Central Queensland Coal Project

Appendix 10c – Stygofauna Assessment

Central Queensland Coal

CQC SEIS, Version 3

October 2020

Yeats Consulting

DRAFT ONLY*

Report for Styx Coal South Project EM Plan

Stygofauna Survey

July 2012

Contents

Table Index

Figure Index

Appendices

1. Introduction

1.1 Background

Styx Coal Pty Ltd and Fairway Coal Pty Ltd (collectively referred to in this report as Styx Coal) are seeking to develop a coal deposit in the Styx Coal Basin 150km north of Rockhampton in Central Queensland, Australia. The Styx Coal South Project (SCSP) is a small scale open cut with coal processing and rail infrastructure and is located on EPC 1029.

In 2010 YEATS Consulting (YEATS) was contracted by Styx Coal (then Waratah Coal) to undertake a preliminary assessment of the environmental resources associated with SCSP. In August 2011 YEATS commissioned ALS Water Sciences (now GHD Water Sciences and referred to in this report as GHD) to conduct a baseline stygofauna survey within the SCSP MLA in accordance with best practice procedures defined in WA Guidelines (2003 & 2007). In December 2011 GHD prepared an overview report for YEATS describing the scope and nature of the baseline stygofauna survey conducted in November 2011 and a summary of key preliminary findings. This preliminary report was produced by GHD to assist YEATS develop an Environmental Management (EM) Plan for the proposed mine. On 23 May 2012 YEATS lodged the Mine EM Plan with DEHP (formerly DERM) for informal review prior to the submission of the mining lease application in June 2012. YEATS anticipate submitting a formal EIS for the project to DEHP sometime in late 2012.

GHD conducted the first round of stygofauna sampling during the 2011 pre-wet season between 21 and 24 November. The WA Guidelines (2003 & 2007) specify the need for two sampling events to be conducted across two seasons spaced at least 3 months apart. To comply with this requirement GHD undertook a second round of stygofauna sampling during the 2012 post-wet season between 15 and 18 March. This report presents and analyses the findings from both sampling events and is intended for inclusion as a Technical Report appended to the project EIS.

1.2 Project Objectives and Scope of Work

While the EIS Terms of Reference (TOR) for the Styx Coal South Project have yet to be finalised, the study design and methods adopted by GHD for the SCSP were 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"...

1.3 Relevant Project Legislation

1.3.1 WA EPA Guidance Statements (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. 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 SCSP baseline stygofauna survey conforms to WA Guidelines (2003 & 2007) with the exception that only Order/Family taxonomic resolution has been applied as defined by DEHP generic TOR (see above) and only a limited number of control bores located outside the MLA were selected for sampling.

1.3.2 Environmental Protection and Biodiversity Conservation Act (1999)

The 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 GDE. If a GDE contains a threatened species as listed under this Act, the GDE is then taken to have a higher ecological value.

1.4 GDE's and Stygofauna

Groundwater dependent ecosystems or GDE's is a term occurring more frequently in the scientific literature these days. 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'* (NWC). Based on this definition, GDE's explicitly include any ecosystem that uses 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).

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).

1.5 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 (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 (Simulidae Fly larvae, Caenidae 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** are obligate subterranean species, restricted to subterranean environments and typically possessing character traits related to a subterranean existence (troglomorphisms) such as reduced or absent eyes and pigmentation, and enhanced non-optic sensory structures.
- **Phreatobites** are stygobites (obligate subterranean species) restricted to the 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. 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 chance of finding new species is high.

1.6 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).

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. 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.

1.7 Other Studies

The National Water Commission (NWC) has 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 unsurveyed. 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*) have confirmed the presence of stygofaunal taxa (Copepoda, Bathynellacea, and Amphipoda) in the Bowen Basin. To date, stygofaunal taxa are known from near Clermont, near Collinsville, near Glenden, near Rolleston and near Nebo (GHD *unpublished*). 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) than coal seam aquifers. GHD (*unpublished*) has also recently recovered diverse and abundant stygofaunal communities from both the Surat and Galilee Basins in Queensland. 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.

The present study is the first undertaken by GHD on the Central Queensland coast. The Styx River Catchment is located on the coast approximately 180 km south from Mackay and 150 km north from Rockhampton. The catchment is bordered by the Connors Ranges in the Northwest and the Broadsound Ranges to the Southwest. This study revealed the presence of stygofauna from within the project area.

Only four stygofauna taxa have been recorded by GHD from coal seam aquifers in Queensland to date:

- A species of harpacticoid copepod collected from 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) and a species of Trombidiidae (water mites) from a coal seam aquifer (90m deep) in the Galilee Basin with high groundwater quality (EC 1 505 µS/cm; pH 6.28 and DO 2.51mg/L), and
- A species of Amphipoda and a species of Cyclopoid copepod from one bore from the northern Bowen Basin. 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.

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.

A survey was conducted in 2002 and 2003 in the Pioneer Valley by the Queensland Department of Environment, Heritage and Planning (Hancock, 2003). This survey revealed substantial stygofauna communities with at least 19 taxa from 19 bores in an alluvial aquifer.

Stygofauna also appear to 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*). In Queensland stygofauna have been collected in bores with EC up to 18 000 µS/cm, so it is still quite possible to collect animals in groundwater with EC in excess of 5,000. 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 about 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

Styx Coal are seeking to develop a coal deposit in the Styx Coal Basin on the Central Queensland coast approximately 180 km south from Mackay and 150 km north from Rockhampton (Figure 1). The Styx Coal South Project (SCSP) is a small scale open cut with coal processing and rail infrastructure and is located on EPC 1029. The catchment is bordered by the Connors Ranges in the Northwest and the Broadsound Ranges to the Southwest.

Figure 1: Location of Styx Coal South Project EPC 1029 (www.waratahcoal.com/styx-coal-project.htm).

2.1.1 **Geology** (www.ga.gov.au/oceans/ea_ofs_Styx.jsp)

Styx Basin – Cretaceous

The Styx Coal Measures of the Styx Basin were laid down on a coastal plain which developed on the Palaeozoic Strathmuir Syncline during the Early Cretaceous. The Styx Basin has largely fault bounded margins.

The Styx Basin is a small Early Cretaceous intracratonic sag basin straddling the central Queensland coast near the town of St Lawrence. The basin covers an area of approximately 300 km2 onshore and 500 km2 offshore, under water depths of up to 100 meters. The maximum known thickness of sediments is 387 meters from a coal exploration bore, but magnetic data suggest a thickening offshore.

