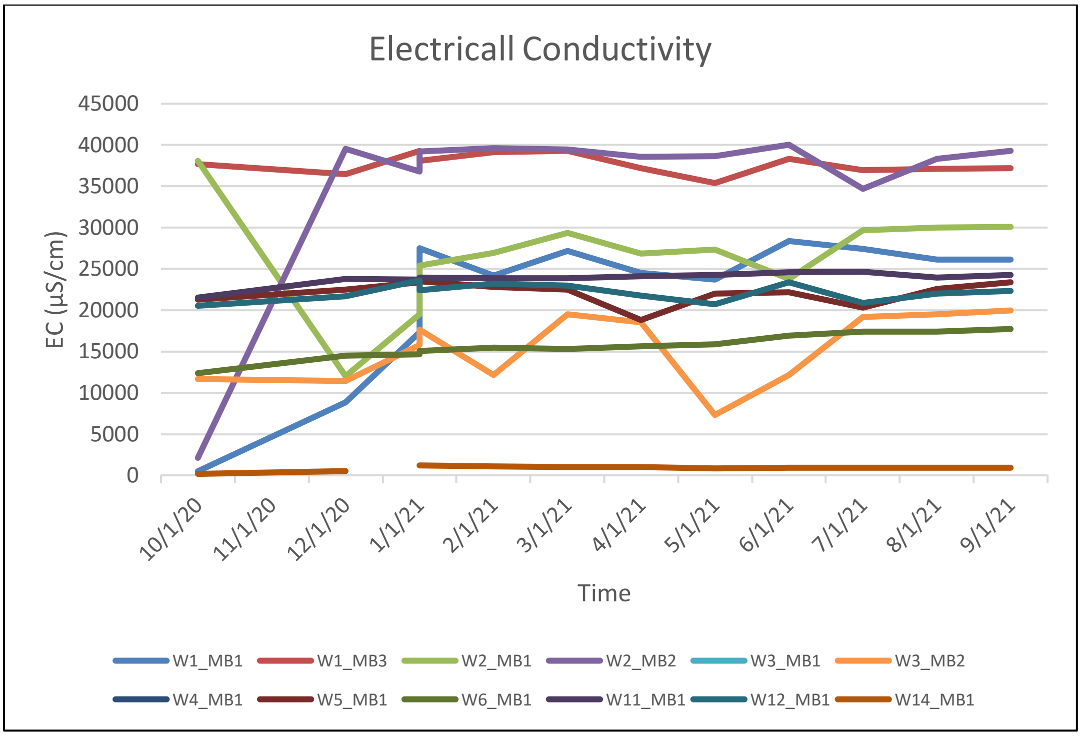

Figure 6. Electrical Conductivity for each bore over time.

Bores	Groundwater Unit	Total Depth (m)	20/10/20	9/12/20	15/01/2021	26/1/21	16/2/21	24/3/21	14/4/21	26/5/21	29/6/21	26/7/21	24/8/21	14/9/21
W1_MB1	Tertiary sediments	45.5	6.77	6.79	6.82	6.70	6.67	6.71	6.65	6.76	6.51	6.58	6.54	6.50
W1_MB3	Vermont Seam	124	6.48	6.73	6.8	6.75	6.66	6.67	6.65	6.77	6.58	6.69	6.60	6.55
W2_MB1	Tertiary sediments	42	6.37	6.70	6.78	6.67	6.61	6.62	6.62	6.72	6.53	6.56	6.46	6.39
W2_MB2	Girrah 1 Seam	110	6.77	6.39	6.52	6.45	6.42	6.42	6.38	6.53	6.31	6.47	6.34	6.26
W3_MB1	Quaternary alluvium	12												
W3_MB2	Tertiary sediments	41	6.41	6.62	6.7	6.61	6.60	6.59	6.56	6.65	6.45	6.52	6.43	6.31
W4_MB1	Quaternary alluvium	12												
W5_MB1	Rewan Group	50	6.60	6.78	6.78	6.74	6.65	6.59	6.68	6.68	6.52	6.67	6.57	6.47
W6_MB1	Permian overburden	56	7.03	6.92	7.05	6.99	6.93	6.93	6.97	7.03	6.83	6.95	6.82	6.75
W11_MB1	Rewan Group	120	6.91	7.10	6.98	6.93	6.86	6.81	6.90	7.00	6.80	6.87	6.82	6.72
W12_MB1	Tertiary sediments	60	6.69	6.89	6.88	6.79	6.73	6.77	6.80	6.88	6.62	6.73	6.59	6.48
W14_MB1	Tertiary sediments	20	6.48	6.56		6.07	5.77	5.84	5.81	6.03	5.98	6.06	5.89	5.83

Table 5. pH data (pH units) from each site collected. Blue rows represent stygobites, green represents Stygoxenes/stygophiles, white represents no fauna.

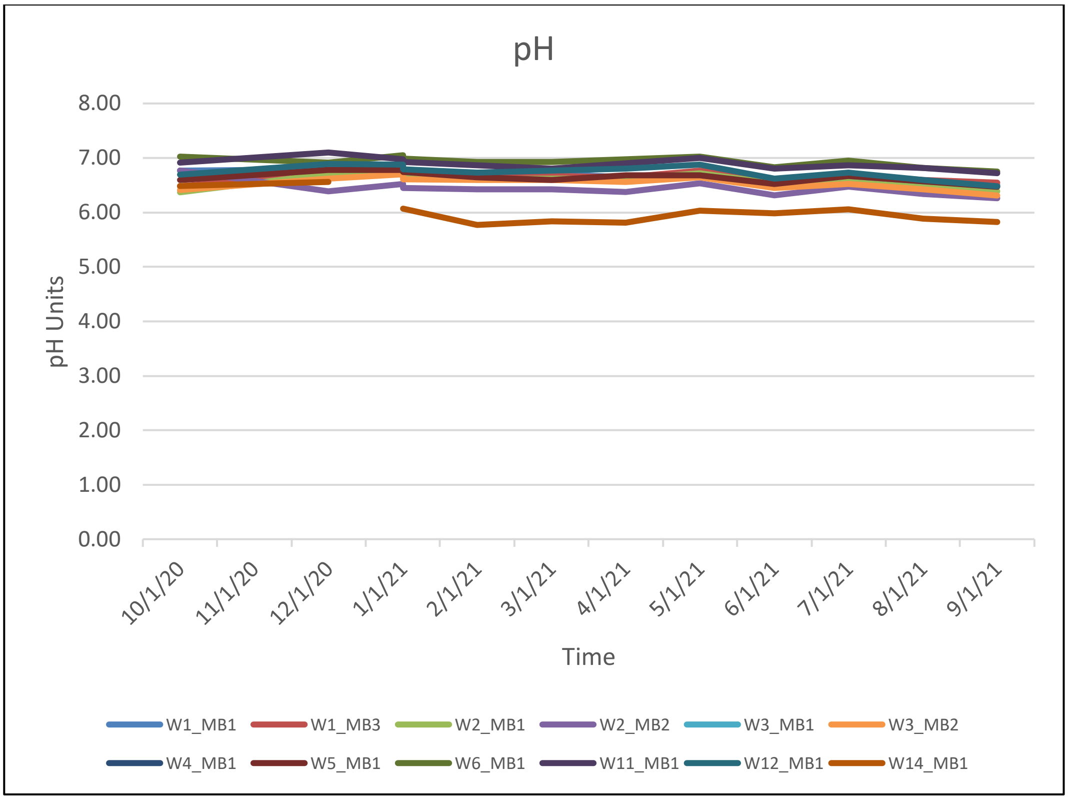

Figure 7. pH for each bore over time.

