Adani Mining Pty Ltd

Technical Report for Carmichael Coal Mine and Rail Project EIS

'Stygofauna Survey'

14 November 2012

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1. Introduction

1.1 Project Description

Adani Mining Pty Ltd (Adani) is proposing to develop a 60 million tonne (product) per annum (Mtpa) thermal coal mine in the north Galilee Basin approximately 160 kilometres (km) north-west of the town of Clermont, Central Queensland. All coal will be railed via a privately owned rail line connecting to the existing QR National rail infrastructure, and shipped through coal terminal facilities at the Port of Abbot Point and the Port of Hay Point (Dudgeon Point expansion). The Carmichael Coal Mine and Rail Project (the Project) will have an operating life of approximately 90 years.

The Project comprises of two major components:

- The Project (Mine): a greenfield coal mine over EPC1690 and the eastern portion of EPC1080, which includes both open cut and underground mining, on mine infrastructure and associated mine processing facilities (the Mine) and the Mine (offsite) infrastructure including:
  - A workers accommodation village and associated facilities
  - A permanent airport site
  - Water supply infrastructure
- The Project (Rail): a greenfield rail line connecting the Mine to the existing Goonyella and Newlands rail systems to provide for the export of coal via the Port of Hay Point (Dudgeon Point expansion) and the Port of Abbot Point, respectively; including:
  - Rail (west): a 120 km dual gauge portion from the Mine site running west to east to Diamond Creek
  - Rail (east): a 69 km narrow gauge portion running east from Diamond Creek connecting to the Goonyella rail system south of Moranbah

1.1.1 Project Area

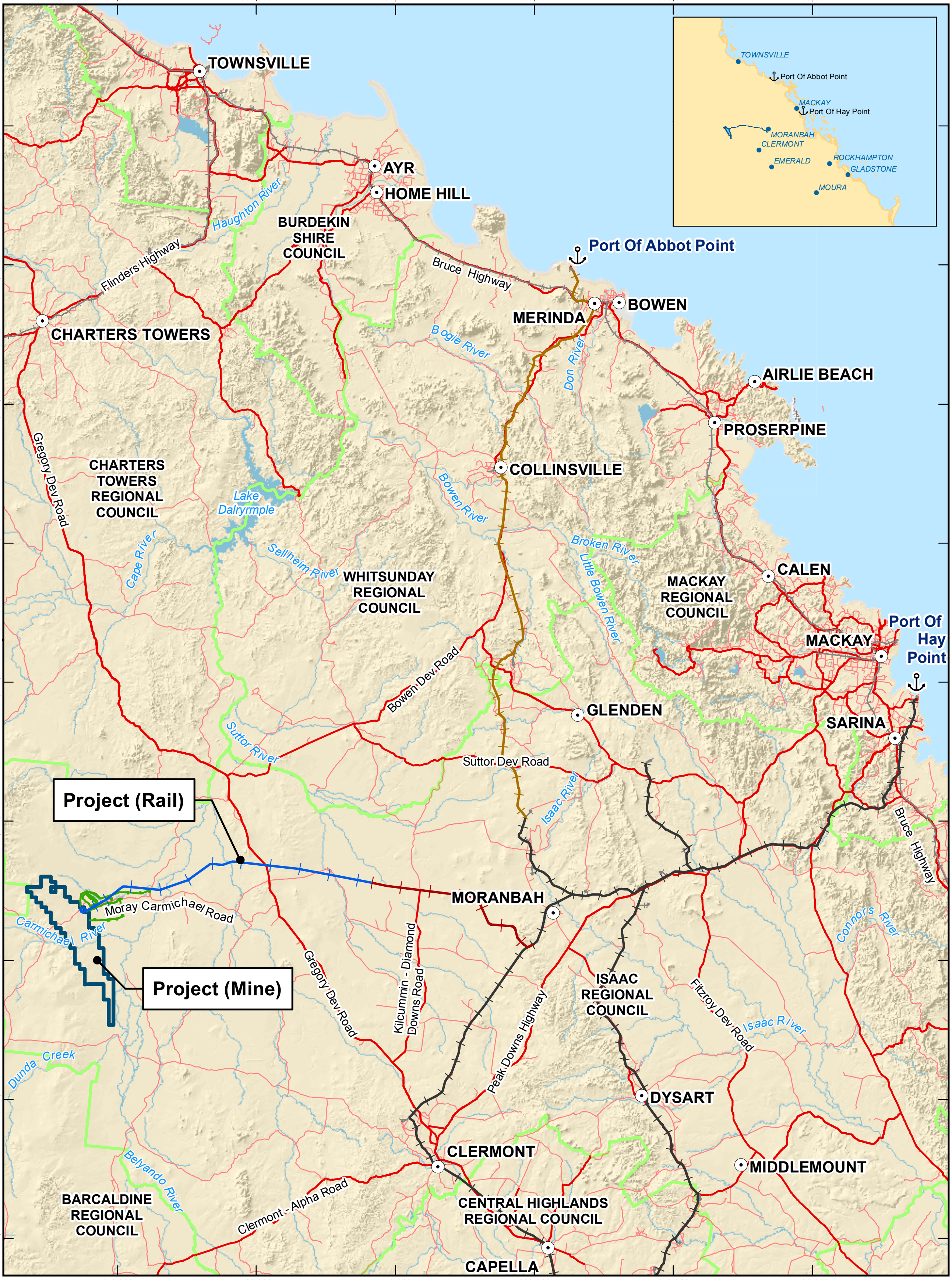
The Carmichael Coal Mine is located mostly on the Moray Downs cattle station, within the jurisdiction of Isaac Regional Council, with railway development located in Mackay and Whitsunday Regional Council areas. The mine is situated approximately 160 Km to the north-west of Clermont, which in turn is located approximately 100 Km north of Emerald (Figure 1-1).

1.1.2 Study Area

The Adani Coal Mine EIS Study Area is located in the Belyando Suttor sub-catchment of the Burdekin Basin defined as part of the central coast region in the Queensland Water Quality Guidelines (DERM, 2009).

The Hydrology Study Area is located within the Carmichael River catchment and contains one major waterway, the Carmichael River, which flows through the southern section of EPC 1690. The Hydrology Study Area is located within the Belyando River Basin. The Belyando catchment is approximately 35,400 km^2 and is one of the main catchments in the Burdekin Basin.

The Hydrogeology Study Area is defined by a 10 km radius extending outwards from the boundary of EPC 1690 and the eastern portion of EPC 1080.



LEGEND

- Town
- Major Port
- Other Rail Network
- Goonyella System
- Newlands System
- State Road
- Local Road
- Watercourse
- Local Government Area
- Project (Rail)
  - Rail (West)
  - Rail (East)
- Project (Mine)
- Mine (Offsite)

Based on or contains data provided by the State of QLD (DERM) [2010]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for marketing or be used in breach of the privacy laws.

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Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

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GHD adani

Adani Mining Pty Ltd

Carmichael Coal Mine and Rail Project

Job Number	41-25215
Revision	L
Date	28-08-2012

Project Location

Figure: 1-1

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Level 4, 201 Charlotte St Brisbane QLD 4000 T +61 7 3316 3000 F +61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data Source: © Commonwealth of Australia (Geoscience Australia): Town, Railways, Watercourses (2007); DERM: LGA, (2011), Hillshade (2009); DMR: State Roads (2008); Gassman/Hyder: Mine (Offsite) (2012); DME: EPC1690 (2010), EPC1080 (2011); Adani: Alignment Opt9 Rev3 (2012). Created by: BW, JVC

1.2 Assessment Context

The Adani Coal Mine Project has been declared a 'significant project' under the *State Development and Public Works Organisation Act 1971* (SDPWO Act) and as such, an Environmental Impact Statement (EIS) is required for the Project. The Project is also a 'controlled action' and requires assessment and approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The Project EIS has been developed with the objective of avoiding or mitigating all potential adverse impacts to environmental, social and economic values and enhancing positive impacts. Detailed descriptions of the Project are provided in Volume 2 Section 2 Project Description (Mine) and Volume 3 Section 2 Project Description (Rail).

GHD was commissioned by Adani Mining Pty Ltd to prepare an Environmental Impact Statement (EIS) for the Project. It is expected that the Adani Project will be declared a Significant Project under the Queensland *State Development and Public Works Act 1971* and a Controlled Action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1994*.

GHD is responsible for the conduct of all environmental studies to meet the defined Terms of Reference (ToR) for the Adani Project. The studies include:

- Aquatic and terrestrial ecology surveys
- Hydrological assessment of stream and river crossings
- Land use and planning assessment
- Noise and air quality assessment
- Social and economic assessment

The development of environmental management measures will also be undertaken to inform the development of environmental management plans for the construction and operational phases of the Adani Project.

ALS Water Sciences (ALS) was commissioned by GHD in September 2011 to undertake a baseline survey of stygofauna for the Adani Coal Mine Project. A comprehensive survey was undertaken in October 2011 across 20 groundwater bores located within EPC 1690 (MDL 372) and a draft preliminary technical report was submitted to GHD in December 2011. The draft report recommended that a second stygofauna survey be undertaken in order to fully comply with WA guideline requirements (2003 & 2007).

A second stygofauna survey was undertaken by GHD Water Sciences in August 2012. This report combines and summarises the findings of the two stygofauna baseline surveys and is based on a combination of a desktop literature review and two field investigations. It covers the assessment of potential impacts on stygofauna communities associated with proposed coal mining activities by the Adani Coal Mine Project.

This report will serve as a technical appendix to the project EIS.

1.3 Project Objectives and Scope of Work

As part of the project EIS a baseline assessment of stygofauna is required in accordance with the Queensland Department of Environment and Heritage Protection (DEHP – previously DERM) generic Terms of Reference.

The aim of the baseline stygofauna survey was to determine if stygofauna are present in groundwater associated with the Adani Coal Mine Project, and within the constraints of the study design, determine the range of taxa present, their conservation significance and sustainable management strategies. The need for a comprehensive stygofauna survey is enhanced by the fact that the Adani Mining Development Lease is in close proximity to the Great Artesian Basin eastern recharge area.

The study design adopted by GHD for both stygofauna field events conducted in October 2011 and August 2012 was based on the requirement to satisfy relevant DEHP generic EIS TOR for stygofauna studies in Queensland. These can be defined as follows :

Aquatic biology:

... "The EIS should provide a description to Order or Family taxonomic rank of the presence and nature of stygofauna occurring in groundwater likely to be affected by the Project. Sampling and survey methods should follow the best practice guideline which is currently that published by the Western Australian Environmental Protection Authority - Guidance for the Assessment of Environmental Factors No.54 (December 2003) and No.54a (August 2007)"...

Potential impacts and mitigation measures:

... "In any groundwater aquifers found to contain stygofauna, describe the potential impacts on stygofauna of any changes in the quality and quantity of the groundwater and describe any mitigation measures that may be applied"...

1.4 Relevant Project Legislation

1.4.1 Western Australian EPA Guidance Statements 54 and 54a (2003 & 2007)

DEHP requires sampling in areas where stygofauna are 'likely' to occur and for the SCSP sampling was required to meet the requirements for surveys undertaken for Environmental Impact Assessments in Western Australia, as detailed in the following documents:

- WA EPA Guidance Statement No. 54, Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia (EPA, 2003);
- WA EPA Guidance Statement No. 54a, Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia (EPA, 2007, or its revision).

DEHP do not have any established (published) protocols for sampling stygofauna in Queensland and adopt the WA guidelines (2003 & 2007) by default. The WA Guidance Statements provide information which the WA EPA considers important when assessing proposals where subterranean fauna is a relevant environmental factor.

WA Guidance Statement 54 (2003) specifies that sampling should occur in at least two seasons and bores should encompass the full range of aquifer types present, with the more prospective habitats assigned significant sampling effort (e.g. alluvial aquifers). The guidance statement recommends that the most efficient sampling design will include sampling 20 impact bores (i.e. those located within the zone of mining impact) in two seasons spaced at least 3 months apart. This equates to a total of 40 impact bores across two sampling events within the mine footprint. An equal sampling effort using comparable methods should be expended on control bores located outside the zone of influence of the mine. As it can be difficult for Queensland mining companies to find a sufficient number of suitable bores located outside the impact area, a focus on finding sufficient bores inside the expected zone of impact is usually adopted.

The design of the stygofauna survey conforms to WA Guidelines (2003 & 2007) with the exception that:

- Order/Family taxonomic resolution was applied as defined by DEHP generic TOR for the Adani Coal Mine Project,
- No control bores located outside EPC 1690 were selected for sampling,
- Six hauls (where possible) were undertaken when sampling each bore for stygofauna using a 50 micron mesh net of 40 mm diameter, and
- Significant sampling effort was not directed at shallow, quaternary alluvial aquifers.