The Styx Basin probably developed by subsidence of the Strathmuir Synclinorium, an older feature containing Permian Bowen Basin strata. Styx Basin sediments lap onto Permian strata in the west, but are faulted against them in the east. The basin plunges gently to the north under the waters of Broad Sound but the general dip of the Styx Coal Measures sequence is to the east. The southern part of the basin is bounded to the east by a post-depositional high-angle reverse fault. Adjacent to this fault, the Cretaceous sediments are folded and faulted. The known strata of the basin are referred to as the Styx Coal Measures and consist of quartzose, calcareous, lithic and pebbly sandstones, pebbly conglomerate, siltstone, carbonaceous shale and coal. The environment of deposition was freshwater, deltaic to paludal with occasional marine incursions.

The coals at the base of the Styx Coal Measures lie within the oil window and could potentially generate petroleum, however, there is no known evidence that generation of oil or gas has occurred from this succession. The offshore Styx Basin lies entirely within the Great Barrier Reef Marine Park, in which petroleum exploration activity is prohibited. Coal was mined in the first half of the 20th century with a total production of 1.76 million tonnes, but reserves are currently not of economic importance.

Styx Coal South Project EPC 1029

Require summary geological data specific to EPC 1029. *YEATS to provide*.

2.1.2 Hydrogeology

Need to include summary details of local and regional hydrogeology relative to EPC1029. It will be important to be able to describe:

- the aquifers present within EPC1029.
- the aquifers sampled by the 30 groundwater bores selected for stygofauna sampling.
- spatial and temporal groundwater drawdown contours resulting from proposed mining on EPC1029.
- any cumulative impacts on aquifers resulting from off-lease activities.

YEATS to provide.

2.2 Mining Operations Plan

Require summary of proposed mining operations. *YEATS to provide*.

2.3 Study Design

Stygofauna sampling 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 adopted by DEHP for stygofauna surveys in Queensland.

The aim of the survey was to determine if stygofauna were present in groundwater associated with the SCSP (EPC 1029), and within the constraints of the study design, determine the range of taxa present and their conservation significance. Established best practice 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 two sampling events were undertaken for stygofauna across two seasons spaced 3 months apart as follows:

- Sampling event 1 covered 21 groundwater bores and was conducted during the pre-wet season between 21 and 24 November 2011.
- Sampling event 2 covered 19 groundwater bores and was conducted during the post-wet season between 15 and 18 March 2012.

2.4 Location of Sampling Bores and Bore Characteristics

A total of 25 groundwater bores were selected by YEATS for stygofauna sampling in the November 2011 pre-wet season (Table 1). The sampling sites were geographically well spread across SCSP EPC 1029 (Figure 2). Of the 25 sites selected for sampling, stygofauna samples were collected from 21 of the nominated bores.

A second post-wet stygofauna sampling event was conducted in March 2012. A total of 19 groundwater bores were sampled for stygofauna (Table 1). Of these 19 bores 10 were the same bores that were sampled in November 2011 for stygofauna and 9 were new bores sampled for the first time in March 2012.

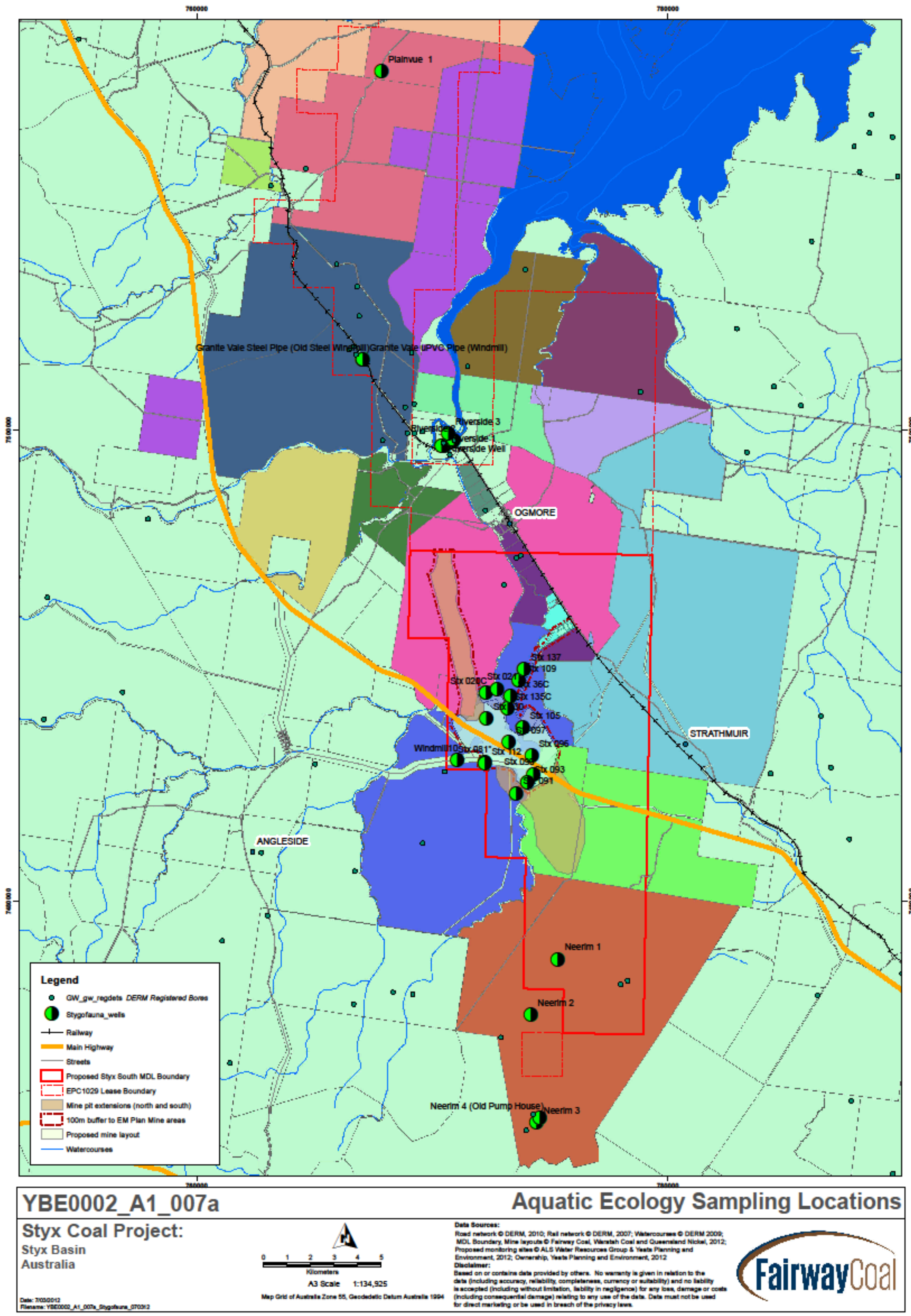

Figure 2: Location of groundwater bores used for stygofauna sampling in November 2011. This locality map requires updating to include new stygofauna sites sampled in March 2012. *YEATS to provide*.