3. Methodology

3.1. Stygofauna Sampling

In order to sample a habitat effectively it is often necessary to use a combination of techniques to comprehensively collect all possible biota as the stygofauna community occupies a range of habitat niches. For routine surveying or monitoring of bores and wells, a submersible pump or hand pump, bailer and/or plankton nets (Mathieu et al. 1991) are the preferred devices. The sampling techniques used for the stygofauna surveys are described below.

The Phreatic/hypogean zone

The phreatic zone is the subsurface area within an aquifer where voids in the rock are filled with water. This is occupied by phreatobites. The stygofauna community was sampled using two standardised methods.

The first technique is the Phreatobiology Net. This is the standard technique that has been used successfully overseas and in Australia (Bou, 1974). This method involves using a weighted long haul or plankton net with a 150 µm mesh. Sampling consisted of dropping the net down to the bottom of the bore and taking at least three consecutive hauls from the entire water column at each bore. Upon removal from the bore the net is washed of sediment and animals and the contents of the sampling jar (the weighted container at the bottom of the net) are decanted through a 150 µm mesh sieve. The contents of the sieve are then transferred to a labelled sample jar and preserved with 100% ethanol.

The second standard method is the use of a groundwater bailer. A bailer is typically used by hydrogeologists to take water samples from bores for water quality/water chemistry analysis. The bailer used for this study is 1 m long by 40 mm clear plastic tube with a running ball valve at the bottom. The advantage of using a bailer is twofold. The main reason for using a bailer is that it can sample the bottom sediment of a bore that cannot be sampled by a haul net and therefore enables the collection of cryptic invertebrates that do not inhabit the water column or sides of the bore. The second advantage is that in shallow bores down to five meters in sediments with low transitivity porosity, a bailer can empty the entire contents of a bore and thereby confidently collect all animals within the bore. The contents of the bailer are emptied into a cleaned bucket from which the water is then decanted through a 150 µm mesh sieve. The contents of the sieve are transferred to a labelled sample jar and preserved with 100% ethanol. Following sampling and preservation of the sample and prior to the next sampling, all equipment including the bailer, net and sieves must be rinsed clean with clean water via a spray bottle to remove any sediment and animals that may have remained attached to the sampling devices. This is to reduce the possibility of cross contamination of organisms (stygofauna or bacteria) or pollutants from one aquifer or bore to another.

3.2. Laboratory Methods

3.2.1. Identification

All samples are preserved in the field with 100% ethanol and returned to the laboratory where each sample is sorted under a stereomicroscope and stored in 100% alcohol. All specimens are identified to the lowest possible taxonomic level, generally to genus, where possible. Specimens are identified under a compound microscope using a combination of current taxonomic works and keys such as Williams (1981) and the taxonomic identification series (Serov 2002) produced by the Murray Darling Freshwater Research Centre as well as the authors taxonomic expertise and experience.

3.2.2. Physico-Chemical Data

Physical and chemical parameter data was supplied by the proponent during each round of survey and their regular water quality monitoring program. Water quality parameters including electrical conductivity and pH were collected in the field using a water quality multimeter. Bore depth and water level (SWL) data was collected at each site during each survey using a depth probe in the field during the survey.

3.3. Data Analysis

3.3.1. Risk Assessment Methodology

The “Risk Assessment Guidelines for Groundwater Dependent Ecosystems” (Serov et al. 2012) provide an ecological valuation and risk assessment process for identified GDEs and was used as a reference in this study. In summary, GDEs are first identified and classified and the level of dependency on groundwater for individual GDEs inferred. Once the ecological value of individual aquifers has been determined, the ecological value of the GDEs associated with that aquifer can then be assessed. The individual value of each GDE within the aquifer can also be assessed as a stand-alone unit. Following an assessment of the aquifer and associated GDEs current value, the potential future impact of a proposed activity on the aquifer and associated GDEs can then be determined. The Guidelines include a Risk Matrix (Table 6 which combines the ecological; value and Ecological risk to categorise the most appropriate management class for each `GDE. Each class then has a prescribed management response (Table 7. This risk assessment framework has been used to guide the ecological valuation and assessment of potential impacts on stygofauna for the Project.

Diagram 1. Ecological valuation and risk assessment process (Serov et al 2012).

Identify the type and Location of GDEs

Infer or determine groundwater dependency

Identify High Ecological Assets of aquifer/groundwater source if any

Determine ecological value of GDEs of the associated aquifer/groundwater source

Determine the impact of an activity to the identified GDEs

Determine the magnitude of the risks to the identified GDEs

Apply the GDE Risk Matrix

Apply management actions, including mitigation measures associated with each "box" in the risk matrix

3.3.2. Aquifer Risk Assessment

The aquifer risk assessment considers the risk that groundwater extraction and mining places on the groundwater source and its GDEs. In this process the ecological value of a GDE is assessed in association with the risk that a groundwater source and associated GDEs would be under from these impacts, which in turn informs the likely level of management action required. That is, if the aquifer has a predetermined high conservation value or a few high priority GDEs and therefore is of high ecological value, its value has a high risk of being altered by extraction. Conversely if a groundwater source/GDE has low ecological value then there is a low risk of altering its value by extraction. This assessment was completed for each groundwater source and identifies risks to three main aquifer assets according to several attributes as follows:

- ❑ Ecological Assets.
- Risk of a change in groundwater levels/pressures on GDEs,
- Risk of a change in the timing of groundwater level fluctuations on GDEs,
- Risk of changing base flow conditions on GDEs.
- Risk of changing aquifer flow paths.
- ❑ Water Quality Assets.
- Risk of changing the chemical conditions of the water source,
- Risk on the water source by a change in the freshwater/saltwater interface, and
- Likelihood of a change in beneficial use of the water source.
- ❑ Aquifer Integrity Assets.
- Risk of substrate compaction.

3.3.3. The Risk Matrix

The Risk Matrix (Table 2) was built on the concept developed as a method of outlining the most appropriate management response for a given environmental value under a particular activity. The Risk Matrix is a component of adaptive management and is designed to:

1. Recommend the most appropriate management strategies for each given scenario at the outset; and

2. Test the effectiveness of the management strategies over a time by combining a monitoring program with an effective framework for adaptive management (i.e., responding to the monitoring outcomes).

The aims of the management strategies are to:

1. Maintain and/or improve the ecological value of an aquifer and its associated GDEs; and

2. To reduce the level of risk to that aquifer and associated GDEs.

The management strategies for an aquifer and its associated GDEs are based on the comparison of the ecological value of the aquifer and its associated GDEs against the risk to them by the proposed or current activity. The risk is a combination of the likelihood that an altered groundwater regime will impact adversely on the ability of the asset to access sufficient groundwater to meet its requirements and the degree of threat posed to the groundwater regime by the proposed or current activity.