1.4.2 Environmental Protection and Biodiversity Conservation Act (1999)

The Environment Protection and Biodiversity Conservation Act (EPBC Act, 1999) is the Australian Government's central piece of environmental legislation. The Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places – defined in the Act as matters of national environmental significance. The EPBC Act is relevant to the determination of the ecological value of a Groundwater Dependent Ecosystem (GDE). If a GDE contains a threatened species as listed under this Act, the GDE is then taken to have a higher ecological value.

1.5 GDE's and Stygofauna

Groundwater dependent ecosystems or GDE's is a term occurring more frequently in the scientific literature. GDE's represent a vital and significant component of the natural environment (ARMCANZ 1996; ANZECC 1996) and can be simply defined as *'ecosystems that depend on groundwater for their existence and health'* (National Water Commission). Based on this definition, GDE's explicitly include any ecosystem that depends on groundwater at any time or for any duration in order to maintain its composition and condition.

GDE's include a broad range of environments from highly specialised species and ecosystems that possess unique biotic and abiotic characteristics that 'separate' them from other ecosystems that do not rely on groundwater to survive, to more general terrestrial and aquatic ecosystems that have an opportunistic dependence on groundwater, or rely on it during times of drought (Serov et al, 2012). The dependence on groundwater can be variable, ranging from partial and infrequent dependence (i.e. seasonal or episodic) to total continual dependence (entire/obligate). It is often difficult, however, to determine the nature of this dependence (Parsons, 2009; Dillon et al, 2009). A GDE's sensitivity to change is therefore dependent in part on their reliance on, or access to groundwater as well as their ability to disperse or relocate should the groundwater regime change.

Stygofauna are entirely groundwater dependent (obligate) and are restricted to locations of groundwater discharge or within aquifers. Due to this dependence, stygofaunal communities are particularly sensitive to, and can be impacted by a range of factors that alter groundwater levels, water pressure, water chemistry and aquifer structure.

Stygofauna communities in Australia consist almost entirely of invertebrates, with the community composition often dominated by crustaceans and oligochaetes, with smaller diversities of molluscs, insects, and other invertebrate groups. The community composition is determined by a range of factors such as type of aquifer, geological/geomorphic history, size of pore spaces, water chemistry and landscape context (i.e. position within the catchment and the association with river systems and the coast). Stygofauna can occur in any aquifer with sufficient pore space and connectivity within the substrate matrix such as limestone karsts and caves, calcrete formations, lava tubes, and fractured rock aquifers, but occur most commonly in alluvial aquifers (Hancock and Boulton, 2008). Within these environments they take on the same roles as surface water aquatic invertebrates in association with the microbial/bacterial community by contributing to water quality through processes such as biochemical processing and filtration (Hancock *et al* 2005). Due to this intrinsic relationship with the physicochemical constraints of the aquifer they are considered as ideal indicators of groundwater health (Gilbert, 1994, Humphreys, 2006, Serov *et al,* 2011). Scientifically, stygofauna are extremely valuable as they have linkages to species with no or very few surface-dwelling representatives. Examples include Bathynellacea, Thermosbaenacea, and Remipedia (Humphreys, 2008). Many stygofauna species are also considered as relictual taxa or living fossils as they are representatives of ancient lineages having evolved from surface-dwelling ancestors with Gondwanan and even Pangaean connections. They are, therefore, critical to improving our understanding of the evolution of the Australian landscape (Humphreys, 2008). Stygofauna also represent a vital and significant component of the natural environment and add to our knowledge of regional, national and global biodiversity.

1.6 Terminology Used In This Report

Subterranean fauna can be classified by the degree to which they are dependent on groundwater. Those that are completely dependent on groundwater are termed stygobites/phreatobites (these animals are the focus of this report) and consist predominantly of crustaceans. Those that rely on groundwater to a lesser extent and can live in mixed surface and groundwater are termed stygoxenes or stygophiles (Marmonier et al*,* 1993). The distinction is often ambiguous because it is difficult to know the degree of surface/groundwater mixing in an aquifer (Boulton et al*,* 2003), 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, and in this report we follow the system originally proposed in the mid 1800's for cave-dwelling animals (Hancock et al. 2005):

- **Stygoxenes** are organisms that have no affinities with groundwater systems but occur accidentally in caves and alluvial sediments. Some planktonic groups (Calanoida Copepoda) and a variety of benthic crustacean and insect species (Simulid Fly larvae, Caenid Mayflies) may passively infiltrate alluvial sediments (Gilbert et al, 1994).
- **Edaphobites** are deep soil dwelling (or endogean) species that frequently display troglomorphisms and may sometimes occur in caves. These animals are not classified as stygofauna.
- **Stygophiles** are facultative subterranean species able to complete their whole life cycles both underground and on the surface. Stygophilic species often have populations above and below ground, with individuals commuting between them and maintaining genetic flow between these populations (Trajano 2001). Examples of stygophiles include some ostracod or copepod species.
- **Stygobites** (Stygobionts) are obligate subterranean species restricted to subterranean environments and typically possessing character traits related to a subterranean existence

(stygomorphisms) such as reduced or absent eyes and pigmentation, and enhanced non-optic sensory structures.

- **Phreatobites** are stygobites (obligate subterranean species) restricted to 'deep' groundwater substrata of alluvial aquifers (Gilbert et al, 1994). All species within this classification have specialised morphological and physiological adaptations.
- **Stygofauna** is an all encompassing term for all animals that occur in subsurface waters (Ward et al, 2000).

From a conservation biology perspective, stygobites/phreatobites usually face a higher risk of extinction because they are frequently short range endemic (SRE) species (Harvey, 2002). As SREs live only in a small geographical area, any impact on their range can severely reduce their population. In assessing the environmental impact of projects on subterranean species it may become important to distinguish stygobites/phreatobites from other ecological categories of subterranean fauna, but it is still critical that the range of non-stygobites also be assessed, especially in areas where few groundwater biological surveys have been conducted and the likelihood of finding new species is high.

1.7 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 or 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 (< 20m) to the land surface (Humphreys, 2000; Hancock and Boulton, 2008). This is because the water table is likely to have the highest concentration of oxygen and organic matter. Stygofauna still 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 some karstic aquifers, where there is relatively high vertical exchange, or flow does not come into contact with large microbial surface areas (such as occurs in sedimentary aquifers), stygofaunal communities can occur at depths exceeding 100 m (Humphreys, 2000) and have been recorded at depths of 600m to 800m in the Edwards aquifer in Texas and near 800m from an aquifer in Mexico.

In Australia, stygofauna are known from alluvial, limestone, fractured rock, and calcrete aquifers (Hancock et al, 2005; Humphreys, 2008). As yet, few species are known from coal aquifers (although this is changing as further targeted sampling is undertaken in Queensland and NSW). As stygofauna require a space to live, the porosity of the sediments, degree of fracturing, or extent of cavity development must be sufficient, as must the connectivity between the living spaces.

1.8 Other Studies

The National Water Commission (NWC) reported (NWC Waterlines, 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. They are also often of high scientific interest; for example, the occurrence of the only known southern hemisphere representatives of several phylogenetic relictual lineages.

In Australia, at least 750 stygofauna species have been described (Humphreys, 2008), but this is a conservative estimate of total continental biodiversity as more than 66 % of known species come from just two regions of Western Australia (Humphreys, 2008) and large parts of Australia remain un-surveyed. In Queensland there are approximately 40 species of stygofauna known, but this estimate will certainly increase as more surveys are conducted and taxonomic knowledge improves.

Several surveys (GHD unpublished data) have confirmed the presence of stygofaunal taxa (Copepoda, Bathynellacea, and Amphipoda) in the Bowen Basin including the Central Queensland Coast region. To date, stygofaunal taxa are known from near Clermont, near Collinsville, near Glenden, near Rolleston and near Nebo (GHD unpublished data). These were collected from alluvial/sedimentary aquifers rather than coal seam aquifers. The likely reason for this is that the water in the alluvial aquifers has lower electrical conductivity (EC), porosity and connectivity than coal seam aquifers. GHD (unpublished data) has also recovered diverse and abundant stygofaunal communities from the Surat Basin in southern Queensland. Recent surveys in the Galilee Basin (GHD unpublished data) have also recovered stygofauna, however, diversity and abundance has been generally lower than from other Queensland mining regions although this may also reflect the fact that far fewer stygofauna surveys have been undertaken to date in the Galilee Basin. No attempt has yet been made to identify these animals beyond Family level so it is not clear if they represent new species (or even new genera) and what their geographic distribution might be.

Eight stygofauna taxa have been recorded by GHD (unpublished data) from coal seam aquifers in Queensland which strengthens the fact that coal seam aquifers in Queensland contain stygofaunal communities:

- A species of harpacticoid copepod was collected from the Bowen Basin in Central Queensland (GHD unpublished). This specimen occurred in a shallow coal seam (50m deep), with low electrical conductivity (< 2 000 µS/cm), a moderate to high amount of fracturing, and a good connection to a small alluvial aquifer,
- A species of *Notobathynella* (Syncarida), a species of Trombidiidae (water mites) and two species of Pezidae (water mites) were collected from a coal seam aquifer (89m deep with SWL at 38.5m) in the Galilee Basin as part of the current Adani Coal Mine Project. The bore recorded high groundwater quality (EC 1 505 µS/cm; pH 6.28 and DO 2.51mg/L),
- A species of Amphipoda and a species of Cyclopoid copepod were collected from one bore from the northern Bowen Basin (GHD unpublished). The bore tapped a shallow coal seam aquifer (Fort Cooper Coal Measures 59.5m deep) with a relatively deep water table at 33.47m and poor groundwater quality with an EC concentration of 9,975 µS/cm, and
- A species of Astigmata (water mite) from a single bore (i.e. 75m deep and tapping a sub-artesian fractured rock aquifer described as the Cretaceous ‘Styx Coal Measures’) with poor groundwater quality (i.e. high salinity and low dissolved oxygen concentrations) from the Styx

Basin on the Central Queensland Coast (GHD unpublished).

One coal mining area that has a longer history of stygofauna sampling is the Hunter Valley in NSW, where surveys of alluvial aquifers were conducted between 2000 and 2008. Surveys of the groundwater/surface water interface along the Hunter River between Singleton and Glenbawn Dam from 2000 and 2003 found a diverse community of stygofauna (Hancock, 2004). A follow-up project from 2004 to 2008 surveyed groundwater monitoring bores in agricultural areas and on several mine sites of the upper Hunter Valley (Hancock and Boulton, 2008). The latter work found at least 40 taxa new to science (this number is likely to increase since not all specimens have yet been identified to species) and confirmed that stygofauna can exist in areas dominated by coal mining.

Surveys were conducted in 2002 and 2003 in the Queensland Pioneer Valley by DEHP (Hancock, 2004). These surveys revealed substantial stygofauna communities with at least 19 taxa from 19 bores in an alluvial aquifer.

Early studies in Queensland suggest that stygofauna prefer water with EC less than 5 000 µS/cm, although records of some syncarid species and genera of Koonungidae in Victoria and Tasmania are adapted to exist in naturally high EC waters of 33 000 µS/cm (Serov, P. *pers comm*) and stygofauna have been recorded in salinity up to 60,000 mg/L TDS in Western Australia (Moulds, T. *pers comm*). In Queensland, stygofauna have been collected in bores with EC up to 21 000 µS/cm (GHD unpublished), so it is still quite possible to collect animals in groundwater with EC in excess of 5,000 µS/cm. Other variables thought to be favorable for stygofauna are a shallow water table (<20 m), moderate concentrations of dissolved oxygen (1-5 mg/L), and pH between 6.5 and 7.5 (Hancock, 2008), although this range is considered quite narrow (Serov, P, *pers comm*). Despite these observations, surveys should be conducted across the entire water quality range for baseline studies.

2. Project Methodology

2.1 Study Area

The Carmichael Coal Mine is located mostly on the Moray Downs cattle station, within the jurisdiction of Isaac Regional Council, with railway development located in Mackay and Whitsunday Regional Council areas. The mine is situated approximately 160 Km to the north-west of Clermont, which in turn is located approximately 100 Km north of Emerald (EPC 1690; MDL 372) (Figure 1). The Adani Coal Mine Project is the single largest tenement in Australia in terms of Coal resources. The tenement covers an area of 25,740 ha.

2.1.1 Local/Regional Geology Overview

Regional Geology

The Project (Mine) is located within the Galilee Basin, which is a Late Carboniferous to Mid-Triassic extensional intracratonic terrestrial basin of predominantly fluvial sediment infill (SRK Consulting, 2012). Galilee Basin covers an area of 247,000 m^2 and is separated from the Bowen Basin to the east by the north-south trending Anakie Inlier (refer to Figure 2-1). In the southern portion of the Galilee Basin, the Late Permian and Triassic sequences merge with the Bowen Basin sequences across the Nebine Ridge, which essentially separates the two basins.