Table 1: Location and characteristics of 33 SCSP groundwater bores sampled for groundwater quality and stygofauna in November 2011 and March 2012. Three bores {*****} were sampled for WQ only. *YEATS to provide data on Lithology.*

BORE ID	Latitude / Easting	Longitude / Northing	Date Sampled	SWL (m)	Depth to EoH (m)	Hole Diameter (mm)	Bore Type	Lithology
Stx 20C	22.68559°	149.65006°	23/11/11	15.50	75.6	PVC 100	Exploration Hole	
Stx 21	22°41.038’	149°39.274’	23/11/11	10.31	25.0	PVC 100	Exploration Hole	
Stx 081	772235	7485928	22/11/11	9.22	107.55	PVC 100	Exploration Hole	
Stx 081	772235	7485928	16/03/12	9.20	107.55	PVC 100	Exploration Hole	
Stx 090	22°42.987’	149°40.214’	21/11/11	10.73	77.80	PVC 100	Exploration Hole	
Stx 090	774287	7485398	15/03/12	10.93	77.80	PVC 100	Exploration Hole	
Stx 091	773562	7484585	22/11/11	10.85	75.15	PVC 100	Exploration Hole	
Stx 091	773562	7484585	15/03/12	10.74	75.15	PVC 100	Exploration Hole	
Stx 093	774042	7485069	22/11/11	12.0	75.0	PVC 100	Exploration Hole	
Stx 093	774042	7485069	15/03/12	11.95	75.0	PVC 100	Exploration Hole	
Stx 096	22°42.564’	149°40.172’	21/11/11	12.39	74.6	PVC 100	Exploration Hole	
Stx 096	22°42.564’	149°40.172’	16/03/12	12.42	74.6	PVC 100	Exploration Hole	
Stx 097	22°42.263’	149°39.589’	23/11/11	11.96	74.9	PVC 100	Exploration Hole	
Stx 105	22°41.922’	149°39.933’	21/11/11	14.18	74.64	PVC 100	Exploration Hole	
Stx 109*	22°40.845’	149°39.816’	23/11/11	14.11	74.64	PVC 100	Exploration Hole	
Stx 112	772235	7485856	22/11/11	9.94	95.0	PVC 100	Exploration Hole	
Stx 112	772235	7485856	16/03/12	9.38	95.0	PVC 100	Exploration Hole	
Stx 130	22°41.730’	149°39.030’	23/11/11	15.6	30.0	PVC 100	Exploration Hole	
Stx 135C*	22°41.488’	149°39.550’	23/11/11	14.01	74.6	PVC 100	Exploration Hole	
Stx 36C	22°41.213’	149°39.618’	23/11/11	14.29	74.6	PVC 100	Exploration Hole	
Stx 137*	22°40.586’	149°39.934’	23/11/11	15.41	149.7	PVC 100	Exploration Hole	

Table 1: ctd.

BORE ID	Latitude / Easting	Longitude / Northing	Date Sampled	SWL (m)	Depth to EoH (m)	Hole Diameter (mm)	Bore Type	Lithology
Granite vale Steel pipe (Old Steel Windmill 1)	767044	7502984	22/11/11	6.55	est.8.0	Steel 100	Windmill	Quaternary Alluvium
Granite vale PVC pipe (Windmill)	767044	7502983	22/11/11	6.58	est.8.0	PVC 100	Windmill	Quaternary Alluvium
Plainvue 1	767838	7515168	22/11/11	7.47	est.17.0	Steel 150	Production with pump attached	
Plainvue 1	767838	7515168	17/03/12	7.28	est.17.0	Steel 150	Production with pump attached	
Neerim 1	22.78703°	149.68169°	23/11/11	2.12	est.12.0	PVC 150	Exploration Hole	Quaternary Alluvium
Neerim 2	22.80842°	149.67090°	23/11/11	4.43	50.0	PVC 150	Exploration Hole	
Neerim 3	22.84967°	149.67422°	23/11/11	4.44	est.30.0	PVC 150	Exploration Hole	
Riverside Well	22°35.477’	149°37.797’	24/11/11	7.79	est.10.0	Steel 1,000	Well	Quaternary Alluvium
Riverside Well	770391	7499336	17/03/12	7.06	est.10.0	Steel 1,000	Well	Quaternary Alluvium
Riverside 1	22°35.501’	149°37.863’	24/11/11	7.59	9.30	PVC 150	Production NO pump attached	Quaternary Alluvium
Riverside 1	770508	7499285	17/03/12	7.34	9.30	PVC 150	Production NO pump attached	Quaternary Alluvium
Riverside 2	22°35.365’	149°38.104’	24/11/11	6.82	8.89	PVC 150	Exploration Hole	
Riverside 2	770920	7499544	17/03/12	6.89	8.89	PVC 150	Exploration Hole	
Riverside 3	22°35.210’	149°37.961’	24/11/11	5.95	11.0	PVC 50	Monitoring Piezo	Quaternary Alluvium
Riverside 3	770679	7499830	17/03/12	5.33	11.0	PVC 50	Monitoring Piezo	Quaternary Alluvium
Stx 038	772160	7486136	16/03/12	9.28	75.10	PVC 100	Exploration Hole	
Stx 077	774032	7486352	16/03/12	13.84	est. 35.0	PVC 150	Exploration Hole	
Stx 095	774549	7486255	16/03/12	13.36	75.75	PVC 150	Exploration Hole	
Stx 100	772046	7486619	16/03/12	6.79	77.75	PVC 100	Exploration Hole	
Stx 113	773634	7486170	16/03/12	10.96	est.110.0	PVC 150	Exploration Hole	
Stx 114	772965	7486034	16/03/12	9.88	25.0	PVC 100	Exploration Hole	
Stx 126B	771954	7487122	16/03/12	16.65	74.6	PVC 150	Exploration Hole	
Stx 127	771436	7487316	16/03/12	16.14	81.0	PVC 100	Exploration Hole	

2.4.1 Selection of Groundwater Bores for Stygofauna Sampling

The basic criteria for selection of groundwater bores for stygofauna sampling for the SCSP was 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 1029) 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;
- 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 with a salinity less than 5,000 µS/cm EC (and preferable less than 1,500 µS/cm EC), a DO in the range of 2 to 4 mg/L and pH within the range 6.2 to 7.2.