The matrix consists of two axes, the vertical axis plots the level of ecological value, and the horizontal axis plots the level of risk of an activity does or may impose on the aquifer and its associated GDEs. For the purpose of matrix function and structure, the ranking of both ecological values and risk is divided into a three-category system of “High, Medium and Low” values. These categories apply to both aquifers and their associated GDEs.

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**
	Category 1. Low Risk	**Category 2. Moderate Risk**	**Category 3. High Risk**

Table 6. Risk Matrix.

4. Results

4.1. Ecological Response - Stygofauna Data

4.1.1. Community Structure

The stygofauna survey collected 12 samples from nine bores across the study area over two occasions, i.e., one each in May and September 2021. The results of the surveys are provided in Table 5 and illustrated on Figure 9. There are five sites that recorded fauna including 2 sites that recorded stygofauna (W3 MB2 and W14 MB1) and 4 sites that recorded stygophiles/stygoxenes (W3 MB1, W4 MB1, W5 MB1, and W14 MB1). The bores contained a total of eight families of invertebrates, including two aquatic groundwater families and six terrestrial invertebrate families. There were no repeat records of stygofauna families at any site i.e., each stygofauna location has a unique family. There was, however, records of the terrestrial families occurring in more than one bore. The aquatic fauna was present within two shallow bores (W3 MB2 and W14 MB1) geographically separate along Boomerang Creek. These two locations are now designated 'Biodiversity Hotspots' where a 'Hotspot' is defined as a locality that records the highest biodiversity within a designated area. The designated area in this case is the proposed mine development area or Project area. The bores were situated approximately 5km apart adjacent to Boomerang Creek. The stygofauna community composition included one family of aquatic worms (Oligochaeta), one family of Copepoda (Crustacea), whereas the Stygophiles included three families of Edaphobites (soil dweller terrestrial fauna) consisting of 1 family of Diplura (primitive insects), one Prostigmata mite (Arachnida) and one family of Collembola (primitive insects). There were no listed threatened species collected, however, as is the case with most assessments in this emerging field, some species are likely to be new to science and may have restricted distributions in particular, the Stygobites. All bores that recorded fauna occurred in native woodlands.

The sites can be delineated into two different ecotones by the fauna present (see below). The bores in which the Oligochaeta and Copepoda were found within the study area can be characterised by the shallow depth of the standing water levels, the lower electrical conductivity (compared with the surrounding bores) and the moderately acidic pH as well as the high sand/low clay composition of the substrate.

				Locality	W3 MB1	W3 MB1	W3 MB2	W4 MB1	W5 MB1	W14 MB1	W14 MB1
Phylum	Class	Order	Family	Habitus	25/5/21	15/9/21	26/5/21	14/9/21	25/5/21	26/5/21	15/9/21
Annelida	Clitellata	Oligochaeta	Naididae	Stygobite	0	0	0	0	0	0	1
Arthropoda	Arachnida	Prostigmata	Halacaridae	*Stygophile*	0	0	0	0	2	0	0
Arthropoda	Collembola	Poduromorpha	Hypogastruridae	Stygophile	0	1	0	0	0	1	0
Arthropoda	Entognatha	Diplura	Campodeidae	*Stygophile*	2	0	0	1	0	0	0
Arthropoda	Insecta	Diptera	Chironomidae	*Stygoxene*	0	0	0	1	0	0	0
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Stygoxene*	0	0	0	1	0	0	0
Arthropoda	Insecta	Terebrantia	Thripidae	*Stygoxene*	2	0	0	1	0	0	0
Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Stygobite	0	0	3	0	0	0	0
				No. Taxa	2	1	1	4	1	1	1
				No. Animals	4	1	1	4	2	1	1
				No. Stygobite	0	0	1	0	0	0	1
				No. Stygophile	1	1	0	1	1	1	0
				No.Stygoxenes	1	0	0	3	0	0	0

Table 7. Taxa listed by site. Blue rows represent sites that recorded fauna, white represents no fauna.

Ecotone 1 - Stygobites – Sites: W3 MB2 and W14 MB1

The obligate groundwater/aquifer fauna recorded during the surveys belonged to the Oligochaeta (aquatic worm) Family Naididae (Aquatic Worms) and the small crustaceans, Copepoda, that belongs to the Family Cyclopidae. These two families are relatively common in alluvial sediments (Coineau. (2000), Gibert & Deharveng. (2002), Hancock, et al. (2005), Tomlinson & Boulton. (2008)) and possess the characteristic morphological features including absent eyes, no pigmentation. The samples contained very fine sand and minor silts and clay sediments of between approximately 50-100µm. The low number of taxa and specimens collected at each site indicates that dispersal through the aquifer is limited by the fine-grained nature of the unconsolidated sediments.

The taxon collected belong to the hypogean (true groundwater) ecosystem, which typically has relatively low DO, permanent darkness, highly stable water quality, and low energy levels from allochthonous input and bacteria. The presence of Oligochaeta within the groundwater indicates that the stratum was unconsolidated and is probably a paleochannel of an ancient riverbed consisting of inter-bedded medium to coarse grained sands and gravels. Oligochaeta are usually associated with finer unconsolidated substrates that act as slow to trickling filters and play an important role in increasing the efficiency of bacterial growth and maintaining open interstitial spaces through their feeding activities (Danielopol, et al, 2000). The family Naididae is a common aquatic family of freshwater worms, which currently contains approximately 23 genera and 59 species. In terms of their use within current environmental sensitivity indices such as the SIGNAL Index ranking, they can only be assessed at the Order level of Oligochaeta which has a ranking of 2. This equates to a family which is quite tolerant of environmental disturbance. This, however, is misleading as the family is usually associated with high water quality environments.

Subterranean Oligochaetes and Copepoda are an increasingly important component of Australia's groundwater fauna that contain many short-range endemic species with large faunas along the continental marginal areas, particular in the southwest and eastern seaboards. They are a poorly known group that requires further taxonomic work (Pinder & Brinkhurst, 1994). The occurrence of these two groups in the shallow alluvial aquifer indicates a connectivity between the surface water of the watercourses and the shallow groundwater water sources as well as probable distribution along the catchment. This indicates that they are most likely to be widely distributed with a low level of localised endemism.

Oligochaeta

The Naididae typically inhabit and swim in the water column just above the substratum, whereas other aquatic oligochaetes that do not burrow, crawl along the substratum. The feeding habit of most aquatic oligochaetes is to ingest detritus and sediments although some species of Naididae may be carnivorous, while others are parasitic. Naididae species reproduce by a process of budding from a special segment

(Pinder & Brinkhurst, 1994). The Australian naidid fauna consists mostly of cosmopolitan species, although there are indications of greater endemicity than currently recognised. Increasingly, new Naidid species are being collected from seasonal habitats on granite outcrops in the south-west and from refugial habitats (caves, groundwater, and permanent river pools) in drier regions. A complete picture of oligochaete distributions will require much more work and patterns suggested by current data are presented here as hypotheses (Pinder, 2001).