According to SRK Consulting (2012), the Galilee Basin is bisected by the east to west trending Barcaldine Ridge as follows:

- To the north of the ridge the Galilee Basin is further subdivided by the Maneroo Platform and the Beryl Ridge which resulted in the development of a western depression (the Lovelle Depression) and an eastern depression (the Koburra Trough)
- To the south of the ridge the Galilee Basin is subdivided by the Pleasant Creek Arch, into the western Powell Depression and the Springsure Shelf

The dominant structural feature is the Koburra Trough, which on seismic evidence is about 300 km long and reaches depths of approximately 3,000 m (refer to Figure 2-1). SRK Consulting (2012) reports that the maximum known drilled stratigraphic thickness of the Koburra Trough is 2,818 m. , This is the deepest point of the Galilee Basin.

At its north eastern margin, the Galilee Basin adjuncts the older Devonian-Carboniferous Drummond Basin. An outcrop of the Galilee Basin sequences is confined to a linear belt expressed at the surface by a topographic high. This reflects the underlying control of the Mingobar monocline. To the west of this structure, the down-warped sequences towards the axis of the Koburra Trough are obscured beneath extensive cover of the Jurassic-Cretaceous Eromanga Basin. Post-sedimentation inversion of the Mingobar structure is also responsible for the broad shallow westerly dip of the sequences along this margin. The eastern rim on-laps the older Devonian Carboniferous Drummond Basin and is connected to the Bowen Basin in the south east by the Springsure Self, along the north to south trending Nebine Ridge (SRK Consulting, 2012).

The structural style of the Galilee Basin is dominated by a series of inversion structures, which is related to the Hunter-Bowen Orogenic event. The structures of the Galilee Basin are of similar style and orientation to the ones found in the Bowen Basin, although on a much smaller scale (SRK Consulting 2012).

The stratigraphic units which are relevant to the Project (Mine) are the conformable interval between the coal-bearing Colinlea Sandstone-Bandanna Formation and the overlying Rewan Formation with an unconformable and variable veneer of Tertiary sediments, which covers the deposit.

The two geological maps encompassing the offsite infrastructure area and EPC1080 area are Buchanan Sheet SF 55-6 (Olgers, 1970) and Galilee Sheet SF 56-10 (Vine and Doutch, 1972). Most of the area lies across two main tectonic elements i.e. the Drummond Basin and Galilee Basin. Further details are provided on these basins below:

- The Drummond Basin is a large intracratonic basin which developed in Central Queensland between the Late Devonian and the Early Carboniferous. The Drummond Basin in and around the Project (Mine) is characterised by the formations of Bulliwallah, Star of Hope, Raymond and some Mount Hall formations consisting largely of the coarse-grained thickly bedded conglomerate quartz sandstone sequence (Olgers, 1970)
- The Galilee Basin is a meridional depression that developed west of the Drummond Basin and received about 8,000 feet of sediment from the Upper Carboniferous to the end of the Triassic. The major feature observed within the Galilee Basin is the Belyando feature which comprises a major lineament along the straight course of Belyando River (Vine and Doutch, 1972). The feature generally separates the Galilee Basin from Drummond Basin rocks and is marked by steep gravity gradients along the Belyando River

Colinlea Sandstone

This sequence comprises of dominantly quartz sandstone and conglomerate with minor shale and a number of low rank sub-bituminous and sub-hydrous coal seams. The Colinlea Sandstone sequence represents fluvial deposition with sandy braided channel and flood plain deposits associated with mire and coal seam development. Three coal seams, namely seams D to F are laterally persistent and correlated regionally.

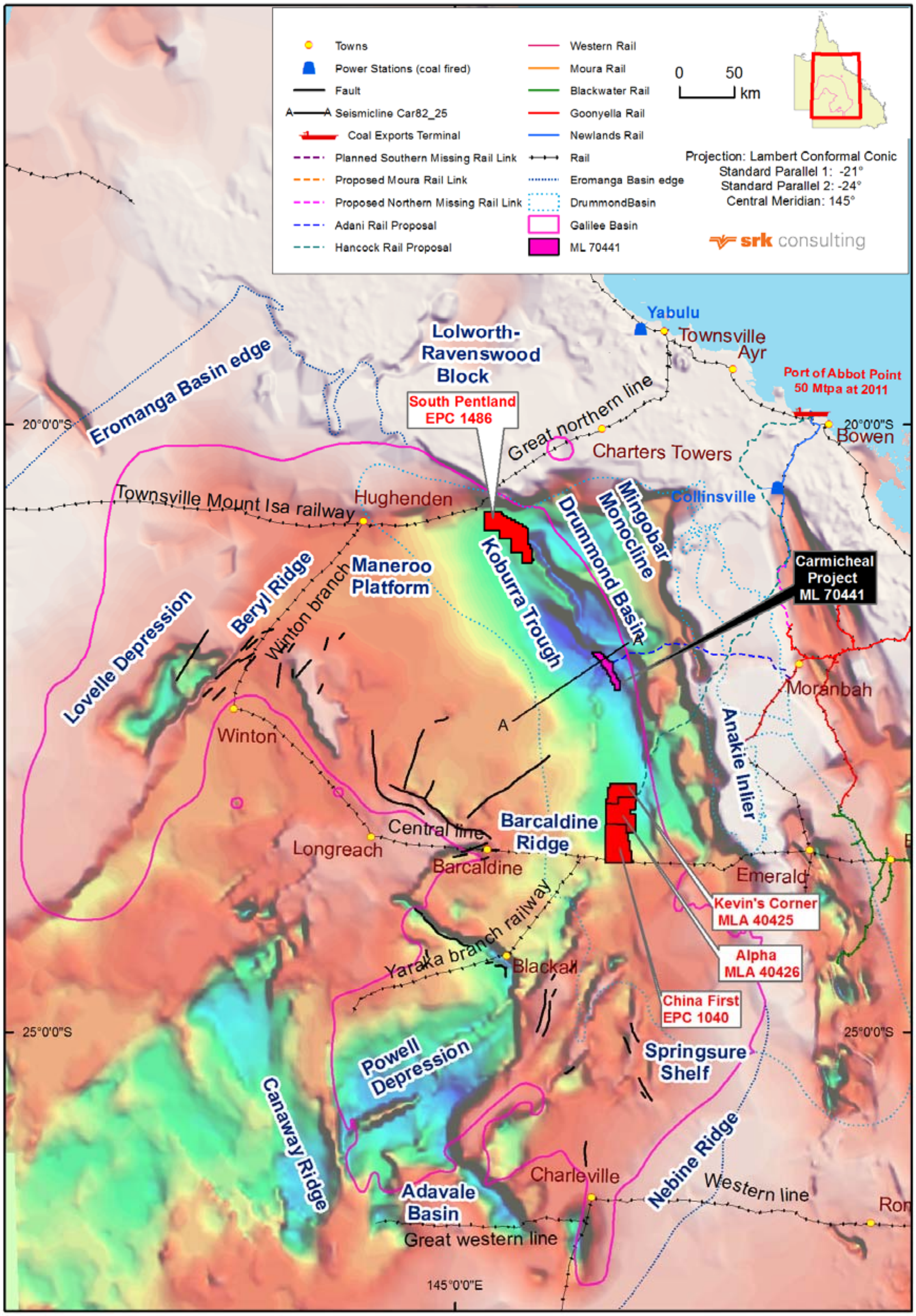
Bandanna Formation

The Bandanna Formation comprises of calcareous, lithic sandstone, siltstone and a number of low rank sub-bituminous and sub-hydrous coal seams. This sequence represents fluvial deposition with sandy braided channel and flood plain deposits associated with mire and coal seam development. Three coal seams, namely seems A, B and C, are laterally present and correlated regionally.

The Rewan Formation

The Rewan Formation comprises of monotonous sequence labile sandstones and multi-coloured argillaceous sediments, which are continuous across the Nebine Ridge and extensive throughout the Bowen, Galilee and Surat Basins.

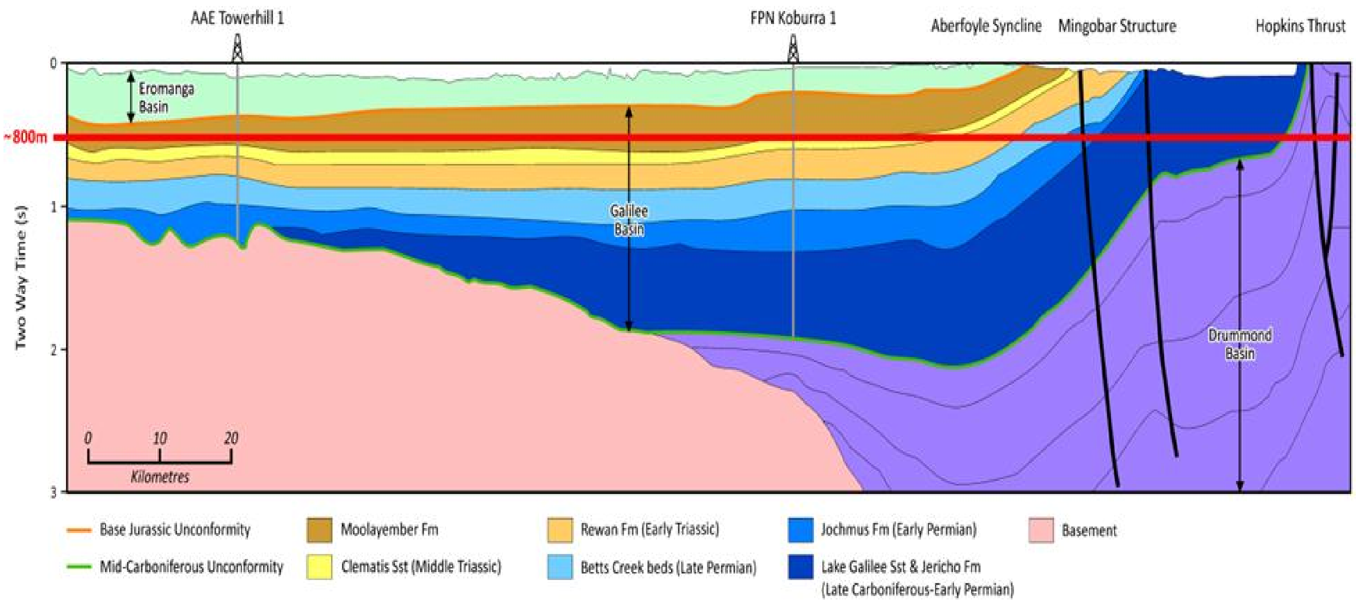
Figure 2-1 Structural Features of the Galilee Basin



Source: SRK Consulting, 2012

According to SRK Consulting (2012) along the eastern margin of the northern Galilee Basin (refer to Figure 2-2), this conformable sequence of stratigraphic units has a consistent regional expression, which means that the paleaogeographic characteristics extend over broad areas. Furthermore, a number of key economic coal seams with similar coal properties, which are hosted within the Colinlea Sandstone/Bandanna Formation interval, can be correlated along the eastern margin of the northern Galilee Basin between a number of deposits. A number of mining projects target this seam group for potential open-cut and underground coal extraction.

Figure 2-2 Schematic of the North Eastern Margin of the Galilee basin



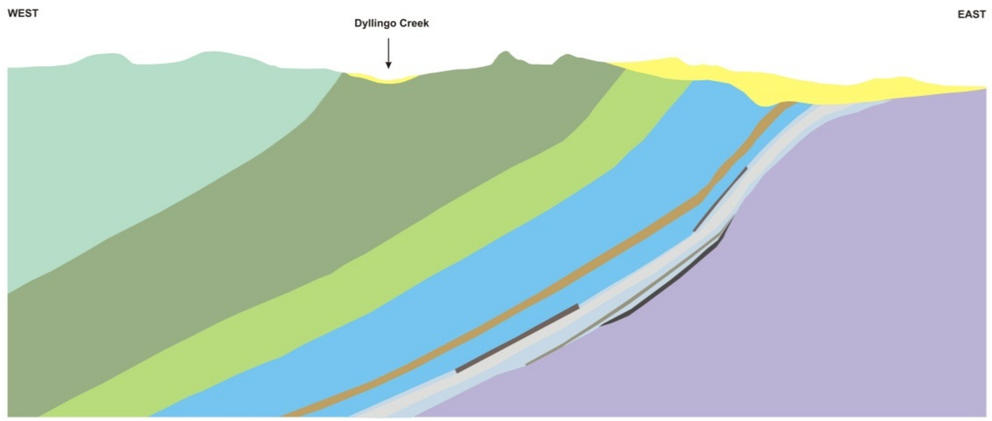
(Source: Queensland Carbon Dioxide Geological Storage Atlas, 2009).