2.5 Field Sampling and Sample Processing Methodology

2.5.1 Stygofauna Sampling

A 50mm diameter phreatobiological net was used for stygofauna sampling (GHD nets conform to WA guideline 2003 & 2007 specifications) for all bores/holes greater than 50mm in diameter. For bores that were 50mm in diameter a 40mm diameter stygofauna net was used. 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 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 SCSP sampling events conducted in November 2011 and March 2012.

2.5.2 Laboratory Processing of Field Samples

Sample jars were drained of ethanol and washed gently into channeled sorting 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.

2.5.3 Groundwater Quality Sampling

Groundwater samples were collected using a bailer lowered 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 always 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, 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 ALS recording sheets.

2.6 GHD Project Personnel

The November 2011 and March 2012 field sampling was conducted by Garry Bennison (BSc.Hons. MAIBiol) and Mark Dahm (BSc. MSc.). Both GHD 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 and Surat 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 taxonomic QA/QC conducted 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 SCSP achieved most of the key selection criteria outlined in Section 2.4.1 of this report. The 30 groundwater bores that were sampled across two events in November 2011 and March 2012 were geographically well spread across the existing SCSP MLA (Figure 2). The age of the bores was unknown. 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 WQ 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).

A total of 21 groundwater bores/holes were sampled for stygofauna in November 2011.The round 2 sampling event conducted in March 2012 sampled 9 of the same bores sampled in 2011 and added a further 10 new bores/holes to the sampling program. New bores were selected for sampling in March 2012 in order to provide the broadest possible range and geographic distribution of bores/holes across the study area. The March 2012 sampling program also followed a very heavy rainfall event and some of the bores sampled in November 2011 could not be safely accessed in March 2012.

3.1.1 Quality of Stygofauna Samples Collected

A total of 30 groundwater bores were sampled for stygofauna across November 2011 and March 2012. The quality of stygofauna samples collected is summarized in Table 2 below. The sampling method aimed to collect 6 replicate hauls off the bottom of each bore/hole.

Table 2: Summary of quality of stygofauna samples collected from SCSP in November 2011 and March 2012.

Bore ID	No. Replicate Stygofauna Samples Collected		Comments
	November 2011	March 2012	
Stx 20C	6		Good sample with all hauls off bottom of bore.
Stx 21	6		Good sample with all hauls off bottom of bore.
Stx 081		6	Good sample with all hauls off bottom of bore.
Stx 090	6	6	Good sample with all hauls off bottom of bore.
Stx 091	6		Good sample with all hauls off bottom of bore.
Stx 091		4	Average sample with only 1 haul off bottom of bore.
Stx 093	6	6	Good sample with all hauls off bottom of bore.
Stx 096	6	6	Good sample with all hauls off bottom of bore.
Stx 097	6		Good sample with all hauls off bottom of bore.
Stx 105	6		Good sample with all hauls off bottom of bore.

Stx 112	6	6	Good sample with all hauls off bottom of bore.
Stx 130	6		Good sample with all hauls off bottom of bore.
Stx 36C	6		Good sample with all hauls off bottom of bore.
Granite Vale Steel Pipe (old steel windmill 1)	2		Poor Sample. Net jamming in bore due to fixed PVC pipe.
Granite Vale PVC pipe (Windmill)	6		Good sample with all hauls off bottom of bore.
Plainvue 1	6	6	Good sample with all hauls off bottom of bore.
Neerim 1	6		Good sample with all hauls off bottom of bore.
Neerim 2	6		Good sample with all hauls off bottom of bore.
Neerim 3	6		Good sample with all hauls off bottom of bore.
Riverside Well	6	6	Good sample with all hauls off bottom of bore.
Riverside 1	6	6	Good sample with all hauls off bottom of bore.
Riverside 2	6	6	Good sample with all hauls off bottom of bore.
Riverside 3	6	6	Good sample with all hauls off bottom of bore.
Stx 038		6	Good sample with all hauls off bottom of bore.
Stx 077		6	Good sample with all hauls off bottom of bore.
Stx 095		6	Average sample. Bore collapsed at ~50m so all samples not off true bottom.
Stx 100		6	Good sample with all hauls off bottom of bore.
Stx 113		6	Average sample. Only 1 sample off bottom of bore.
Stx 114		6	Good sample with all hauls off bottom of bore.
Stx 126B		6	Average sample. Bore collapsed at ~32m so all samples not off true bottom.
Stx 127		6	Average sample. Only 1 sample off bottom of bore.
TOTAL Sites Sampled for Stygofauna	**21**	**19**	

3.2 Groundwater Quality

A total of 33 groundwater bores were sampled for *in-situ* water quality across November 2011 and March 2012 (Table 3). Of these 33 groundwater bores, 25 bores were sampled for water quality in November 2011 and 19 bores were sampled for water quality in March 2012.

The overall depth of the water table was generally shallow across the study area (Table 1) with a standing water level (SWL) range of between 2.12m and 16.65m (average 10.13m). Waratah Coal drill records show a SWL in the vicinity of Mamelon at around 16m below ground although this varied between 0m (i.e. ground level) and 30m below ground level (YEATS 2011). Stygofauna have been reported as preferring a shallow water table less than 20m (Hancock 2008).

Average groundwater quality differed between November 2011 and March 2012 (Table 3). In March 2012 pH was generally lower than recorded in November 2011 (by 0.7 of a pH unit), EC was slightly higher (by 800 µS/cm), dissolved oxygen lower (by 7.5% or 0.6mg/L) and water temperature was higher (by 0.4^{o}C). The March 2012 sampling event was preceded by a significant rainfall event across the Styx catchment which lasted a number of days. These data reflect the generally variability in water quality both spatially and temporally across EPC 1029 and regionally.

pH across all groundwater bores was slightly alkaline with mean values of 8.16 in November 2011 and 7.47 in March 2012 (Table 3). These elevated pH values are supported by historic data (YEATS 2011) which shows average pH levels from registered well records in the proximity to EPC 1029 of between 7.5 and 7.7. The highest pH recorded from the current study was 9.77 which occurred at site Stx 105 in November 2011 and the lowest pH was recorded at site Plainvue 1 also in November 2011. Stygofauna have been reported as preferring a pH concentration of between 6.5 and 7.5 (Hancock 2008).