The presence of worms and a general paucity of large crustaceans at these sites indicates that the water quality is characterised by elevated organic carbon, and possibly high levels of dissolved iron, lower (acidic) pH levels ranging from approximately 6-4 pH units and relatively low DO. The relatively small size (1-2mm) of the Oligochaete (worm) species present indicates a low to moderate connectivity within the river/aquifer environment. The shallow water table levels within the riverine hyporheic zone suggests a direct association/connectivity with a slow base flow river system with a shallow alluvial water table. The direction of flow discussed earlier i.e., away from the river into the aquifer suggests that the stygofauna recorded are associated with and limited to the river channel sediments i.e., the narrow alluvium along the river rather than the alluvial plain which has higher EC and finer sediments. Although primarily stygobites i.e., belonging to the shallow groundwater ecotone, this family can also be found within the riverine, hyporheic zones in areas of groundwater discharge where the discharge can be either point source springs or diffuse discharge through a moderate to course grained substrate such as sand or gravels (Gilbert 1994).

Copepoda

The Copepoda are a subclass of Crustacea comprising over 10,000 known species (Williamson and Read 2001). Copepoda are predominantly marine, although 3 of the 10 orders are widespread and abundant in freshwater habitats. These are the Calanoida, Cyclopoida and Harpacticoida. The first order occurs in the water column as plankton only, whereas the latter two are common in benthic habitats of surface waters and are important components of many groundwater communities.

The Copepoda Cyclopidae is normally associated with fine to course sandy substrates of still water environments of rivers, wetlands, the hyporheic zone and shallow groundwaters. Although they are a ubiquitous component of these habitats, their small size means that they are often overlooked and undercounted. In terms of management, therefore, they are potentially very useful bioindicators, particular of base flow fed streams or alluvial aquifers or flow through wetlands, as they are sensitive to changes in the environment (Tomlinson & Boulton, 2008). The Cyclopidae were collected on one occasion at 1 site (Bore W3 MB2) which is located within the shallow alluvial adjacent to Boomerang Creek. This site is characterised as being shallow (41m), occurring within the alluvium and having moderate salinity and slightly acid pH.

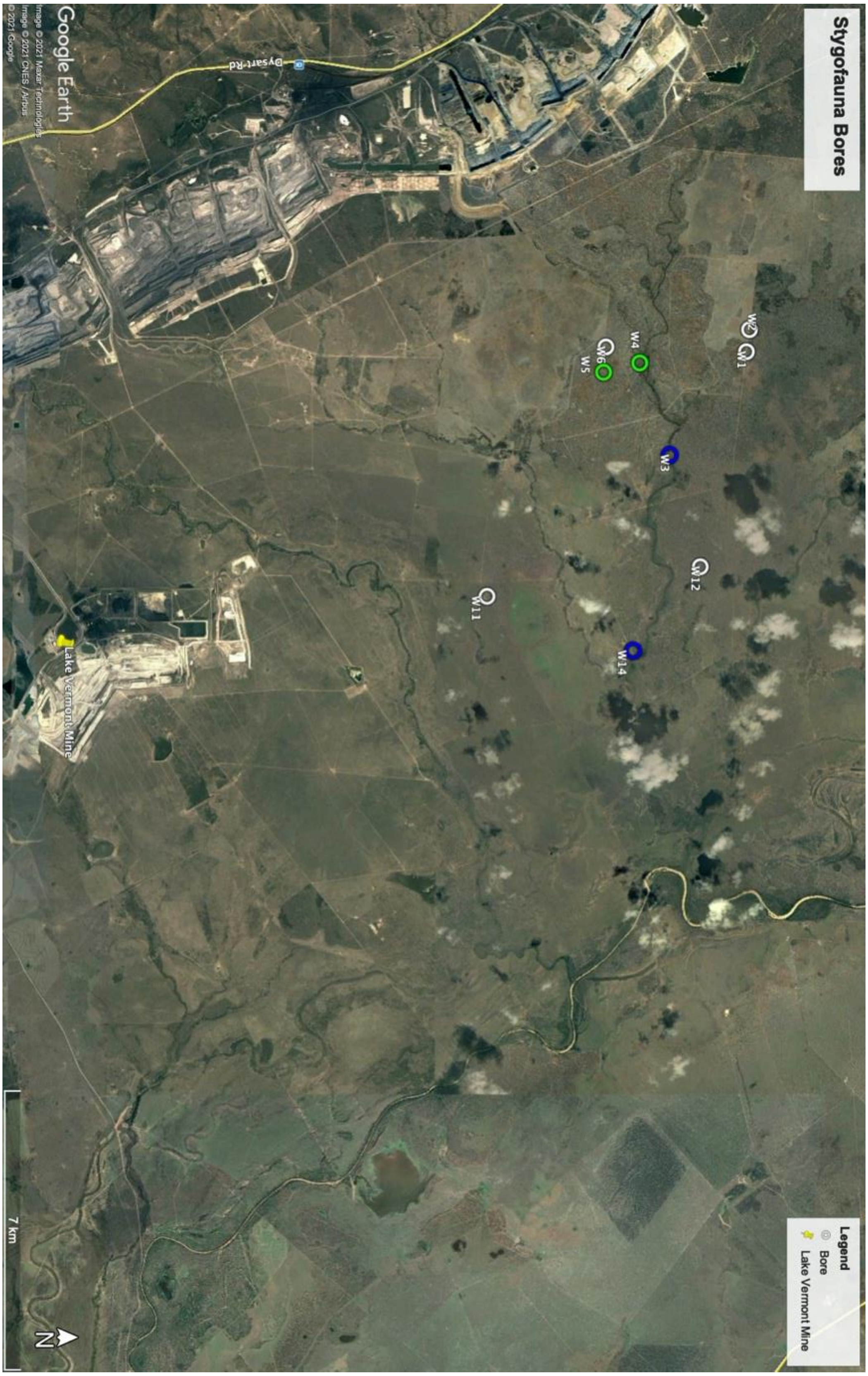

Figure 8. Google Earth image of bores sampled. Blue pins represent stygobites, green represents Stygoxenes/stygophiles, white represents no fauna.

Ecotone 2 – Stygophiles/Stygoxenes/Edaphobites – Terrestrial Fauna. Sites: W3 MB1, W4 MB1, W5 MB1, and W14 MB1

Four sites recorded the presence of terrestrial invertebrates with only one site (W3 MB1) recording fauna on two occasions. No site recorded the same fauna more than once. The common reason for the presence of a range of terrestrial based fauna in bores is that these sites offer a reliable source of moisture in arid to semi-arid regions. The humic rich, subsurface soils and interiors of bores provide moist environments that can harbor a rich community of soil and leaf litter invertebrates. These communities as well as surface ground and arboreal terrestrial invertebrates will gravitate to these environments for water, particularly during dry periods such as summer or droughts. As the edaphobites in particular, have physiological requirements for higher humidity levels, they occupy the transition zone between the terrestrial and aquatic environments and other refugial environments such as inside bores. Their presence in these habitats including bores is therefore regarded as incidental. The family Thripidae, for example is an entirely terrestrial family associated with terrestrial vegetation and is regarded as an accidental occurrence.