Local Geology

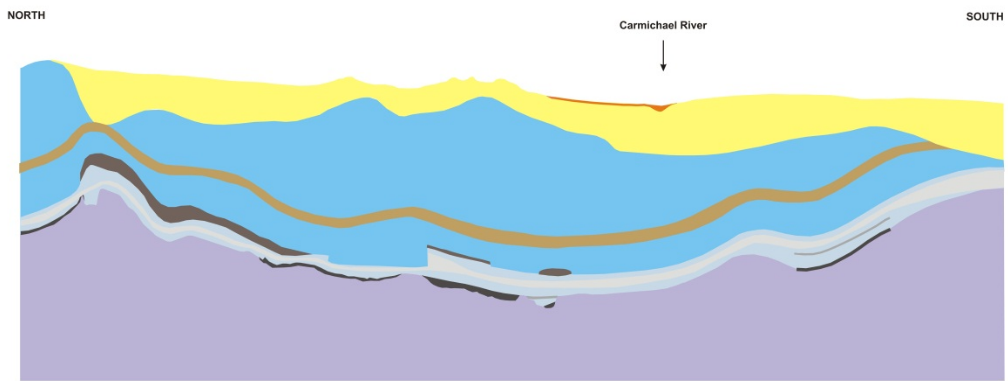
Within the area of the proposed Project (Mine), including on- and off-site infrastructure, Tertiary-age strata (i.e. sandstones, mudstones and conglomerates) are mapped at outcrop over the eastern side of EPC1690. Along the Carmichael River and over much of the Belyando River system to the east of EPC1690, these strata are indicated to be overlain by Quaternary-aged floodplain alluvium (i.e. sands, silts, gravels and clays). Beneath much of EPC1690 an unconformity defines the boundary between the Tertiary-age strata and the underlying Late Permian-age coal bearing strata (a sequence of siltstones, mudstones, sandstones, shales and coal of the Bandana Formation and Colinlea Sandstone). Geological cross sections (Geological Survey of Queensland) and modelled cross sections of the geology (GHD, 2010) indicate that the Late Permian-age strata dip at approximately 2-4° to the west, steepening slightly in the southern half of the lease.

Along the western margins of EPC1690, a sequence of Triassic-age strata forms an angular unconformity with the overlying Tertiary-age strata and is mapped at outcrop as the Dunda Beds (predominantly sandstone). The Rewan Group (mudstone and sandstone) underlies the Dunda Beds, as shown in Figure 2-3, (developed based on the Xenith geological model dated 26 October 2011) and overlies the Late Permian-age strata. It has been reported that a fault has been interpreted through the middle of the lease but requires further drilling to confirm (Xenith Consulting, 2009).

Figure 2-3 Cross-section of Project Area Geology



The west-east section, cut through EPC1690 and part of EPC1080



The north-south section, cut through EPC1690

2.1.2 Relationship to the GAB

The Great Artesian Basin (GAB) is a large hydrogeological basin consisting of the Eromanga, Surat and Carpentaria Basins as well as parts of the Bowen, Surat and Galilee Basins. The GAB consists of confined artesian and sub-artesian groundwater and the confined aquifers of the Basin are bounded by the Rewan Group sediments which form the basement of the aquifers, with the Winton Formation acting as the upper confining layer.

Triassic-age GAB units comprising, from oldest to youngest, the Rewan Group, Dunda Beds, Clematis Sandstone and Moolayember Formation lie within and to the west of Study Area. The Rewan Group (comprising layers of sandstone, mudstone and conglomerate) is considered to be a major confining bed of the GAB and bounds the base of the GAB aquifers (GABCC, 1998). Within Study Area the Rewan Group is indicated to be dominated by clays and mudstones with some interbeds of sandier lithology and is considered to be an aquitard. It separates the Project coal resource within the underlying Permian-age strata from the stratigraphically younger Dunda Beds (predominantly sandstones) and Clematis Sandstone (a GAB aquifer) to the west.

In the vicinity of the Project (Mine) the permeability of these sandstone aquifers is likely to be variable and dependent on the degree of fracturing and/or grain sizes. This is supported by the available yield data, which suggests yields from as low as 0.1 L/s to as high as 4 L/s for registered bores thought to be completed in Triassic-age units within the Study Area.

2.1.3 Existing Groundwater Environment

Groundwater level data collected from monitoring boreholes located close to the Carmichael River confirm the potential for groundwater to discharge to the river, particularly towards the west of the Study Area. Data for the riverside monitoring location C027 that includes monitoring in the Quaternary alluvium (C027P1) and underlying Tertiary deposits (C027P2) and is located close to the western limit of the EPC 1690 lease suggests:

- An upward gradient from the Tertiary deposits to the overlying alluvium
- Groundwater levels in the alluvium which are above the bed of the adjacent river based on LIDAR survey data

This suggests the potential for groundwater discharge from the underlying deposits to the Carmichael River in this area. Data for two further nested riverside monitoring sites towards the east of the EPC1690 lease area (C025 and C029) show:

- Similar upward gradients from the Tertiary deposits to the overlying alluvium; but
- Groundwater levels in the alluvium, which appear to be below the bed of the adjacent river.

This suggests the potential for leakage from the river to groundwater in this area. Based on the groundwater level data alone it appears that the Carmichael River may switch from gaining flow from groundwater to losing flow to groundwater within the eastern and western boundaries of the site.

Analysis of the major ion chemistry of groundwater samples taken from the Quaternary alluvium and surface water samples taken from the Carmichael River suggests that groundwater discharge becomes an increasingly important component of flow in the river as the dry season progresses. This is considered to be consistent with the upward gradients from the alluvium to the river close to the western boundary of the Study Area.

An assessment of the water chemistry of the Carmichael River and nearby groundwater resources identified that it is likely that the surface water of the Carmichael River is influenced by the nearby groundwater aquifers. Temporal changes in the surface water chemistry also indicate that the influence of groundwater on the Carmichael River is greater in the dry season than in the wet season when rain water is entering the system.

Recharge of alluvium underlying the creeks and rivers likely occurs during the wet season when surface water levels are highest. Recharge of Tertiary-aged aquifers is via rainfall recharge at outcrop areas and from percolation through alluvial deposits during peak flow of surface water. The underlying Permian and Cambrian aquifers are recharged through leakage from alluvial and Tertiary sediments and via direct recharge at outcrop areas.

Further Details in relation to hydrogeology are provided in Volume 4 Appendix R Mine Hydrogeological Report.

2.2 Study Design

Stygofauna sampling conducted by GHD used methods outlined in the Western Australian EPA Guidance Statements No. 54 “Guidance for the Assessment of Environmental Factors – Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in WA” (2003) and No. 54a “Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia” (2007). The WA sampling protocols are specified by DEHP in the project TOR for conducting stygofauna surveys.

The aim of the surveys was to determine if stygofauna were present in groundwater associated with the Adani Project (EPC 1690), and within the constraints of the study design, determine the range of taxa present and their conservation significance. Established standard sampling techniques used in Australia and overseas (Hancock and Boulton 2008; Dumas and Fontanini 2001) were adopted for this project and all field equipment was of high quality, well maintained, fully calibrated and operated to manufacturers specifications. The stygofauna sampling program was conducted by professionally qualified and experienced GHD aquatic ecologists (refer section 2.6 of this report).

In accordance with WA guidelines (2003 & 2007) two sampling events were undertaken for stygofauna across two seasons spaced 10 months apart as follows:

- Sampling event 1 covered 20 groundwater bores and was conducted during the post-wet season between 24 and 27 October 2011.
- Sampling event 2 covered 20 groundwater bores and was conducted during the post-wet season between 10 and 13 August 2012. The same 20 groundwater bores were sampled in August 2012 as were sampled in October 2011.

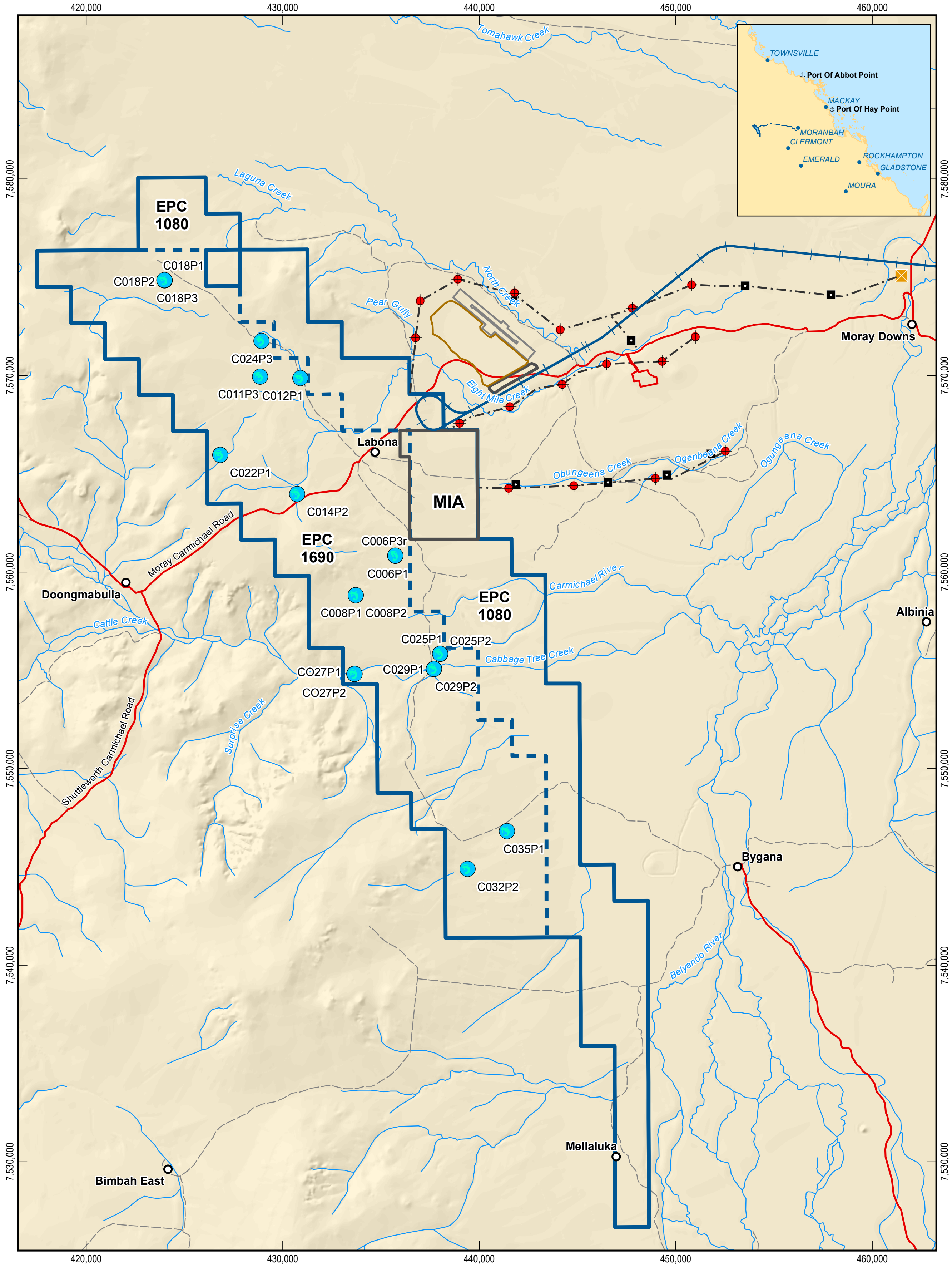
2.3 Location of Sampling Bores and Bore Characteristics

A total of 20 groundwater bores were selected for stygofauna sampling in October 2011 and August 2012 (Table 1). The sampling sites were geographically well spread across EPC 1690 (Figure 2-4) and covered all major hydrogeological units present.

A combination of Rotary Wash Bore and Percussion Air-hammer drilling were used to create the groundwater bores. Each bore was installed with a 50 mm diameter uPVC casing (glued and/or screwed), machine slotted screen and fitted with a secure, lockable cover. The bore annulus of the screwed interval was filled with washed 2 mm silica sand, sealed with a bentonite plug and grouted to the surface. Each bore was developed by airlifting.

Table 1: Location and characteristics of groundwater bores sampled for stygofauna for the Adani Coal Mine Project in October 2011 and August 2012. All bores were 50 mm diameter piezometers and securely sealed at the surface. Colour coding identifies distinct geological strata (NS = Not sampled as bore was dry) (*****[S] = Bores containing stygofauna; *****[T] = Bore containing troglofauna).