YEATS (2011) report that typically the groundwaters of the study area can be described as occasionally fresh but mostly brackish on alluvial and consolidated/unconsolidated material and brackish in fractured and weathered rock on hills and slopes. Historic data (YEATS 2011) shows average groundwater quality from registered well records in proximity to EPC 1029 to range between 1,580 µS/cm (Quaternary alluvium) and 8,000 µS/cm (unconsolidated/consolidated material on terraces and lower slopes). This is in agreement with current *in-situ* data which shows mean EC values ranging from 6,275 µS/cm in November 2011 to 7,085 µS/cm in March 2012 (Table 3). Ranges in EC concentrations also reflected the extreme variability in water quality across EPC 1029 with the lowest EC recording of 377 µS/cm occurring at site Neerim 2 in November 2011 and the highest EC recording of 30,237 µS/cm occurring at site Plainvue 1 in March 2012. Stygofauna 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 2008). Of the 33 groundwater bores sampled for stygofauna across November 2011 and March 2012, 24 bores recorded an EC concentration below 5,000 µS/cm and 5 bores recorded an EC concentration below 1,500 µS/cm.

Groundwater temperatures were generally warm with a mean temperature of 25.91 ^{o}C in November 2011 and 26.34 ^{o}C in March 2012 and a range between 24.31 ^{o}C (Neerim 3) and 27.49 ^{o}C (Stx 114) (Table 3).

Dissolved Oxygen (DO) concentrations were low to medium for groundwater with an average of 2.29 mg/L (28.8% satn) in November 2011 and 1.61 mg/L (21.3% satn) in March 2012 (Table 3). These figures should only be used as being indicative of true dissolved oxygen values since water was collected using a bailer and may have received agitation and artificial oxygenation during collection. Dissolved oxygen concentrations ranged from a low of 0.57 mg/L at bore Stx 093 in March 2012 to a high of 6.01 mg/L at Granite Vale PVC Windmill in November 2011. Thirty one groundwater bores recorded DO concentrations between 1mg/L and 6mg/L which would be considered ‘prospective’ for the presence of stygofauna (Hancock 2008).

Table 3: Groundwater quality data for 33 SCSP bores sampled in November 2011 and March 2012. All bores were sampled for stygofauna with the exception of Stx 109, Stx 135C and Stx 137 which were sampled for WQ *only*. Shaded rows indicate bores that contained stygofauna. *YEATS to provide data on bore age*.

BORE ID	**Age of Bore**	**pH** (units)	**pH** (units)	**EC** (µS/cm)	**EC** (µS/cm)	**DO** (% satn)	**DO** (% satn)	**DO** (mg/L)	**DO** (mg/L)	**Water Temp** (^{o}C)
		Nov’11	**Mar’12**	**Nov’11**	**Mar’12**	**Nov’11**	**Mar’12**	**Nov’11**	**Mar’12**	**Nov’11**
Stx 20C		9.37	-	3,180	-	37.5	-	3.05	-	25.28
Stx 21		9.57	-	4,293	-	33.8	-	2.64	-	26.65
Stx 081		7.29	6.95	17,184	24,502	23.7	16.2	1.80	1.17	26.41
Stx 090		8.61	7.87	4,223	6,458	13.5	18.0	1.03	1.40	**27.44**
Stx 091		8.46	7.90	1,105	1,556	32.2	15.3	2.58	1.21	26.35
Stx 093		7.13	7.54	17,579	11,881	13.5	**7.3**	1.03	**0.57**	26.04
Stx 096		8.18	7.76	2,511	3,706	**8.8**	11.7	**0.70**	0.94	26.88
Stx 097		8.38	-	2,471	-	21.5	-	1.71	-	26.68
Stx 105		**9.77**	-	1,891	-	58.4	-	4.84	-	25.03
Stx 109		8.90	-	3,288	-	23.2	-	1.87	-	25.50
Stx 112		8.46	7.75	2,046	**497**	31.8	**54.8**	2.54	**4.35**	26.19
Stx 130		8.97	-	2,964	-	20.6	-	1.63	-	26.73
Stx 135C		9.56	-	2,159	-	18.5	-	1.51	-	25.62
Stx 36C		8.08	-	6,244	-	17.5	-	1.41	-	25.01
Stx 137		7.84	-	**27,434**	-	19.8	-	1.46	-	25.20
Granite Vale Steel Pipe (old steel windmill 1)		8.07	-	2,048	-	67.7	-	5.38	-	25.79
Granite Vale PVC pipe (Windmill)		7.70	-	1,708	-	**75.5**	-	**6.01**	-	26.28
Plainvue 1		**6.03**	**6.43**	26,249	**30,237**	15.5	19.5	1.14	1.41	26.63
Neerim 1		8.04	-	679	-	23.4	-	1.95	-	24.52
Neerim 2		7.73	-	**377**	-	43.4	-	3.57	-	**24.31**
Neerim 3		8.05	-	2,646	-	15.0	-	1.20	-	24.51
Riverside Well		7.80	7.25	4,727	4,565	20.6	35.7	1.63	2.93	26.53
Riverside 1		7.45	7.25	925	1,052	17.0	31.0	1.39	2.51	25.43
Riverside 2		7.29	7.17	14,431	16,678	25.6	11.3	1.96	0.85	25.41
Riverside 3		7.35	7.03	4,509	4,759	41.7	41.2	3.24	3.32	27.42
Stx 038		-	7.84	-	5,405	-	11.2	-	0.89	-
Stx 077		-	6.89	-	4,289	-	23.0	-	1.79	-
Stx 095		-	6.97	-	2,044	-	14.3	-	1.14	-
Stx 100		-	8.10	-	2,908	-	28.4	-	2.26	-

Stx 113		-	7.68	-	2,218	-	16.3	-	1.34	-
Stx 114		-	**8.76**	-	586	-	14.9	-	1.17	-
Stx 126B		-	7.09	-	8,005	-	21.3	-	1.68	-
Stx 127		-	7.67	-	3,274	-	13.2	-	1.04	-
		pH (units)	**pH** (units)	**EC** (µS/cm)	**EC** (µS/cm)	**DO** (% satn)	**DO** (% satn)	**DO** (mg/L)	**DO** (mg/L)	**Water Temp** (°C)
		Nov'11	**Mar'12**	**Nov'11**	**Mar'12**	**Nov'11**	**Mar'12**	**Nov'11**	**Mar'12**	**Nov'11**
Mean Value		8.16	7.47	6,275	7,085	28.8	21.3	2.29	1.61	25.91
Range		6.03 - 9.77	6.43 – 8.76	377 – 27,434	497 – 30,237	8.8 – 75.5	7.3 – 54.8	0.70 – 6.01	0.57 – 4.35	24.31 – 27.44

3.3 Groundwater Dependent Fauna

A total of 30 groundwater bores, exploration holes, wells and piezometers were sampled for stygofauna in November 2011 and March 2012 within and adjoining the Styx Coal MLA (EPC 1029) using standard sampling methods described in WA Guidelines 54 and 54a (2003 & 2007). Sample quality was generally high across all 30 bores/holes (Table 2).