The dominant group collected belonged to the primitive soil insects, the Diplura and Collembola. They are common in leaf litter. They are typically detrital or fungal feeders associated with the ground litter layer and tree bark. Their presence in the samples is most likely coincidental either by falling in or occupying the vegetation adjacent to the bore or living within the bore above the water table, as they prefer humid environments. As they are terrestrial soil and leaf litter fauna and not associated with groundwater environments no further description will be given.

The other group of invertebrates are regarded as true Stygoxenes as they have no affinity with groundwater at all and only occur within bores either where there is no cap on the bore or through flooding where the animals wash in. The fauna includes families that are normally associated with surface water aquatic environments and are collectively termed Aquatic Macroinvertebrates. This group includes the Families Chironomidae (Midges) and Caenidae (Mayflies).

4.1.2. GDE Risk Assessment Results

The ecological value and risk value assessment undertaken for the Project was based on data collected over one year of groundwater physico-chemical parameters and water levels, two stygofauna surveys and the predicted drawdown models for the Tertiary Sediments (Figure 9) and Quaternary Alluvial Aquifers (Figure 10). This has provided a snapshot of the current condition of the subterranean environments and the possible impact to the subterranean community as a result of the development of the Project. An overall value and risk assessment was conducted by focusing on the stygofauna within the shallow aquifer of the study area to demonstrate the condition and ecosystem function performed by these aquifers.

The assessment of the ecological value and risk to the stygofauna community at each of the sites surveyed as well as an overall ecological assessment of the shallow aquifers is presented in Table 8 The blue colour represents the bore sites that registered positive to stygofauna, green represents stygoxenes/stygophiles and white represent negative results.

Locality Name	Habitat	Survey Result	Ecological Value	Ecological Risk	Matrix Ranking
W1_MB1	Bore	Negative	Low	Low	G
W1_MB3	Bore	Negative	Low	Low	G
W2_MB1	Bore	Negative	Low	Low	G
W2_MB2	Bore	Negative	Low	Low	G
W3_MB1	Bore	Stygophile	Low	Low	G
W3_MB2	Bore	Stygobite	Low	Low	G
W4_MB1	Bore	Stygophile	Low	Low	G
W5_MB1	Bore	Stygophile	Low	Low	G
W6_MB1	Bore	Negative	Low	Low	G
W11_MB1	Bore	Negative	Low	Low	G
W12_MB1	Bore	Negative	Low	Low	G
W14_MB1	Bore	Stygobite	Low	Low	G

Table 8. Risk assessment results. Blue rows represent stygobites, green represents Stygoxenes/stygophiles, white represents no fauna.

The Ecological Value (EV) of the subterranean ecosystems within the alluvial Tertiary and Quaternary aquifers surveyed that recorded a positive value is assessed as low due to the very low numbers of taxa and specimens collected as well as their sporadic occurrence. The groundwater of the alluvial plain is generally too salty (with only minor areas of fresh water) to sustain broad stygofauna communities and the sediments porosity are too fine to enable the migration of fauna to accommodate a more diverse subterranean biodiversity. The Ecological Value of the other aquifers including the Permian Overburden, Rewan Group sandstone and coal seams surveyed across the flood plain are also ranked as low EV as they have no stygofauna, high EC, and very fine sediments. Therefore, all aquifer water sources, including the alluvials are assessed as low ecological value.

The results of this assessment demonstrate that although the alluvial aquifer close to Boomerang Creek, is currently regarded as in a natural state/condition in terms of water levels and water quality, i.e., the surveys indicate there has been little to no change over time in the environmental parameters. The very low biodiversity and sporadic nature of stygofauna distribution has resulted in a low value ranking.

Drawdown Zone

Tertiary Sediments

The predicted maximum drawdown zone caused by the excavations and necessary water extraction for the proposed Project is illustrated in Figures 9-10 (JBT, 2022). The maximum groundwater drawdown within the Tertiary Sediments (Figure 9) occurs along the southern side and adjacent to Boomerang Creek. The centre of the cone of depression is greater than 50m deep and located approximately 100-500 km north of Boomerang Creek and 8.5-9 km west of the junction of Boomerang Creek and Isaacs River. The western boundary of the drawdown is approximately 2 km along Boomerang Ck from bores W2 and W6 and the eastern boundary is approximately 4 km along

Boomerang Ck from Bore W14. The depth of maximum drawdown at the intersection with Boomerang Ck is approximately 40-50m due to the proximity of the centre of the cone of depression (>50m).

The impact of this level of drawdown along a 6km stretch of Boomerang Ck would result in a significant drop in water levels within the two bores that have registered stygofauna. Bore W3 MB2 has an average water column depth within the bore of 23.7m with a predicted maximum drawdown of ~40m whereas Bore W14 MB1 has an average water column depth of 5.5m within the bore and a predicted drawdown of ~15m. These drops in water level by would leave W3 MB2 with the water level -16.3m below the bottom of the bore, whereas the water level of W14 MB1 would be -10m below the bottom of the bore. As the maximum depths of the Tertiary strata/aquifer is approximately 60m (JBT, 2022), it is suggested that there would still be water and habitat remaining within the aquifer, although the exact depths of the strata and available habitat it is not currently known at each bore. Therefore the predicted impact to the stygofauna community at both locations expected to be negligible. In addition, the impact of the drawdown is suggested to be lesser or negligible on the western and eastern end of the creek allowing for the retention of more habitat and dispersal capabilities.