Bore ID	**Easting** (Zone 55K WGS 84)	**Northing** (Zone 55K WGS 84)	**Depth to Water** (m)	**Depth to Water** (m)	**Depth to End of Hole** (m)	**Bore Age** (months at Oct'11)	**Bore Covered**	**Lithology**
			OCT 2011	**AUG 2012**				
C025P1	438017	7555846	**NS**	**NS**	**NS**	1.5	Yes	Alluvial
C027P1	433645	7554821	4.8	3.1	12	1.5	Yes	Alluvial
C029P1*[T]	437695	7555078	11.4	11.2	13.6	1.5	Yes	Alluvial
Mean (n=2)			**8.1**	**7.2**	**12.8**	**1.5**		
C006P1	435725	7560825	23.1	23.1	47	4	Yes	Clay
C008P1*[S]	433713	7558829	26.8	26.9	57.5	3	Yes	Clay
C018P1	423982	7574850	36.3	37.8	50	2	Yes	Clay
C025P2	438013	7555844	10.9	10.4	36.9	1.5	Yes	Clay
C027P2	433649	7554820	1.7	1.1	32	1.5	Yes	Clay
C029P2	437689	7555078	6.2	5.9	46	1.5	Yes	Clay
C035P1	441403	7546820	4.4	4.6	62	1	Yes	Tertiary/Permian
Mean (n=7)			**15.6**	**15.7**	**47**	**1.9**		
C012P1	430890	7569875	26.6	26.6	99	3	Yes	Sandstone
C022P1	426816	7565958	27.6	28.8	67	2	Yes	Sandstone
Mean (n=2)			**27.1**	**27.7**	**83**	**2.5**		
C006P3r	435727	7560835	21.2	21.2	118.4	3	Yes	D Seam
C011P3	428845	7569950	27.9	28.7	105	3	Yes	D Seam
C018P3	423975	7574857	39.1	39.7	146	2	Yes	D Seam
C024P3	428910	7571759	30.3	30.3	49	1.5	Yes	D Seam
Mean (n=4)			**29.6**	**30.0**	**105**	**2.4**		
C008P2	433711	7558827	25.6	25.5	271.5	3	Yes	AB Seam
C014P2	430733	7563976	46.9	47.1	204.4	3	Yes	AB Seam
C018P2*[S]	423991	7574848	38.5	39.3	89	2.5	Yes	AB Seam
C032P2	439407	7544895	23.4	23.2	263	1.5	Yes	AB Seam
Mean (n=4)			**33.6**	**33.8**	**207**	**2.5**		



LEGEND

Stygofauna Bore Locations	Watercourse	Mine (Offsite)	Airport Location
Homestead	Rail (West)	Borehole	Rail Siding
Local Road	Mine (Onsite)	Storage Site (Instream)	Industrial Area
Track	Mine Infrastructure Area	Storage Facility (Offstream)	Workers Accommodation Village
		Pipeline Network	

Based on or contains data provided by the State of QLD (DERM) [2010]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for marketing or be used in breach of the privacy laws.

1:275,000 (at A4)

0 2 4 6 8 10

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

N

Adani Mining Pty Ltd
Carmichael Coal Mine and Rail Project

Job Number 41-25215
Revision A
Date 05-09-2012

Sample Locations

Figure: 2-4

G:\41\25215\GIS\Maps\MXD\Stygofauna_Techincal_Report\41-25215_1005_rev_a.mxd Level 4, 201 Charlotte St Brisbane QLD 4000 T +61 7 3316 3000 F +61 7 3316 3333 E bnemail@ghd.com W www.ghd.com

Data Source: DERM: Elevation (2011); GHD: Stygofauna Bore Locations (2012); © Copyright Commonwealth of Australia - Geoscience Australia: Road, Homestead, Watercourse (2007);
Adani: Alignment Opt9 Rev3 (2012); Gassman/Hyder: Mine (Offsite) (2012); DME: EPC1690 (2010), EPC1080 (2011).Created by: BW.

2.3.1 Selection of Groundwater Bores for Stygofauna Sampling

The criteria for selection of groundwater bores for stygofauna sampling for the Adani Project were as follows :

- Aperture of 50mm diameter or greater;
- Intersect the water table;
- Lined or unlined, but if lined, then slotted through the water column;
- Vertical (not angled);
- Geographically spread across the proposed mine lease (EPC 1690) and include reference bores outside the potential zone of impact (i.e. water drawdown zone);
- Cover all hydrogeological units present, including a focus on shallower alluvial aquifers (where available);
- Of varying age, in excess of six months, and preferably undisturbed (i.e. not regularly pumped or purged); and
- Include a high number of bores (if possible) with a salinity less than 5,000 µS/cm EC (and preferably less than 1,500 µS/cm EC), a DO of $\geq$1 mg/L and pH within the range 6.5 to 7.5.

2.4 Field Sampling and Sample Processing Methodology

2.4.1 Stygofauna Sampling

A 40mm diameter phreatobiological net was used for stygofauna sampling (GHD nets conform to WA guideline 2003 & 2007 specifications). Nets were made of 50µm nybolt mesh material and weighted at the bottom with a brass fixture and an attached plastic collecting jar. The net was lowered to the bottom of the bore, bounced three to five times to dislodge resting animals, and slowly retrieved. At the top of each haul, the collecting jar was rinsed into a 50µm mesh brass sieve and the net lowered again. Once six hauls were completed (the aim was always to collect between 4 and 6 hauls with all hauls reaching the bottom of the bore), the entire sieve contents were transferred to a labeled sample jar and preserved in 100% AR Grade ethanol. A small amount of Rose Bengal, which stains animal tissue pink, was added to each sample to aid sample processing.

The same field sampling methodology and field equipment was used for both Adani sampling events conducted in June 2011 and May 2012.

2.4.2 Laboratory Processing of Field Samples

Sample jars were drained of ethanol and stain and washed gently into channeled Sedgwick-Rafter counting trays to create a thin layer of sediment spread across the bottom of the tray. Samples were then sorted under a Leica MZ9 stereomicroscope with plan achromatic 10x objective lenses and a zoom capability of between 6.3x and 60x. All aquatic animals were removed, identified to Order/Family level (or lower taxonomic rank if possible) in accordance with DEHP generic TOR and placed in labeled, polyethylene containers filled with 100% AR Grade ethanol for long-term storage at GHD's specialist aquatic ecology laboratory in Brisbane.

2.4.3 Groundwater Quality Sampling

Groundwater samples were collected using a bailer lowered by hand to approximately 3m below the water surface prior to stygofauna sampling. Water was measured for temperature (^oC), pH, electrical conductivity (µs/cm) and dissolved oxygen (mg/L and % saturation) using a YSI 556 multi-parameter water quality meter.

Groundwater sampling preceded biological sampling to ensure the groundwater contained within the bore was undisturbed. The YSI field meter was calibrated in the laboratory prior to its use in the field, with calibrations regularly cross-checked in the field. The meter was used in accordance with the manufacturer's specifications.

In addition to *in-situ* water quality, measurements were also collected from each groundwater bore on depth to water table (using a Solinst electronic dip probe), depth to end of hole (where possible), bore diameter and construction, purpose of bore, GPS location and bore ID, presence of tree roots, surrounding land use, sampling date, time and sampling team. A photographic record of each bore and surrounding land use was also collected. All field data were recorded on specialised GHD recording sheets.

2.5 GHD Project Personnel

Both field sampling events (October 2011 and August 2012) were conducted by Garry Bennison (BSc.Hons. MAIBiol) and Mark Dahm (BSc. MSc.). Both project staff are professional aquatic ecologists and experienced in stygofauna sample collection and analysis. Garry Bennison is a Principal Scientist with GHD Water Sciences in Queensland and has in excess of 30 years experience as an aquatic ecologist and 8 years experience working specifically on stygofauna/hyporheic fauna/troglofauna projects in WA, NSW, VIC and QLD. Garry has designed, conducted and managed stygofauna projects in Queensland’s Bowen, Galilee, Surat and Styx Basins. Mark Dahm is an Environmental Scientist with GHD Water Sciences in Queensland and has 5 years experience as an aquatic ecologist working on surface water and groundwater ecosystems. Mark has in excess of 3 years experience working on stygofauna projects in Queensland and NSW.

Laboratory processing of samples, including stygofauna taxonomy, was undertaken by GHD Senior Taxonomist Gavin Williams (Advanced Diploma of Aquatic Resource Management) with independent taxonomic QA/QC provided by Dr Peter Serov (BSc.Hons. PhD) from the NSW Office of Water. Garry Bennison prepared the written report for this project.

3. Results

3.1 Groundwater Bore Selection

The bores selected for stygofauna sampling for the Adani Project achieved most of the key selection criteria outlined in Section 2.3.1 of this report. The 20 groundwater bores that were sampled across two events in October 2011 and August 2012 were geographically well spread across EPC 1690 (Figure 2-4) and covered all the hydrogeological units present within the mining lease area (Alluvial, Sandstone, Tertiary/Permian, D Seam and AB Seam). Alluvial aquifers were under represented in the makeup of bores selected for sampling with only 3 bores from 20 specifically targeting alluvial aquifers (and one alluvial bore was dry and could not be sampled). Bore age for the round 1 sampling event in October 2011 was also an issue with all 20 bores less than 6 months old when sampled, with 13 of the 20 bores being 2 months or less in age. Bore age can be a significant feature in the likelihood of collecting stygofauna from groundwater as it usually takes some time (nominally 6 months) for a bore to stabilise following drilling and purging, for water quality within the bore to reach an equilibrium with the aquifer (i.e. pH, turbidity, breakdown of toxicants etc.) and for stygofauna to fully populate the bore environment (assuming they are present in the aquifer). Bore age was not an issue for the round 2 sampling event conducted in August 2012 where all bores were in excess of 11 months old.

3.1.1 Sampling Effort and Quality of Samples

A total of 20 distinct groundwater bores were sampled for stygofauna across October 2011 and August 2012. The quality of stygofauna samples collected is summarised in Table 2 below. The sampling method aimed to collect between 4 and 6 replicate hauls off the bottom of each bore. Overall, high quality samples were collected from 13 of 19 bores that could be sampled (68%) which is a good return for a significant sampling effort. Three bores were very deep (i.e. >200 m to EoH see Table 1) which made netting for stygofauna extremely difficult and reduced the quality of the samples obtained.

Table 2: Summary of sampling effort and quality of stygofauna samples collected for the Adani Coal Mine Project in October 2011 and August 2012. Bore C025P1 was dry and could not be sampled. (NS = No Sample). {$*^{S}$ = Bores containing stygofauna; $*^{T}$ = Bore containing troglofauna}

Bore ID	No. Replicate Stygofauna Samples Collected		Comments
	October 2011	August 2012	
C006P1	6	4	Good samples with all hauls off bottom of bore.
C006P3r	4	4	Good samples with all hauls off bottom of bore.
C008P1$*^{S}$	3	4	Average sample overall
C008P2	3	3	Average sample overall
C011P3	6	5	Good samples with all hauls off bottom of bore.
C012P1	6	6	Good samples with all hauls off bottom of bore.
C014P2	3	**NS**	Poor sample overall. Net lost in bore in Aug'12
C018P1	3	4	Average sample overall
C018P2$*^{S}$	6	4	Good samples with all hauls off bottom of bore.
C018P3	4	4	Good samples with all hauls off bottom of bore.

C022P1	6	6	Good samples with all hauls off bottom of bore.
C024P3	6	6	Good samples with all hauls off bottom of bore.
Bore ID	**No. Replicate Stygofauna Samples Collected**		**Comments**
	October 2011	August 2012	
C025P1	**NS**	**NS**	Bore Dry. No sample collected.
C025P2	3	6	Good samples with all hauls off bottom of bore.
C027P1	6	1	Average sample overall.Net jamming in Aug'12
C027P2	6	6	Good samples with all hauls off bottom of bore.
C029P1*[T]	6	6	Good samples with all hauls off bottom of bore.
C029P2	3	6	Good samples with all hauls off bottom of bore.
C032P2	3	4	Average sample overall
C035P1	6	6	Good samples with all hauls off bottom of bore.
TOTAL Sites Sampled for Stygofauna	**19**	**18**	

3.2 Groundwater Quality

A total of 20 groundwater bores were sampled for *in-situ* water quality in October 2011 and August 2012 (Table 3) with results obtained from 19 bores (bore C025P1 was dry).

All groundwater bores were hand bailed (not purged) with water collected approximately 3m below the water table level where possible. *In-situ* groundwater chemistry results, therefore, may not be a totally accurate reflection of aquifer groundwater quality. An assessment of the water chemistry of the Carmichael River and nearby groundwater resources identified that it is likely that the surface water of the Carmichael River is influenced by the nearby groundwater aquifers. Temporal changes in the surface water chemistry also indicate that the influence of groundwater on the Carmichael River is greater in the dry season than in the wet season when rain water is entering the system.