A total of 2 bores/holes (Riverside 1 and Granite Vale Old Steel Windmill 1) registered the presence of stygofauna in November 2011 from 21 sites sampled and 4 bores/holes (Riverside 1, Stx 093, Riverside Well and Riverside 3) registered the presence of stygofauna in March 2012 from 19 sites sampled (Table 4) (Figure 3).

Table 4: List of subterranean fauna collected from SCSP in November 2011 and March 2012. Shaded row indicates non-stygofauna animal. Refer Section 1.5 of this report for a definition of terms. ND= Not Determined.

Bore ID	Class	Order	Family	Genus	Species	No. Animals	Habitus	Habitat	Co M
Riverside 1	Annelida	Clitellata	Capilloventridae	*Capilloventer*	sp.	1	Stygobite	Interstitial	5
Riverside 1	Annelida	Tubificida	Naididae	*Nais*	sp.	1	Phreatobite	Interstitial	5
Granite Vale Old Steel Windmill1	Crustacea	Copepoda	Cyclopidae	ND	ND	2	Phreatobite	Interstitial	5
Stx 093	Entognatha	Collembola	Entomodryidae	ND	ND	1	Edaphobite	Soil	5
Stx 093	Acariformes	Astigmata ?	ND	ND	ND	5	Stygophile	Interstitial	5
Riverside Well	Annelida	Tubificida	Enchytraeidae	*ND*	ND	1	Phreatobite	Interstitial	5
Riverside 3	Crustacea	Syncarida	Parabathynellidae	*c.f.Notobathynella*	sp.	4	Phreatobite	Interstitial	5

Figure 3: Photos of bores/holes containing stygofauna (GHD Water Sciences). **Top Left –** Riverside 3 bore on David Sapa's property. **Top Right –** Stx 093 bore on Mamelon property. **Middle Left –** Riverside Well on David Sapa's property. **Middle Right –** Riverside 1 bore on David Sapa's property. **Bottom Left –** Old Steel Windmill bore on Granite Vale property.

A total of five sites recorded the presence of subterranean fauna with four sites recording subsurface species which can be classed as stygofauna, including obligate groundwater species associated with the hypogean and permanent hyporheic environments (Table 4). The fauna collected included a single specimen of a terrestrial, edaphobitic (soil dwelling), species of Collembola in March 2012 at site Stx 093. The relatively moderate to small size (0.5-2mm) of the species present indicates a moderate connectivity within the river/aquifer environment. This soil dwelling species will not be considered further in this report as its presence/absence is not directly linked to changes in groundwater quantity or quality.

The shallow water table levels within the riverine bores (Riverside Well, Riverside 1, Riverside 3 and Granite Vale Old Steel Windmill 1) and the presence of Bathynellacea Syncarida, three families of Oligochaeta and Copepoda suggests a fine to moderate grained unconsolidated alluvial aquifer with direct association/connectivity of the baseflow river system with an interconnected hyporheic zone (Boulton & Hancock, 2006). The species also indicate moderate to high water quality. Shallow water tables in either unconsolidated aquifers of alluvial plains or fractured rock aquifers often support a range of Groundwater Dependent Ecosystems such as deep rooted terrestrial vegetation communities and wetlands as well as refugial pools and surface and subsurface hyporheic zone ecosystems.

3.3.1 Phreatobite Fauna

- Cyclopoida, Copepoda
- Syncarida, *c.f.Notobathynella sp.*

The obligate groundwater fauna is characterised by the Syncarida (Riverside 3) and Copepoda (Granite Vale Old Steel Windmill 1) where as the other interstitial fauna including the Oligochaeta and mites, are more commonly associated with the hyporheic zone. Their presence within the bores is an indicator of a permanent flow of water through this ecotone. All interstitial species can be found in both the permanent hyporheic and hypogean whereas the Syncarid and Copepod belong intrinsically to the hypogean (true groundwater) ecosystem. The hypogean is characterised by relatively low DO, permanent darkness, highly stable water quality, whereas the hyporheic generally differs by having higher DO and organic carbon levels (Gilbert, 1994). The presence of both the phreatic and hyporheic faunas within the shallow groundwater/hyporheic zone indicates that it is a baseflow or gaining river system that receives perennial subsurface flow from the adjoining groundwater system.

The subterranean crustaceans and oligochaetes are an important component of Australia's groundwater fauna that contain a large number of short range endemic species with large faunas along the continental marginal areas, particular in the southwest and eastern seaboards.

The Family Parabathynellidae belongs to a group of crustaceans that are widespread across Australia's groundwater ecosystems. The generic and species distributions are, however, far more restricted, with most species being endemic to an aquifer. Although they occur in a range of specialised habitats such as caves, alluvials and the hyporheic zone of sand and gravel bed river systems, the common environmental denominator is that the water is principally from groundwater. The Bathynellacea 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 Parabathynellidae are one of the major faunal components within Queensland's groundwater ecosystems. They have an ancient lineage dating back to Pangaea, and are often the largest faunal group within western and north-western regions of Australia. The species collected belongs to the genus *Notobathynella* (Figure 4), 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.

Figure 4: Photo of a syncarid crustacean from the order Bathynellacea collected from a central QLD mine site (Photo: GHD Water Sciences).

Site Granite Vale Old Steel Windmill 1 contained the microcrustacea group, the Copepoda. Cyclopoida represent the only group of Copepoda collected during this study. Both specimens are of the same species. Cyclopoida represent a common group of stygofauna found in association with riverine alluvial aquifers with a strong connectivity between the aquifer and the river (Gibert *et al*. 1994).

3.3.2 Stygobite/Permanent Hyproheic Fauna

- Tubificida, Naididae
- Tubificida, Enchytraeidae
- Clitellata, Capilloventridae

The hyporheic zone of a river is characterized by being nonphotic, exhibiting chemical/redox gradients, and having a heterotrophic food web based on the consumption of organic carbon sourced from surface waters (Feris et al, 2003). The subsurface fauna collected included three species and families of Oligochaeta. Although occurring within the subterranean environment these three groups 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).