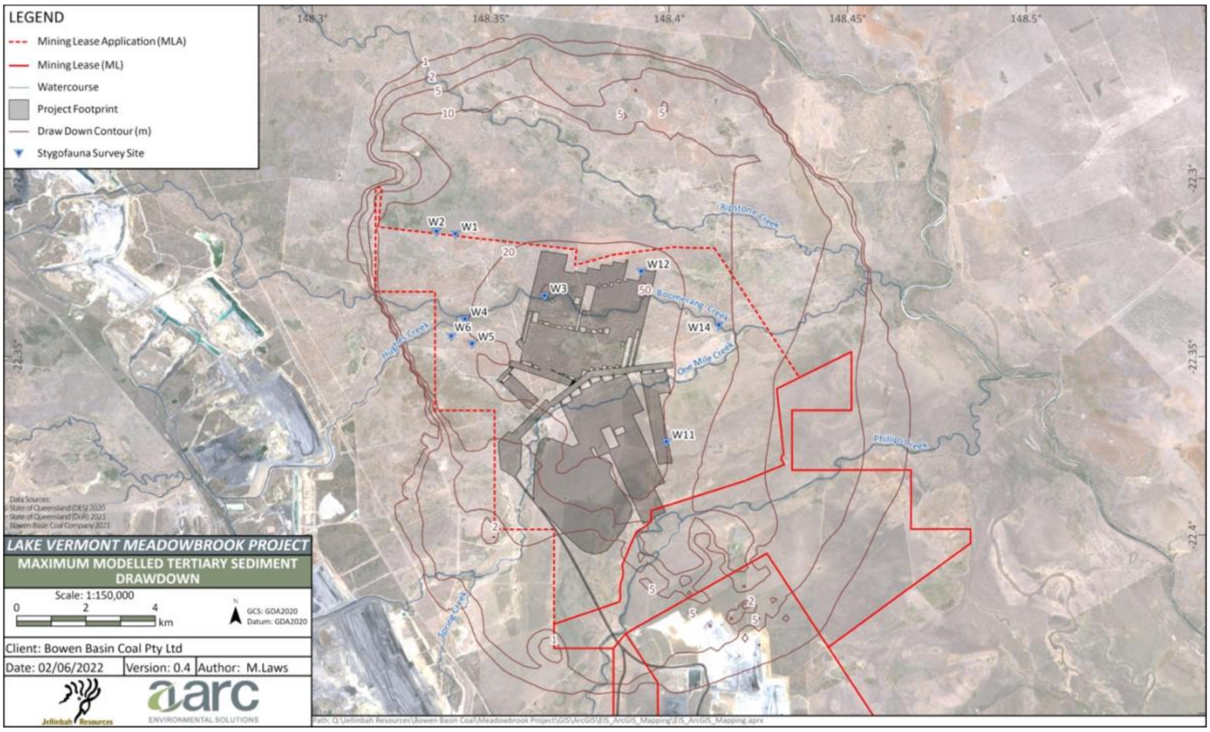

Figure 9. Maximum drawdown zone within the Tertiary Sediments aquifer across the Project Area (JBT, 2022).

Quaternary Alluvium

The maximum extent of the cone of depression within the Quaternary Alluvium Sediments (Figure 10) is estimated to be approximately 1.0 km along Boomerang Ck (JBT, 2022), with the centre of the cone being on the southern side of the watercourse and including Bore W14 MB1, to a maximum depth of drawdown of approximately 2-3m deep and located approximately 2.0 km east of the development and 5 km west of the junction of Boomerang Creek and Isaacs River.

The impact of this level of drawdown along an estimated 1.0 km stretch of Boomerang Ck would result in only a minor drop in water levels within the water table at this location. Bore W14 MB1 is the only bore within proximity to the centre of this cone of depression and has an average water column depth within the bore of 5.5m. This bore, however, has been drilled to monitor the Tertiary Aquifer and is not directly influenced by the Quaternary Aquifer. As there were no stygofauna recorded in this aquifer, there would be negligible impact from this drawdown.

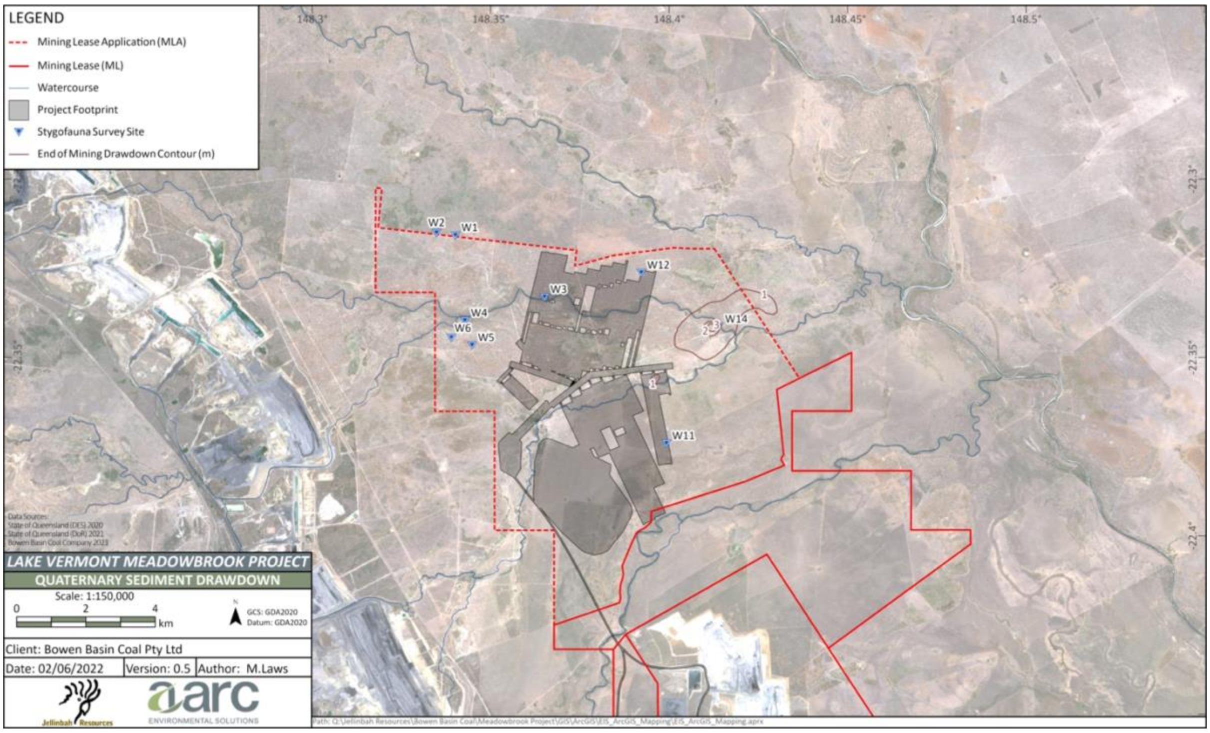

Figure 10. Maximum drawdown zone within the Quaternary aquifer across the Project Area (JBT, 2022).

The GDE Risk Assessment Ranking is G (Low Value/Low Risk) for the aquifer that has recorded stygofauna and for the remainder of the aquifer as the Project is unlikely to significantly reduce the depth of available habitat in the long-term. The maximum predicted drawdown of approximately 50m in the centre of the pit approximately 2km to the south of Boomerang Creek may alter the direction of groundwater flow of the shallow groundwater, which will in term reduce the flow and depth of water to the eastern section of Boomerang Creek and ultimately into Isaacs River. This may also impact on water chemistry in the alluvials and Tertiary Sediments downstream if there is any mixing of the deeper coal measure groundwaters with the shallow aquifers either through upwards leakage from the deeper aquifers or through inadequate surface disposal of the groundwater extracted from the underground mine and open pit. This scenario, however, is unlikely. As the stygofauna is associated only with the stream channel section of the alluvium and not the broader floodplain, it is also unlikely that the population will be adversely impacted by the Project. The study area therefore recorded an overall low risk value for the ecological risk assessment for those sites that recorded stygofauna, as there was a negligible potential for impact as a result of the modelled drawdown levels (JBT, 2022).