The water table occurred at essentially two depths across EPC 1690 (Table 1). The shallower alluvial/tertiary aquifers recorded a mean SWL of between 8.1 m and 15.7 m (although SWL data for the Tertiary aged aquifers indicated two distinct levels – a shallower SWL ranging between 1.1 m and 10.9 m and a deeper SWL ranging between 23.1 m and 37.8 m) whilst the deeper sandstone and coal seam aquifers recorded a mean SWL of between 27.1 m and 33.8 m. The overall depth of the water table ranged across the Adani Mining Lease area from 1.1 m at site C027P2 (Tertiary deposit) to 47.1 m at site C014P2 (AB Coal Seam). Stygofauna in Australia have been reported as preferring a shallow water table less than 20 m (Hancock and Boulton 2008) but stygofauna have been recorded from overseas studies at depths of between 600 m and 800 m.

Mean groundwater quality differed slightly between October 2011 and August 2012 (Table 3). In August 2012, pH was slightly higher than that recorded in June 2011 (by 0.3 of a pH unit) as was EC (by 660 µS/cm) and dissolved oxygen (by 0.2 mg/L). Water temperature recorded in August 2012 was lower than that recorded in June 2011 (by 2.8 ^{o}C).

Groundwater pH varied across all bores and geological strata but tended to be in the neutral to slightly alkaline range (Tables 3 & 4). In the deeper coal seam aquifers (D Seam and AB Seam) pH was generally higher (i.e. more alkaline) with mean pH values ranging between 7.56 (D Seam) and

8.69 (AB Seam). The AB Seam recorded highly variable pH values (mean depth of bore was 207 m) ranging from 6.28 (C018P2) to 11.24 (C014P2). pH values tended to be consistent for each bore across both sampling events (Table 4). The waters of the Carmichael River displayed an alkaline pH throughout the monitoring program. Stygofauna in Australia have been reported as preferring a pH level of between 6.5 and 7.5 (Hancock and Boulton 2008).

EC values were also highly variable across all 19 groundwater bores ranging from 285 µS/cm at bore C022P1 in October 2011 to 30,222 µS/cm at bore C029P1 in August 2012 (Tables 3 & 4). It is of interest that the shallower alluvial bores (mean depth of 13 m and mean SWL of 7.7 m) recorded the highest salinities of all bores tested ranging from 5,950 µS/cm to 30,222 µS/cm. Bore C029P1 recorded an EC value of 24,388 µS/cm in October 2011 and 30,222 µS/cm in August 2012. This bore is located on the banks of the Carmichael River. Salinity concentrations in the Tertiary aged aquifers were also highly variable ranging from 601 µS/cm to 21,840 µS/cm. The deeper Sandstone and Coal seam aquifers recorded substantially lower EC concentrations than the shallower alluvial and Tertiary aquifers (Tables 3 & 4). Groundwater bores associated with these deeper aquifers all recorded EC concentrations across both sampling events of less than 5,000 µS/cm (with the exception of bore C014P2 in October 2012 which recorded an EC value of 5,505 µS/cm). Of the 19 groundwater bores tested a total of 13 bores (68%) recorded an EC concentration of less than 5,000 µS/cm and 7 bores (37%) recorded an EC concentration less than 1,500 µS/cm. Salinity is a major determinant of stygofauna species presence (Pinder *et al*, 2005). Stygofauna in Australia have been reported as preferring an EC concentration of generally less than 5,000 µS/cm and preferably less than 1,500 µS/cm (Hancock and Boulton 2008) (Table 4), however, stygofauna have been recorded in WA at salinities of up to 60,000 mg/L TDS (Moulds,T *pers comm*) and in Queensland at salinities of up to 21,000 µS/cm (current study).

Groundwater temperatures were considered to be within the normal range with a mean temperature of 27.57^{o}C in October 2011 and 24.78 ^{o}C in August 2012 and ranging between 20.8 ^{o}C (C027P2) and 29.87^{o}C (C014P2) (Table 3). There was no significant difference in groundwater temperature between geological strata across either seasonal sampling event.

Dissolved Oxygen (DO) concentrations were medium to high for groundwater with a mean of 1.42 mg/L (18.65% saturation) in October 2011 and 1.65 mg/L (18.66% saturation) in August 2012 (Table 3). These figures should only be used as being indicative of true dissolved oxygen values as water was collected using a hand operated bailer and would have received agitation and artificial oxygenation during collection. Dissolved oxygen concentrations ranged from a low of 0.69 mg/L at bores C029P1 and C029P2 to a high of 4.19 mg/L at C027P1. There was no significant difference in DO concentrations between geological strata across either seasonal sampling event. Seventeen groundwater bores recorded DO concentrations between 1mg/L and 5mg/L (89%). Stygofauna in Australia have been reported as preferring a DO concentration in excess of 1 mg/L (Hancock and Boulton, 2008).

3.3 Groundwater Dependent Fauna

A total of 19 groundwater bores were sampled for stygofauna in October 2011 and August 2012 within Adani EPC 1690 using standard sampling methods described in WA Guidelines 54 and 54a (2003 & 2007). Sample quality was generally high across all 19 bores (Table 2).

3.3.1 October 2011 Sampling Event

Analysis of the October 2011 field samples revealed the presence of stygofauna in one bore C018P2 (Table 5 and Figure 3) which included two obligate groundwater species. SWL for Bore C018P2 was relatively deep at 38.5m with high water quality including a pH of 6.28, salinity of 1,505 μScm^{-1} and a dissolved oxygen concentration of 2.51 mg/L. These water quality values are all highly prospective for stygofauna and the water table was at a suitable depth to allow adequate vertical movement of organic matter through the soil horizon (Hancock et al, 2005).

3.3.2 August 2012 Sampling Event

Analysis of the August 2012 samples revealed the presence of stygofauna in two bores C018P2 and C008P1 (Table 5 and Figure 3) which included two obligate groundwater species. Bore C018P2 recorded the presence of stygofauna on both sampling occasions. Bore C018P2 was identified as being prospective for stygofauna from sampling conducted in October 2011 (refer Section 3.3.1 above). Bore C008P1 recorded very high salinity concentrations in excess of 21,000 μScm^{-1} on both sampling occasions, and based on this poor water quality result would normally be considered as unlikely to contain stygofauna.

Table 3: *In-situ* water quality data from 20 groundwater bores sampled for stygofauna in October 2011 and August 2012 as part of the Adani Coal Mine Project. Colour coding identifies distinct geological strata. (NS = Not Sampled) (NR = Not Recorded) (DO = Dissolved Oxygen) (EC = Electrical Conductivity) (*[S] = Bores containing stygofauna; *[T] = Bore containing troglofauna).

BORE ID	Depth to End of Hole (m)	pH (units)	pH (units)	EC (µS/cm)	EC (µS/cm)	DO (% satn)	DO (% satn)	DO (mg/L)	DO (mg/L)	Water Temp (°C)	Water Temp (°C)	Lithology
		Oct'11	**Aug'12**	**Oct'11**	**Aug'12**	**Oct'11**	**Aug'12**	**Oct'11**	**Aug'12**	**Oct'11**	**Aug'12**	
C025P1	11.0	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	Alluvial
C027P1	12.0	6.64	7.00	5,950	6,095	17.7	48.5	1.42	4.19	25.91	21.55	Alluvial
C029P1*[T]	13.6	6.46	6.90	24,388	30,222	9.1	10.7	0.69	0.78	28.78	26.60	Alluvial
C006P1	47.0	7.37	7.29	13,269	13,106	15.7	22.1	1.19	1.93	26.66	22.94	Clay
C008P1*[S]	57.5	6.86	6.41	21,008	21,840	10.2	16.5	0.76	1.30	27.10	23.81	Clay
C018P1	50.0	6.36	7.77	601	751	19.7	46.7	1.56	3.98	27.53	23.49	Clay
C025P2	36.9	6.61	6.85	13,070	13,866	NR	11.9	1.02	0.92	28.20	25.87	Clay
C027P2	32.0	7.05	7.05	670	743	21.7	16.1	1.75	1.45	25.98	20.80	Clay
C029P2	46.0	6.66	7.04	9,930	11,860	10.7	8.8	0.82	0.69	27.74	26.06	Clay
C035P1	62.0	7.20	7.63	3,869	3,916	24.9	16.7	1.96	1.39	26.32	24.17	Tertiary/Permian
C012P1	99.0	6.57	7.66	1,836	1,990	NR	26.3	1.23	2.16	28.13	25.61	Sandstone
C022P1	67.0	6.77	8.18	285	373	13.8	19.7	1.05	1.57	28.64	26.81	Sandstone
C006P3r	118.4	8.69	7.72	899	996	22.7	10.6	1.82	0.91	26.32	22.97	D Seam
C011P3	105.0	8.77	8.11	949	997	23.2	14.6	1.81	1.19	28.23	26.57	D Seam
C018P3	146.0	6.40	7.34	944	1,003	15.7	18.1	1.23	2.54	27.43	23.84	D Seam
C024P3	49.0	6.45	7.20	1,504	1,708	23.6	15.56	1.82	1.25	28.42	26.14	D Seam
C008P2	271.5	7.80	7.52	3,273	3,302	22.1	10.5	1.75	0.88	27.18	23.44	AB Seam
C014P2	204.4	11.34	11.24	3,725	5,505	19.6	21.6	1.45	1.67	29.87	28.01	AB Seam
C018P2*[S]	89.0	6.28	7.23	1,505	1,771	31.4	10.7	2.51	0.90	27.39	24.47	AB Seam
C032P2	263.0	9.24	8.90	1,123	1,280	15.2	8.8	1.18	0.70	27.92	27.28	AB Seam
		pH (units)	**pH** (units)	**EC** (µS/cm)	**EC** (µS/cm)	**DO** (% satn)	**DO** (% satn)	**DO** (mg/L)	**DO** (mg/L)	**Water Temp** (°C)	**Water Temp** (°C)	
		Oct'11	**Aug'12**	**Oct'11**	**Aug'12**	**Oct'11**	**Aug'12**	**Oct'11**	**Aug'12**	**Oct'11**	**Aug'12**	
Mean Value		**7.34**	**7.63**	**5,726**	**6,385**	**18.65**	**18.66**	**1.42**	**1.65**	**27.57**	**24.78**	
Range		**6.28 to 11.34**	**6.41 to 11.24**	**285 to 24,388**	**373 to 30,222**	**9.1 to 31.4**	**8.8 to 48.5**	**0.69 to 2.51**	**0.69 to 4.19**	**25.91 to 29.87**	**20.80 to 28.01**	

Table 4: General physical and chemical characteristics of groundwater across both sampling events in October 2011 and August 2012 associated with geological strata on EPC 1690 and the likelihood of individual strata containing stygofauna. Colour coding identifies distinct geological strata.

Lithology	Bores Sampled	pH (units)	pH (units)	DO (mg/l)	DO (mg/l)	EC (µS/cm)	EC (µS/cm)	Depth to End of Hole (m)	Depth to End of Hole (m)	Bore Characteristics and Suitability for Stygofauna
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	
Alluvial	2	6.75	6.46 to 7.00	1.77	0.69 to 4.19	16,664	5,950 to 30,222	12.8	12 to 14	Salinity concentrations were variable and were the highest of all bores tested. Low likelihood of containing stygofauna based on EC concentrations.
Clay/ Tertiary/Permian	7	7.01	6.36 to 7.77	1.48	0.69 to 3.98	9.179	601 to 21,840	47	32 to 62	Highly variable salinity. Low salinity bores (C018P1, C027P2 & C035P1 with EC < 4,000 µS/cm) would suggest medium to high likelihood of containing stygofauna. Remaining bores would not be considered prospective for stygofauna.
Sandstone	2	7.30	6.57 to 8.18	1.50	1.05 to 2.16	1,121	285 to 1,990	83	67 to 99	Key chemical and physical determinants would suit stygofauna and would suggest medium to high likelihood of containing stygofauna.
D Seam	4	7.56	6.40 to 8.77	1.57	0.91 to 2.54	1,125	899 to 1,708	105	49 to 146	EC and pH ranges would generally suit stygofauna, however, depth of D Seam bores would suggest only medium likelihood of containing stygofauna
AB Seam	4	8.69	6.28 to 11.34	1.38	0.70 to 2.51	2,686	1,123 to 5,505	207	89 to 272	Highly variable pH. EC range would generally suit stygofauna. Depth of AB Seam bores would suggest medium to low likelihood of containing stygofauna.
Preferred Range for Stygofauna			**6.5 to 7.5**		**≥ 1.0**		**≤ 5,000**		**≤ 20**	**General Guide Only** (Hancock & Boulton, 2008). Stygofauna are known to occur outside these ranges.

Table 5: List of stygofauna and troglofauna***** collected from Adani EPC 1690 in October 2011 and August 2012. Refer Section 1.7 of this report for terminology (ND = Not Determined). All other sampling sites across both sampling events did not record the presence of stygofauna or troglofauna.