Site Riverside 1 contained 1 oligochaete specimen belonging to the family Capilloventridae. This finding suggests that the stratum was a fine to moderate grained unconsolidated substrate with a strong connection to the river as the previous freshwater species of this family have been recorded from baseflow sandy bed streams associated with riverine hyproheic zones (Pinder & Brinkhurst, 1994).

The Capilloventridae is a relatively rare aquatic Oligichaete family that has previously only been recorded in Australia from NSW and Victoria, and one species in south-west WA. This is possibly the first known record of the animal in Queensland and is an exciting find. A more detailed analysis of this species is recommended. The family was first described from marine sediments from the Bay of Rio De Janeiro and the Weddell Sea in Antarctica. This distribution suggests a possible Gondwanan distribution with an affinity/relationship with coastal environments although more recent Australian research suggests a stronger freshwater affinity (Pinder & Brinkhurst, 2005). Site Riverside 1 is located within 300 m of the Styx River which is tidally impacted at that location with groundwater salinities measured in November 2011 and March 2012 across the 4 Riverside sampling sites (Riverside 1, 2 & 3 and Riverside Well) ranging between 925 µS/cm and 16,678 µS/cm (Table 3). As there is almost nothing known of their biology or ecology little can be said of their environmental requirements except to say that they are found in environments with high water quality and porous sediments.

Sites Riverside 1 and Riverside Well recorded two additional families of oligochaeta within the Order Tubificida. These were the Family Enchytraeidae and the Family Naididae. There is very little known about the diversity and distribution of freshwater Enchytraeidae, therefore the identification can only be provided at family level. A more detailed analysis of this species is recommended. The Naididae is better understood with approximately 23 genera and 59 species currently described, although again very little is known from Queensland and a more detailed analysis of this species is also recommended.

In general the microdrile oligochaetes occur in both running and still waters including oligotrophic lakes and streams, typically in environments with higher levels of organic carbon sourced through direct connections with the surface lands and waters (Pinder & Brinkhurst, 1994). They are found in or on the substratum. Species without gills may be found in small burrows. Aquatic worms ingest large amounts of the substratum, feeding on organic material (diatoms, algae, plant) and bacteria in silt and mud, however, some species of Naididae may be carnivorous, while others are parasitic (Pinder & Brinkhurst, 1994). This group of oligochaetes is a vital component of groundwater ecosystems in Queensland and occurs frequently within ecosystems with high water quality. They exhibit high diversity and possible high endemicity. The description to species level would be invaluable in gaining a better understanding of their species ranges and environmental requirements.

The Australian naidid fauna consists mostly of cosmopolitan species, although there are indications of greater endemicity than currently recognised. Increasingly, new Naidid species are being collected from seasonal habitats on granite outcrops and from refugial habitats (caves, groundwater and permanent river pools) in drier regions (Peter Serov *pers comm*). A complete picture of oligochaete distribution will require a great deal more research (Pinder 2001).

3.3.3 Stygophile/Hyporheic Fauna

- Acariformes, Astigmata ? (water mites)

Site Stx 093 recorded the presence of water mites. There is little known of the biodiversity and distribution of the water mite fauna in Queensland. They have been described by Smit 2007, as typically having a high diversity, and can reach high densities in the substrates of streams and rivers. Although they are a ubiquitous component of these habitats, their small size means that they are often overlooked and undercounted. In terms of management, therefore, they are potentially very useful bioindicators, particular of baseflow fed streams, as they are sensitive to changes in the environment such as flow, land use (logging, agriculture), pollution and changes in water table (Boulton, 2001; Boulton and Harvey, 2003, Boulton *et al.*, 2003).

4. Discussion

A total of 30 groundwater bores, exploration holes, wells and piezometers were sampled for stygofauna in November 2011 and March 2012 within and adjoining the SCSP MLA (EPC 1029) using standard sampling methods described in WA Guidelines 54 and 54a (2003 & 2007). A total of five sites recorded the presence of subterranean fauna with four sites recording subsurface species which can be classed as stygofauna, including obligate groundwater species associated with the hypogean and permanent hyporheic environments. This is an important find and provides further indication that stygofauna biodiversity and abundance may be significant along the central Queensland coast. It is highly likely that other groundwater bores within the existing SCSP MLA would contain stygofauna.

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). 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). Parts of aquifers with short hydrological transit time, such as those with a shallow water table or close to recharge areas, often have high stygofauna diversity (Datry *et al* 2005), as do those aquifers with tree roots entering the water table (Hancock and Boulton 2008).

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 18 000 µS/cm (GHD *unpublished* data), 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 10 000 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 2008). Most of these key criteria are met for the riverine bores/holes (Riverside 1 and 3, Riverside Well and Granite Vale Old Steel Windmill 1) drilled in unconfined aquifers on quaternary alluvium (clay, silt, sand and gravel associated with floodplains). These bores/holes all recorded *in-situ* salinities less than 5,000 µS/cm and dissolved oxygen concentrations in excess of 1 mg/L. pH values tended to be variable and slightly alkaline ranging from 7.35 to 8.07 which is in excess of the 7.5 pH upper limit suggested by Hancock (2008). In addition to suitable water chemistry the bores/holes recording stygofauna also had a shallow water table (SWL less than 8m) with a total bore depth of less than 11m. Of particular interest is bore Stx 093 which diverges significantly from this pattern and from which stygofauna (water mites) were collected. Bore Stx 093 was a deep bore (75m) with a high salinity of up to 17,579 µS/cm in November 2011 and a low dissolved oxygen concentration of 0.57 mg/L in March 2012. On face value this bore would not be considered highly prospective for stygofauna, however, it produced 5 specimens of water mite. Water mites are known to comprise many different species exhibiting a full range of salinity tolerances from freshwater to saltwater. GHD is finding that as more stygofauna samples are collected both seasonally and over a wide geographic area encompassing different geologies and hydrogeologies, we are learning a great deal more about the ecological tolerances of Queensland stygofauna. This information is critically important when considering sustainable management strategies for local/regional stygofauna communities.

In Australia, stygofauna are known from alluvial, limestone karsts, fractured rock, and calcrete aquifers (Hancock *et al* 2005; Humphreys 2008). 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.

As yet, few species are known from coal seam aquifers. Four stygofauna taxa have been recorded by GHD (*unpublished*) from coal seam aquifers in Queensland to date:

- A species of harpacticoid copepod collected from central Queensland. 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) and a species of Trombidiidae (water mites) from a coal seam aquifer (90m deep) in the Galilee Basin with high groundwater quality (EC 1 505 µS/cm; pH 6.28 and DO 2.51mg/L), and
- A species of Amphipoda and a species of Cyclopoid copepod from one bore from the northern Bowen Basin. 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.