5. Management

This baseline stygofauna assessment has identified the presence of groundwater dependent fauna within two bores of the Lake Vermont Meadowbank Mine Project Area. Since the numbers of animals and diversity were very low, they indicate adequate water quality but a weak connectivity between the river and groundwater system (Serov et al. 2012.). The narrow distribution of the fauna recorded would strongly suggest that there is weak connectivity within and between the river and alluvium. The fauna should be considered as having restricted dispersal capabilities and the Oligochaeta and Copepoda should be considered as possible short-range endemics (SREs) species that are associated with this area, however as the survey area was quite small and did not cover other subcatchments it is not possible to estimate their overall distribution. From a management perspective stygobites usually face a higher risk of community change or extinction than other invertebrate communities as they live usually occur in small geographical areas and typically have narrow physiological tolerance ranges.

The risk assessment presented in Tables 8 identified the Tertiary Sediments (where stygofauna were recorded) and the remainder of the aquifers in the Study Area to have a Class G risk ranking i.e., Low Ecological Value/Low Ecological Risk) for the current ecological conditions and the risk from the proposed development. The Class G suggests that following actions are required over the life of the development.

a) *Protection measures for aquifers and GDEs* in the short and mid-term,

b) *Baseline risk monitoring* in the short and mid-term

c) *Ongoing adaptive management* and continued monitoring in the long term.

This also indicates that the ecological values of the aquifers and the stygofauna community where present in the Study Area is low. In addition, the potential for detrimental impacts from the proposed developments is also low as the bores mentioned are associated with the shallow groundwaters along the streamlines and adjacent alluvial aquifers that dependent on surface water flow than from being recharged by the deeper aquifers.

5.1. Cumulative Impacts

Cumulative effects may result from a number of activities interacting with the environment. The nature and scale of these effects can vary depending on factors such as the type of activity performed, the proximity of activities to each other and the characteristics of the surrounding natural, social, and economic environments. They may also be caused by the synergistic and antagonistic effects of different individual activities, as well as the temporal or spatial characteristics of the activities. Importantly, cumulative effects are not necessarily just additive. The implication of multiple mining actives in one region, as proposed within the Study Area i.e., the proposed combined open pit and underground mines coal mine along the existing Lake Vermont Coal Mine other nearby mines, is that impacts may overlap and result in larger impacts than would be expected for a single mining operation (cumulative effects).

In addition, the cumulative impact of flow-on impacts can occur downstream along the flow paths for groundwater and surface waters. All waters flow dispersing both contaminants and depressions in groundwater levels as plumes. The groundwater and surface waters originating in the Lake Vermont Meadowbrook Coal Mine area of development will transport any contamination and drawdown impacts along a flow path to the east and northeast of the mine. Therefore, the area of highest risk from flow-on impacts is the lands, streams, and groundwater sources downstream. This area therefore should have a high priority for monitoring.

5.2. Suggested Management Actions

Further work suggested for future stygofauna monitoring includes:

- ❑ Conduct annual biodiversity hotspot surveys in conjunction with monthly water quality monitoring program to monitor potential changes/impacts to the stygofauna community over the life of the mine until after the mine closure and rehabilitation period.
- ❑ Continue ongoing monthly monitoring of water levels, and water chemistry, with the addition of water temperature.

6. Conclusions

The baseline sampling and assessment of the subterranean groundwater ecosystems has demonstrated that:

- ❑ A low diversity of subterranean diversity of groundwater dependent fauna were recorded in the shallow, unconfined Tertiary/alluvial aquifers of the Boomerang Creek Alluvium close to the stream but not into the floodplain *per se*.
- ❑ Stygofauna were present within the groundwater drawdown zone of the Project (i.e., the impact zone) and the groundwater flow path of any potential contamination event downstream of the development .
- ❑ There is an apparent connectivity within and between aquifers and the associated watercourses.
- ❑ None of these species are currently listed as endemic, relictual, rare, or endangered or Threatened biota (fauna or flora), populations or communities as listed under the Qld Nature Conservation Act or the Commonwealth EPBC Act.
- ❑ The ecological value of the two positive bores is considered low due the restricted nature of the habitat and the very low number of disturbance tolerant taxa collected.
- ❑ The disjunct distribution of the fauna between the bores i.e., the lack of repeat records and dissimilarity of fauna between bores indicates a discontinuous connectivity between the shallow alluvial aquifers and Boomerang Creek.
- ❑ The risk of the proposed development to these subterranean ecosystems was rated as low based on the shallow modelled depth of drawdown within the Tertiary Sediments compared to the depth of the aquifer, the limited potential water quality changes to Boomerang Creek as the shallow alluvium is a losing system i.e., water from the stream is draining down into the lower strata/aquifers.
- ❑ The Risk valuation for the bores that did not record stygofauna in the other aquifers is also low due to the lack of fauna.
- ❑ There was insufficient long-term data to determine whether past land use practices have impacted aquifers and associated GDEs. However, as the water quality were relatively consistent across the study area it is a strong indication that the aquifers were in good or at least natural condition.
- ❑ The short-term management recommendations to these risk ratings include continuing the ongoing risk monitoring of physicochemical parameters such as water level and water chemistry; periodic biological survey monitoring for the identified hot spot sites (the two positive bores).

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9. Appendix 1 - Ecological Risk Assessment Sheets

Table 9. Ecological Valuation of Shallow aquifers that recorded stygofauna.

Locality	Quaternary and Tertiary Alluvial Aquifers (W3 MB2 and W14 MB1)				
GDE ENVIRONMENT	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
GDE or part thereof occurs or is reserved in National Estates, listed wetlands, SEPP 26 etc.			No		
Presence of exotic flora or fauna within GDE	None exist				
Removal or alteration of GDE type or subtype			Major change/alternation in physical structure, species composition, or size resulting in a permanent change in GDE type or subtype.		
AQUIFER					
Water quantity parameters	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
Alteration of the frequency and/or magnitude and/or timing of watertable level fluctuations.			Fluctuation in groundwater levels resulting in permanent loss of any dependent habitat type. *		
Alteration to direction of hydraulic gradients			Permanent reversals in hydraulic gradients resulting in changes to any dependent habitat type.		
Water quality parameters	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
Degree of acid runoff or acidification of groundwater source.				X	
Degree of nutrient load.				X	
Degree of groundwater salinity.			Permanent increase in salinity to dependent ecosystem.		
Degree of bioaccumulation i.e. heavy metal contamination			Permanent exposure of dependent ecosystem to heavy metal and/or toxins.		
Aquifer structure	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
Degree of alteration of aquifer structure (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction, compaction of aquifer, etc).			Major change/alternation of aquifer structure resulting in a permanent change in GDE habitat**		
BIODIVERSITY					
Rarity within catchment/groundwater source	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
Presence of Threatened, Rare, Vulnerable or Endangered species, population or ecological community within GDE.			No		
Presence of indicator, keystone, flagship, endemic or significant species, populations or communities within GDE			No		
Diversity within catchment/groundwater source	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
Diversity of groundwater dependent native flora and fauna species within a GDE.			Presence of one species or less than 50% of species relative to reference sites		
SPECIAL FEATURES WITHIN CATCHMENT/GROUNDWATER SOURCE	**High**	**Moderate**	**Low**	**Unknown**	**Comments**
Presence of rare physical/physico-chemical features or environments (e.g. karsts, mound springs, natural saline wetlands, peat swamps etc)			Occurs only within the State		
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation through aquifer connectivity	Unconfined aquifer with connection to terrestrial and aquatic ecosystems.				
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation relating to aquifer structure and porosity	Unconsolidated aquifer with connection to terrestrial and aquatic ecosystems.				
TOTAL NUMBER OF ATTRIBUTES (n=16)	3	0	11		
OVERALL VALUE			Low	2	
COMMENTS	The ecological value of the subterranean ecosystem for the bores that recorded a positive value is given as low due to the low numbers of taxa and specimens collected. The groundwater of the alluvial plain and is generally too salty to sustain broad stygofauna communities and the sediments are to fine to accommodate a more diverse subterranean biodivesity				

Table 10. Ecological Valuation of aquifers that did not record stygofauna.