Bore ID	Class	Order	Family	Genus	Species	No. Animals	Habitus	Collection Method	Collection Date
C018P2	Acarina	Prostigmata	Trombidiidae	ND	sp.	7	Stygobite	50µ Net	25/10/2011
C018P2	Crustacea	Syncarida	Parabathyneliidae	*Notobathynella*	sp.	1	Phreatobite	50µ Net	25/10/2011
C008P1	Crustacea	Copepoda	Cyclopoida	ND	sp.	2	Phreatobite	50µ Net	11/08/2012
C018P2	Acarina	Halacaroidea	Pezidae	ND	sp1	2	Phreatobite	50µ Net	11/08/2012
C018P2	Acarina	Halacaroidea	Pezidae	ND	sp2	2	Phreatobite	50µ Net	11/08/2012
C029P1	Myriapoda	Symphyla	ND	ND	sp.	4	Troglophile*****	50µ Net	12/08/2012

Figure 3: Photos of groundwater bores from which stygofauna and troglofauna were collected in October 2011 and August 2012 (top photos) and general landuse surrounding the bores (bottom photos) (Photos: GHD Water Sciences).

3.3.3 Edaphobite Fauna

- Hymenoptera sp. (unidentified) (C06P1; C008P2; C022P1; C027P1)
- Psocoptera, Trogiomorpha sp. (C06P3r; C018P2; C022P1; C035P1)
- Collembola sp. (unidentified) (C022P1)

Seven groundwater bores recorded the presence of terrestrial invertebrate fauna (Edaphobites) including Collembola (springtails), Psocoptera (book lice), Hymenoptera (ants) and Coleoptera (beetles). All terrestrial species demonstrated varying degrees of decomposition indicating that they were not living within the aquifer when collected and would have either accidentally fallen into the bore and drowned or were occupying the area above the water table. None of these groups are aquatic or groundwater dependent. Their presence is of no direct interest or relevance to this study and they will not be considered further in this report.

3.3.4 Stygoxene Fauna

- Diptera, Chironomidae sp. (C012P1)
- Hemiptera, Aphidoidea sp. (C018P3)

Two groundwater bores contained adult terrestrial invertebrate fauna (Stygoxenes) including Chironomidae (Diptera – true flies) and Hemiptera (Aphids). Neither of these groups are aquatic or groundwater dependent and would have entered the bores by accident. Their presence is of no direct interest or relevance to this study and they will not be considered further in this report.

3.3.5 Edaphobite/Troglobitic Fauna

- Myriapoda, Symphyla (C029P1)

The Myriapoda specimens collected from bore C029P1 belong to the Symphyla. The Myriapoda is a subphylum of arthropods containing millipedes, centipedes, and others. The group contains 13,000 species. The Symphyla are small (less than 1cm), mainly white and blind myriapoda. They are generally confined to moist areas (thus their presence within a groundwater bore) where they feed on living and dead vegetation. Symphylans are primary decomposers, helping break down and recycle decaying plant material. There are approximately 500 species worldwide. They have a life cycle of about 5-6 weeks and are therefore good indicators of environmental condition and generally their presence indicates a healthy soil system. The Symphyla are a poorly understood group. Although they belong predominantly to the soil invertebrate community they have been collected from limestone geology in the Ludlow Tuart Forest in the south-west of Western Australia (Biota 2005) as well as from Barrow Island, off south-west Western Australia.

Their presence in bore C029P1 is most likely coincidental occupying the soil layers adjacent to the bore or living within the bore above the water table as they have a preference for humid environments. Symphylans have been recorded as components of the troglobite fauna in Western Australia associated with course unconsolidated or karstic environment. Bore C029P1 is located on the banks of the Carmichael River and is an alluvial bore with a SWL of around 11 m and a total bore depth of 13.6 m (Table 1). Water quality within the bore is highly saline with EC concentrations recorded up to 30,222 µS/cm (Table 3) although being a subterranean terrestrial animal (not aquatic) they would not come into direct contact with the groundwater. Whilst this is a very interesting find from a scientific viewpoint and may indicate the presence of troglofauna within the study area it is of no direct relevance to this study of groundwater dependent fauna, and as such, will not be considered further in this report.

3.3.6 Stygobite/Permanent Hyporheic Fauna

- Acarina, Trombidiidae (C018P2)
- Acarina, Pezidae sp1 (C018P2)
- Acarina, Pezidae sp2 (C018P2)
- Copepoda, Cyclopoida (C008P1)

The stygobite fauna consisted of members of the water mite Families, Trombidiidae and Pezidae (2 species) and a cyclopoid copepod. Stygobites are organisms that are specialised subterranean forms that occupy a range of groundwater systems (both karst and alluvial). Although subterranean water mites are classed as stygobites they have their highest biodiversity within the riverine, hyporheic zones and are classed as members of the ‘permanent hyporheos’ or the community that occurs within the deep sand and gravel beds associated with areas of groundwater discharge (Gilbert, 1994). They typically characterize the transition zone between the temporary or shallow hyporheic ecozone and the groundwater hypogean environment (Boulton & Hancock, 2006, Gilbert, 1994, Humphreys, 2006, Serov et al, 2011).

There is little known of the biodiversity and distribution of water mites belonging to the Superfamily Halacaroidea, Family Pezidae in Queensland. Water mites in general have been described as typically having a high diversity, and can reach high densities in the substrates of streams and rivers. The presence of both mite species suggests that the water quality within this bore is high as water mites are considered good indicators of water quality and sensitive to changes outside the natural range of their environment (Boulton & Harvey 2003, Boulton 2001). Bore C018P2 where these water mites were collected does have high water quality characterised by low salinity, neutral pH and high dissolved oxygen levels, however, the bore is located many kms from a river system and is associated with a deep coal seam aquifer (AB Seam) with a total bore depth of 89 m, therefore, the water mites could not be considered as true hyporheic fauna.

Bore C008P1 contained the microcrustacea group, the Copepoda. Cyclopoida represent the only group of Copepoda collected during this study. Cyclopoida represent a common group of stygofauna traditionally found in association with riverine alluvial aquifers with a strong connectivity between the aquifer and the river (Gibert *et al*. 1994). Bore C008P1 intersected tertiary deposits and was not located in close proximity to a river system. The bore recorded poor water quality with salinity levels exceeding 21,000 µS/cm (Table 3), a SWL of 26.8 m and a total bore depth of 57.5 m (Table 1). This animal could not be considered as being a member of the hyporheos.

It is possible that the movement of these animals from their traditional habitat in the shallower alluvium to deeper aquifers was prompted by the poor water quality (i.e. high salinity) observed in the alluvial aquifers.

3.3.7 Phreatobite Fauna

- Syncarida, *Notobathynella* sp. (C018P2)

The obligate groundwater fauna is characterised by Bathynellacea (Syncarida) (Figure 4). The Syncarida belongs to the hypogean (true groundwater) ecosystem, which is characterised by relatively low DO, permanent darkness and highly stable water quality.

The Parabathynellidae are an important component of Australia's groundwater fauna as they have an ancient lineage, are often the largest fauna within western and north-western regions of Australia and characteristically occupy only the obligate phreatic zone or hypogean environment. They can also occur in other specialised habitats such as caves and the hyporheic zone of sand and gravel bed river systems which receive their water principally from groundwater. They are predominantly detrital feeders consuming sediment, algae and diatoms, although many will consume animal tissue (they can also be cannibalistic). They occur in environments of high water quality and as such can be used as environmental indicators of groundwater health. The species collected has been identified as belonging to the genus *Notobathynella*, however, as this genus has only been described (so far) from NSW, Victoria, Tasmania and New Zealand, it may belong to a new but related genus. Undescribed species have also been collected in WA and north-west Queensland as well.

As mentioned above it is possible that the movement of these Syncarids from their traditional habitat in the alluvium to deeper aquifers was prompted by the poor water quality (i.e. high salinity) observed in the alluvial aquifers.

Figure 4: Photo of a syncarid crustacean from the order Bathynellacea collected from a central QLD mine site not related to the current study (Photo: GHD Water Sciences - Peter Hancock).

4. Discussion

A total of 19 groundwater bores were sampled for stygofauna in October 2011 and August 2012 within Adani EPC 1690 using standard sampling methods described in WA Guidelines 54 and 54a (2003 & 2007). Two groundwater bores (C018P2 and C008P1) recorded the presence of subsurface species which can be classed as stygofauna, including obligate groundwater species associated with the hypogean and permanent hyporheic environments. Of particular interest was the fact that bore C019P2 intersected the AB Coal Seam with an EoH depth of 89m. The recovery of stygofauna from this bore is significant as it extends our limited body of knowledge on stygofauna in the Galilee Basin as well as providing further evidence that these groundwater dependent animals can exist in coal seam aquifers and that relatively young bores (i.e. less than 6 months old) can be successfully sampled for stygofauna.

In Australia, stygofauna are known from alluvial, limestone karst, fractured rock, and calcrete aquifers (Hancock et al 2005; Humphreys 2008). To be suitable for stygofauna, aquifers must have sufficient porosity or fractionation (connectivity) for adequate living space, and have a sufficient flux of organic matter (DOC) and dissolved oxygen (Humphreys 2008). Stygofauna are groundwater invertebrates intricately linked to the aquifer environment and are adapted to the relative stability of their surroundings. Compared to surface environments, groundwater fluctuates less in level and in physico-chemical variables such as EC, temperature, and pH (Hancock et al. 2005). Groundwater ecosystems also generally have lower DO and 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 or 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). Alluvial aquifers adjacent to large permanent rivers often have suitable conditions, and can contain diverse stygofauna communities (Danielopol and Marmonier 1992; Hancock and Boulton 2008). Stygofauna biodiversity is also higher in areas of recharge where the water table is close (< 10 m) to the land surface (Humphreys 2000, Hancock and Boulton 2008). This is because the water table is likely to have the highest concentration of oxygen and organic matter. Stygofauna still occur at considerable depth below the water table, but are fewer in number, have lower diversity, and may be different species (Datry et al 2005). In some karstic aquifers, where there is relatively high vertical exchange, or flow does not come into contact with large microbial surface areas (such as occurs in sedimentary aquifers), stygofaunal communities can occur at depths exceeding 100m (Humphreys 2000) and overseas studies have recorded the presence of stygofauna at depths of 600m to 800m.

Stygofauna generally prefer water with an EC less than 5 000 µS/cm although stygofauna have been collected in bores in Queensland with EC up to 21 000 µS/cm (current study), and up to 33 000 µS/cm from springs and riverine hyporheic zones in Victoria and Tasmania (Serov, P. *pers comm*) so it is still quite possible to collect animals from salinities in excess of 5 000 EC. Other variables thought to be suitable for stygofauna are a shallow water table (< 20m), moderate concentrations of dissolved oxygen (1-5 mg/L), and pH between 6.5 and 7.5 (Hancock and Boulton 2008). These criteria are met for bore C018P2 (Table 3). This bore recorded an *in-situ* salinity of less than 1,800 µS/cm and dissolved oxygen concentrations in excess of 1 mg/L. pH values tended to be variable ranging from 6.28 in October 2011 to 7.23 in October 2012 which is generally within the suggested preferential physic-chemical range for stygofauna (Hancock and Boulton, 2008), however, bore C018P2 had a relatively deep water table at 38.9m with a total bore depth estimated to be around 89m intersecting a deep coal seam aquifer (AB Seam). As more stygofauna sampling occurs both seasonally and over a wide geographic area encompassing different geologies and hydrogeologies, a better understanding of the ecological requirements of Queensland stygofauna will develop. This information is critically important when considering sustainable management strategies for stygofauna communities.

As yet, few stygofauna species are known from coal seam aquifers. Eight taxa have been recorded by GHD (unpublished data) from coal seam aquifers in Queensland to date including a species of harpacticoid copepod collected from central Queensland; a species of *Notobathynella* (Syncarida), a species of Trombidiidae (water mites) and two species of Pezidae (water mites) from a coal seam aquifer (89m deep) in the Galilee Basin (current study), a species of Amphipoda and a species of Cyclopoid copepod from one bore from the northern Bowen Basin and a species of Astigmata (water mite) from a groundwater bore (75m deep) from the Styx Basin located on Central Queensland Coast.

In Queensland, diverse stygofauna communities have been collected from alluvial aquifers of the Pioneer River, Burnett River, as well as in the Clermont, Nebo, Glenden, Collinsville, Rolleston, Marlborough, and Wandoan regions of the Bowen, Galilee, Styx and Surat Basins (GHD unpublished data). These communities were mostly collected from shallow alluvial aquifers of unconsolidated, heterogeneous sediments. Other significant stygofauna communities also appear common in alluvial aquifers, particularly where the aquifers are connected to rivers that flow for most of the year (Hancock and Boulton 2008). This is because hydrological exchanges between surface and groundwater may be important sources of nutrients and oxygen to groundwater foodwebs (Hancock et al 2005, Boulton *et al* 2003).