The current study adds to this body of knowledge as groundwater bore Stx 093 recorded the presence of 5 stygophiles (water mites) in March 2012. This bore was measured at 75m deep and tapped a sub-artesian fractured rock aquifer described as the Cretaceous ‘Styx Coal Measures’ (*TO BE CONFIRMED BY Yeats*) with poor groundwater quality (i.e. high salinity and low dissolved oxygen concentrations) The occurrence of these stygophiles strengthens the fact that coal seam aquifers in Queensland indeed contain stygofaunal communities of significance.

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 and Rolleston regions of the Bowen Basin (GHD *unpublished*). More recently, GHD has discovered a diverse stygofaunal community in alluvial aquifers of the Bowen River (GHD *unpublished*), proving that stygofauna are well represented in the Central Queensland region. 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 25 groundwater bores located on the SCSP MLA (EPC 1029) does not necessarily indicate that they are not present in these aquifers, rather, it may be due to unsuitable geological conditions (low porosity, low hydraulic conductivity), poor groundwater quality 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.

4.1 Stygofauna Ecological Requirements

There are three critical factors that make stygofauna communities in aquifers vulnerable to the impacts of human activity and these potential impacts can be more accurately assessed in relation to the Styx Coal South Project when information on hydrogeology and proposed mining operations becomes available:

- ***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 *unpublished*) 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 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 SCSP) 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:

- Quantity (groundwater levels, pressures and fluxes);
- 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 SCSP 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 or evaporative discharge), 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 SCSP 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 SCSP MLA. Knowledge of the extent of the proposed drawdown zone and the specific aquifers impacted would be necessary to fully assess any impacts on the stygofaunal community. Future expansion of the SCSP should also be considered.

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:
SCSP 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 SCSP mining operation involves excavation below the water table and will require active dewatering using a range of procedures. The effect of these dewatering operations manifests itself as groundwater drawdown around the mine pits which may extend for large distances depending on mine life, target depth of dewatering and aquifer hydraulic parameters (permeability and storage). For SCSP 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 SCSP mine pit extending below the water table is also something to consider post mine closure.

Mine Maturity:
The proposed SCSP 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 SCSP to gauge the effects of its operations on existing groundwater conditions through the construction and operational phases. Full compliance with WA guidelines (2003 & 2007) and the adoption of two sampling events across two seasons covering 30 different sampling points using best practice sampling protocols has ensured that this project has established a significant baseline.

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 significantly, 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 SCSP 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 SCSP 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 and hyporheic fauna).

On the basis of the stygofauna that were recovered during the November 2011 and March 2012 sampling event, it is recommended that an annual stygofauna monitoring program be implemented during the operational phase of the SCSP as well as through the closure phase to assess long-term impacts and to inform management plans.

4.4 Implications for the SCSP EIS

The stygofauna collected from five bores on EPC 1029 in November 2011 and March 2012 have been identified as belonging to the Orders Syncarida, Copepoda, Astigmata, Clitellata and Tubificida. Order/Family level taxonomic analysis was undertaken by GHD as this is the level of taxonomic resolution specified by DERM in generic TOR for Queensland mining EIS's. If further taxonomic investigations were conducted on these taxa (both morphological and genetic) the animals may prove to be indeed new species or possibly even new genera. The implications for the SCSP if this was the case could be significant in that efforts would need to be made to either find the animals outside the SCSP MLA and outside the zone of impact of the proposed mine (i.e. area of drawdown) so that DERM could be confident the mining operation would not result in the potential extinction of a species. Alternatively, a suitable stygofauna management plan would need to be developed for the SCSP that would allow the mining operation to continue without risk to the survival of the stygofauna recovered (e.g. the mining operation would not impact on the aquifer(s) containing these animals by significantly altering water quantity or quality).

The implications and commensurate actions described above only come into play if the Syncarida, Copepoda, Astigmata, Clitellata and Tubificida are described at the species level, and if any of the taxa are determined to be new species (which would most likely be the case). In Queensland, to satisfy the DERM generic TOR for a mining EIS, endemism needs to be disproved at the Family or Order level for stygofauna, in which case the

Syncarida, Copepoda, Astigmata, Clitellata and Tubificida collected are not endemic because the Orders/Families they belong to occur in all Australian States (Serov, 2002).

The WA Guidelines (2003 & 2007) require proponents to identify stygofauna to species level (where possible) in order to be able to show that species will not be threatened by development. This requirement in WA provides a stronger basis for protecting biodiversity and may become the future requirement in Queensland. Implications under the EPBC Act (1999), EPA Act (1994) and the Nature Conservation Act (1992) should also be considered.

4.5 Recommended Management Approach

This survey identified the presence of subterranean fauna within the subsurface hyporheic zone of a stream and a shallow alluvial aquifer. While the numbers of animals and diversity were relatively low they do indicate good water quality, a strong connectivity between the river and groundwater system (Danielopol et al, 2003; Serov et al, 2011.) and indicate a high probability of higher biodiversity within the aquifers associated with EPC 1029.

4.5.1 Suggested Further Actions

- Use existing data to characterise lithology of the bores/holes and relate to local/regional hydrogeology;
- Characterise the full water chemistry and water levels of the groundwater over time to establish the natural annual ranges and seasonal fluctuations;
- Characterise the aquifer flow paths to determine the connectivity with any local waterway above and below the mining site by comparing water chemistry and hypogean/hyporheic faunal communities;
- Identify the obligate stygofauna to species (i.e. those listed as stygobites/phreatobites/stygophiles) 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. Despite there being no immediate benefit to Styx Coal in analysing the DNA of the Syncarida, Copepoda, Astigmata, Clitellata and Tubificida there may in fact be longer term benefits. Having this DNA sequence in a database will allow future comparisons with stygofauna from other local, regional, state and national collections, thereby improving the understanding of the conservation significance, evolution and distribution of the species (Finston *et al* 2004). Of equal importance for the SCSP in the future is that if DEHP (as expected) tighten their regulations with regards to the protection of groundwater dependent ecosystems in Queensland, and conform more tightly with the WA Guidelines (2003 & 2007), the ability to link the Syncarida, Copepoda, Astigmata, Clitellata and Tubificida (by molecular DNA) with other animals from other collections and regions would ensure the SCSP was not at risk of potentially causing the extinction of a species. It could be considered an insurance policy.
- Build on the existing baseline by conducting annual stygofauna surveys during mine construction, operation and closure phases in order to measure groundwater health and condition over the life of the mine.

5. References

Appendix A

Conditions

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