Locality	All bores with no stygofauna Aquifers (Vermont Seam, Tertiary Sediments, Girrah 1 Seam, Permian overburden, Rewan Group)				
GDE ENVIRONMENT	High	Moderate	Low	Unknown	Comments
GDE or part thereof occurs or is reserved in National Estates, listed wetlands, SEPP 26 etc.			No		
Presence of exotic flora or fauna within GDE	None exist				
Removal or alteration of GDE type or subtype			Major change/alternation in physical structure, species composition, or size resulting in a permanent change in GDE type or subtype.		
AQUIFER					
Water quantity parameters	High	Moderate	Low	Unknown	Comments
Alteration of the frequency and/or magnitude and/or timing of watertable level fluctuations.			Fluctuation in groundwater levels resulting in permanent loss of any dependent habitat type. *		
Alteration to direction of hydraulic gradients			Permanent reversals in hydraulic gradients resulting in changes to any dependent habitat type.		
Water quality parameters	High	Moderate	Low	Unknown	Comments
Degree of acid runoff or acidification of groundwater source.				X	
Degree of nutrient load.				X	
Degree of groundwater salinity.	No detectable change from natural seasonal variation.				
Degree of bioaccumulation i.e. heavy metal contamination	No detectable change from natural seasonal variation.				
Aquifer structure	High	Moderate	Low	Unknown	Comments
Degree of alteration of aquifer structure (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction, compaction of aquifer, etc).			Major change/alternation of aquifer structure resulting in a permanent change in GDE habitat**		
BIODIVERSITY					
Rarity within catchment/groundwater source	High	Moderate	Low	Unknown	Comments
Presence of Threatened, Rare, Vulnerable or Endangered species, population or ecological community within GDE.			No		
Presence of indicator, keystone, flagship, endemic or significant species, populations or communities within GDE			No		
Diversity within catchment/groundwater source	High	Moderate	Low	Unknown	Comments
Diversity of groundwater dependent native flora and fauna species within a GDE.			Presence of one species or less than 50% of species relative to reference sites		
SPECIAL FEATURES WITHIN CATCHMENT/GROUNDWATER SOURCE	High	Moderate	Low	Unknown	Comments
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation through aquifer connectivity			Confined aquifer has very limited or no connection to terrestrial and aquatic ecosystems		
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation relating to aquifer structure and porosity			Confined aquifer has very limited or no connection to terrestrial and aquatic ecosystems		
TOTAL NUMBER OF ATTRIBUTES (n=16)	3	0	10		
OVERALL VALUE			Low	2	
COMMENTS	The ecological value of the subterranean ecosystem for the bores that recorded a negative value is given as low due to the absence of fauna. The groundwater of the alluvial plain and is generally too salty to sustain broad stygofauna communities and the sediments are to fine to accommodate a more diverse subterranean biodivesity				

Table 11. Ecological Risk Assessment of Shallow aquifers that recorded stygofauna.

Locality	Potential Risk of Project to Quaternary and Tertiary Alluvial Aquifers (W3 MB2 and W14 MB1)			
Water Quantity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What will be the risk of a change in groundwater levels/pressure on GDEs?			No change to aquifer water levels or pressure.	
What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?			No change in timing of water level fluctuations.	
What will be the risk of changing base flow conditions on GDEs?			No change in direction of flow.	
Water Quality Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of changing the chemical conditions of the groundwater source?				X
What is the risk on the groundwater source by a change in the freshwater/salt water interface?				X
What is the likelihood of a change in beneficial use (BU) of the groundwater source?				X
Aquifer Integrity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of damage to the geologic structure?			No change	
Biological Integrity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of alterations to the number of native species within the groundwater dependent communities (fauna and flora)?			No reduction in No. of species.	
What is the risk of alterations to the species composition of the groundwater dependent communities (fauna and flora)?			No change in species composition.	
What is the risk of increasing the presence of exotic flora or fauna?			None exist.	
What is the risk of removing or altering a GDE subtype habitat (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction)?			No removal or alteration of habitat.	
Risk Valuation (n=12)	0	0	8	3
Risk	The Risk value for the sites that recorded stygofauna is minimal to negligible as the mine is unlikely to alter the direction of flow of the shallow groudnwater at these locations as the drawdown values would not be detrimetal to habitat availibility. The potential impacts of drawdown may increase groundwater movement from the alluvium into the cone of depression into the deeper confined aquifers. The movement of water from the shallow aquifers to the deeper aquifers is likely to moderate the potential impacts to water chemistry. The level of impact to water chemistry however is currently unknown. As the stygofauna is associated with the river channel section of the alluvium and not the broader floodplain, the likely impact of water level declines is predicted to be minimal.			

Table 12. Ecological Risk Assessment of aquifers that did not record stygofauna.

Locality	All bores with no stygofauna Aquifers (Vermont Seam, Tertiary Sediments, Girrah 1 Seam, Permian overburden, Rewan Group)			
Water Quantity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What will be the risk of a change in groundwater levels/pressure on GDEs?	Reduction in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in permanent loss or alteration of defined habitat type.			
What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?	Fluctuation in groundwater level(s) or piezometric pressure beyond established seasonal variation, resulting in permanent loss or alteration of defined habitat type.			
Water Quality Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of changing the chemical conditions of the groundwater source?			Negligible change (<5%)	
What is the risk on the groundwater source by a change in the freshwater/salt water interface?			No change or not applicable	
What is the likelihood of a change in beneficial use (BU) of the groundwater source?			Negligible change for identified triggers (<5%)	
Aquifer Integrity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of damage to the geologic structure?	Permanent destruction of the aquifer matrix. Major cracking/fracturing of the bedrock/stream bed leading complete dewatering of the GDE			
Biological Integrity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of alterations to the number of native species within the groundwater dependent communities (fauna and flora)?			No reduction in No. of species.	
What is the risk of alterations to the species composition of the groundwater dependent communities (fauna and flora)?			No change in species composition.	
What is the risk of increasing the presence of exotic flora or fauna?			None exist.	
What is the risk of removing or altering a GDE subtype habitat (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction)?	> 20% removal or alteration of habitat area.			
Risk Valuation (n=11)	4	0	6	
Risk	**The Ecological Risk value for the sites that did not record stygofauna is negligible as there are no stygofauna is associated with the deep coal meaure aquifers therefore there will be no change to the biodiversity.**			