The absence of stygofauna from the remaining 17 groundwater bores located on Adani EPC 1690 (MDL 372) does not necessarily indicate that stygofauna are not present in these aquifers, rather, it may be due to unsuitable geological conditions (low porosity, low hydraulic conductivity), inadequate range of bores selected for sampling, poor groundwater quality (e.g. presence of toxicants or high salinity), recent bore disturbance, or simply a low abundance of animals coupled with a heterogeneous distribution highlighting the basic need for replicated sampling covering different seasons and seasonal events.

Our knowledge of stygofauna in the Galilee Basin is very limited at present based on the fact that very few surveys have been conducted in this extensive region of Queensland. The current study adds substantially to this body of knowledge. Given that only two of 20 groundwater bores sampled recovered stygofauna (C018P2 and C008P1) across two comprehensive sampling events and that only 5 stygobitic taxa were recovered (Table 5), it would seem reasonable to conclude that stygofauna are in low diversity and abundance from this locality. Recent multiple stygofauna surveys conducted by GHD in the southern Galilee Basin around the township of Alpha (approximately 150 kms south of the Adani Coal Mine Project) have also failed to identify significant stygofaunal communities which would tend to suggest that stygofauna (i.e. stygophiles, stygobites, phreatobites) may be poorly represented in wider the geographic region.

It is relevant to note that the current sampling program undertaken for the Adani Coal Mine Project only sampled 2 alluvial aquifers (a third alluvial aquifer that was identified for sampling was dry) so this important aquifer environment for stygofauna was under represented in the sampling design. It is also noteworthy that both alluvial aquifers that were sampled in October 2011 and August 2012 on EPC 1690 (i.e. C025P1 and C027P1) contained groundwater with high EC concentrations ranging between 5,950 µS/cm to 30,222 µS/cm. If this is typical of alluvial aquifers located within EPC 1690 then it is highly unlikely, due to poor water quality, that stygofauna would be recovered from this environment. It is also not clear if the alluvium on EPC 1690 is extensive or continuous and whether it has effective groundwater storage properties and is regarded as a significant groundwater resource.

It must also be noted that the stygofauna that were collected from EPC 1690 (albeit in low abundance) were true obligate groundwater species and that they were recovered from AB Coal seam and Tertiary aquifers which may be impacted by dewatering from future mining activities. Activities of this kind that result in a reduction in groundwater levels can have a detrimental impact on obligate groundwater fauna. In accordance with DERM ToR for the Adani Coal Mine Project the stygofauna collected were identified to Family/Order level so it is not clear if the stygobitic fauna recovered are new species or not (although it is highly likely they would be).

4.1 Stygofauna Ecological Requirements

There are three critical factors that make stygofauna communities in aquifers vulnerable to the impacts of human activity:

- ***Stable water quality/physicochemical parameters***. Many groundwater species have evolved under strict constraints on environmental physicochemical parameters and, therefore, need stable conditions. Stygofauna are able to tolerate natural fluctuations in water parameters such as water level, electrical conductivity, and temperature, and this has been demonstrated experimentally (Tomlinson, M. unpublished data) for stygofaunal 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.
- ***Surface connectivity***. Groundwater communities require links to the surface environment to provide organic matter (DOC) and oxygen. If that linkage is broken or disrupted, the stygofauna community in the area affected could decline over time.
- ***Subterranean connectivity***. The third critical factor that makes stygofauna vulnerable to human activity is their high degree of endemicity (Humphreys 2008). This comes about because, 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 can 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 or 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 recolonisation 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.

4.2 Factors that Threaten Stygofauna

Mining proposals where stygofauna are considered to be a relevant environmental factor need to be closely assessed with respect to the extent of the proposed groundwater drawdown zone and the likely impacts on groundwater quality. Both of these activities, over time, may cause prospective stygofauna habitat to be degraded or lost with the potential for significant impact on groundwater communities.

Mining operations incorporate a range of generic water affecting activities in their operations (not all of which may be applicable to the Adani Project) that have the potential to cause some degree of change in natural water regimes (surface and groundwater), including some or all of the following (SKM, 2010):

- Below water table mining;
- Water supply development (e.g. groundwater, dewatering, surface water);
- Desalination for potable supply (with subsequent brine disposal);
- Dust suppression;
- Seepage;
- Tailings disposal;
- Rock storages;
- Backfilling and rehabilitation works;
- Water diversions and surface sealing;
- Hazardous and dangerous goods storage; and
- Water storages including waste water ponds.

In recognition of the above mining activities, direct effects on groundwater dependent ecosystems (e.g. stygofauna) may be as follows:

- Changes to water quantity (groundwater levels, pressures and fluxes);
- Changes to water quality (concentrations of salts and other toxic water quality constituents);
- Groundwater interactions (interactions between groundwater systems and between groundwater and surface systems); and
- Physical disruption of aquifers (excavation of mining pits and underground workings).

The existence and extent of these water affecting activities, and their potential impact on local to regional scale groundwater resources, and subsequently on groundwater dependent ecosystems (and stygofauna and hyporheic fauna in particular as these animals are the only true ‘obligate’ groundwater dependent fauna) will depend largely on the scale of the Adani operation, mining method, and process water requirements, as well as the climatic and geological setting.

4.2.1 Implications of Threatening Processes

Water Resources:

Water resources might be influenced by mining activities in two important ways, namely:

- aquifer storage depletion (e.g. groundwater pumping to dewater, evaporative discharge or extracting water for use in mining operations), and
- aquifer storage enhancement (e.g. as a result of seepage from mine facilities such as water ponds and tailings storages).

Through aquifer storage depletion (water table decline) the natural water regime may be influenced by the Adani mining operation with subsequent detrimental impacts on stygofauna (which are obligate groundwater dependent animals). This has become a particular issue for mining proponents over the last decade, principally because of their perceived biodiversity significance and the fact that little is known of their environmental water requirements. It needs to be recognised that groundwater drawdown can also occur outside the Adani mining operation (e.g. to the GAB). Knowledge of the spatial and temporal extent of the proposed drawdown zone and the specific aquifers impacted will be necessary to fully assess any impacts on the stygofaunal community. Future expansion of the Adani operation should also be considered.

GHD modeling has indicated that there should be no direct impacts on groundwater in the GAB, however, some indirect impact may be possible primarily via inducing drawdown in the near surface Tertiary and Quaternary age units present throughout the project area and extending into the GAB to the west. Potential impact on recharge of the GAB through dewatering is not anticipated to be significant. Potential impacts on the groundwater ecology of the GAB are unknown and are outside the scope of this project.

Lithology & Soils:

Geology and soil type will influence recharge (and seepage) potential as well as catchment yields. Some rock types can provide suitable capping material for tailings and rock storages and have a beneficial impact on stygofauna by protecting impacts on groundwater quality. Other rock types, however, can present hazards such as Acid Mine Drainage that may cause long-term impacts to surface water drainages if not managed properly. Significant changes to groundwater quality will impact detrimentally on stygofauna.

Mine Process:

The proposed Adani mine will generate waste material through processing operations although coal mining does not have large treatment requirements for the beneficiation process when compared with some other commodity groups (e.g. precious metals). The waste stream from the mine process can have varying levels of contaminants (both native and added through beneficiation). The safe storage of these wastes during mine operations and post-closure will be an important consideration in protecting groundwater quality and managing potential impacts on stygofauna.

Mining Method:

The Adani mining operation will involve excavation below the water table with identified impacts on groundwater resources such as:

- Reduction in groundwater levels and surface water flows through mine dewatering.
- Degradation of groundwater quality through spoil and tailing disposal and operation of processing plants and machinery and general waste landfill, and
- Linkage of aquifers and leakage from surface water courses resulting from longwall mining

The effect of these impacts manifests itself as groundwater drawdown around the mine pits and changes to groundwater quality which may extend for large distances depending on mine life, target depth of dewatering and aquifer hydraulic parameters (permeability and storage). GHD has estimated from groundwater modeling that groundwater levels will be drawn down by more than one metre up to around 10 kms from the project mine site during the operational phase of the mine. For the Adani Project it will be important to assess the location and distribution of the stygofauna recovered against the aquifers from which they originated and the forecasted drawdown zone (zone of impact) over the life of the mine. A rapid decline in the water table would be detrimental to stygofauna, however, laboratory research has shown that stygofauna can cope with a small and slow decline in aquifer storage. Evaporative losses of water and concentration of salts in the Adani mine pit extending below the water table is also something to consider post mine closure.

Another consideration is the impact to overlying bedrock strata as a result of longwall mining operations (particularly relevant to coal mining). In particular, the impact on the rock strata following the decommissioning of longwall mines by the destruction of the mine's support pillars which can cause the mine to collapse into itself. This can cause minor to major cracking of the substrate. The impact of this can include the drainage of surface waters into fractures/cracks following streambed cracking and the drainage of groundwaters out of aquifers through the cracks leading to possible :

- Drying of overlying aquifers
- Drying of entire river systems (and recharge capabilities)
- Contamination of underlying aquifers and outflow streams

The impact of this process could have rapid and irreversible effects on subsurface aquatic fauna.

Mine Maturity:

The proposed Adani mine is currently a greenfield mining operation that will take place within a variety of groundwater regimes, most of which will have been impacted to some degree by agricultural activities. Establishing a baseline prior to the commencement of operations is important in order for the Adani Project to gauge the effects of its operations on existing groundwater conditions through the construction, operational and rehabilitation phases. Full compliance with WA guidelines (2003 & 2007) and the adoption of two sampling events across two seasons covering 20 different sampling points using best practice sampling procedures has ensured that the Adani Coal Mine Project has established a significant baseline. Ongoing (biennial) monitoring of stygofaunal communities through the life of the mine is highly recommended to provide an indication of changes (if any) to groundwater condition and health.

4.3 Cumulative Effects

In relation to mining, cumulative effects can arise from:

- The compounding effects of a single mining or processing operation;
- Interference effects between multiple mining and processing operations; and

- Interaction between mining and non-mining activities.

Cumulative effects may result from a number of activities interacting with the environment. The nature and scale of these effects can vary substantially, 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 (Brereton and Moran, 2008). 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 additive (SKM, 2010).

For the Adani Coal Mine Project quantification of the direct cumulative effects of mining on the regions groundwater systems will need to be considered, particularly the potential for mine water affecting activities to impact on:

- Groundwater quantity (i.e. alteration to groundwater levels and fluxes),
- Groundwater quality (i.e. alteration to regional salinity levels and concentrations of other important toxicants);
- Groundwater – surface water interaction (i.e. reduction to levels of interaction between groundwater and surface systems e.g. reduced baseflow to streams, reduced recharge of aquifers and a reduced water table depth); and
- Physical disruption to aquifers (i.e. will the proposed Adani mine contribute to the permanent disruption of a groundwater system).

All of the above cumulative effects impact on groundwater quantity and quality and ultimately on obligate groundwater dependent fauna (stygofauna including hyporheic fauna).

It is not clear at this stage if mining proposals exist on nearby or adjoining land to EPC 1690. Potential cumulative impacts of adjoining mines on local groundwater resources could have far reaching impacts on groundwater dependent ecosystems and certainly be more significant than a single mine operation (albeit a very large one) on its own.

4.4 Implications for the Adani Project EIS

The stygofauna collected from two bores on EPC 1690 (MDL 372) in October 2011 and August 2012 have been identified as belonging to the Acarina Familes, Trombidiidae and Pezidae, the Syncarid Family, Parabathyneliidae and the Copepod Family, Cyclopoida. These obligate groundwater faunal groups normally have their highest biodiversity within the riverine, hyporheic zones and are classed as members of the ‘permanent hyporheos’ or the community that occurs within the shallow to deep sand and gravel beds associated with areas of groundwater discharge (Gilbert, 1994). They typically characterize the transition zone between the permanent shallow hyporheic ecozone and the groundwater hypogean environment (Gilbert, 1994). The current study has extended the body of knowledge on these animals as they were recovered from deep coal seam and Tertiary deposit aquifers (not directly associated with the hyporheos). It is possible that the movement of these animals from their traditional habitat in the shallower alluvium to deeper aquifers was prompted by the poor water quality (i.e. high salinity) observed in the alluvial aquifers.

4.5 Recommended Management Approach

- Identify the obligate stygofauna to species (i.e. those listed as stygobites and phreatobites) to determine levels of endemicity of the stygofauna community within the aquifers as this community is the most disturbance sensitive environmental indicator for changes in aquifer conditions.
- Consider conducting further stygofauna sampling outside EPC 1690 and outside the zone of impact of the mine (i.e. water drawdown zone) in order to establish the presence of the same or similar species of stygofauna that were collected from EPC 1690.
- Conduct a desk top study on the potential for troglofauna to be present on EPC 1690 and follow up with a pilot study if suitable troglofauna habitat is identified
- Build on the existing baseline by conducting biennial stygofauna surveys during mine construction, operation and closure phases in order to monitor and measure groundwater health and condition over the life of the mine.

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