



Chapter 20

Stygofauna

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20. STYGOFAUNA

20.1 Introduction

This chapter identifies any short and long term impacts of the project on stygofauna in the project area, in particular on species and communities of state and national significance (as applicable), identifies minimisation and mitigation measures that will protect and enhance the stygofauna values of the project area; and describes the potential residual impacts of the project, and any offsets that may be necessary under current Queensland and Australian Government policies.

This chapter summarises the outcomes of the stygofauna pilot study and subsequent technical assessment provided in **Appendix 20**.

The investigations described in **Appendix 20** were undertaken in order to determine the following:

- identify whether stygofauna were present in groundwater associated with the project disturbance area
- assess the diversity of stygofauna taxa present and their conservation significance
- describe the potential impacts of the project on stygofauna in the groundwater.

A description is provided of the stygofauna present on the site, and details how any planned construction and operational activities may affect the existing groundwater ecology. It considers potential changes in the quality, level or quantity of groundwater and the impacts that these changes may have on stygofauna.

Additional information from the adjacent Xstrata Newlands Coal Mine is used to increase the dataset and inform the assessment. A technical groundwater advice note prepared Rob Lait Associates (RLA, 2012) qualifies how the Xstrata Newlands stygofauna dataset relates to (and can be used in conjunction with) the project site dataset, based on hydrogeological assessments.

20.2 Legislative and Guidance Framework

20.2.1 Overview

Chapter 3 details the general legislation, regulation, guidance and policies. Additional information relevant to groundwater and stygofauna is included below.

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

The project Terms of Reference (ToR) requires stygofauna sampling to be undertaken in accordance with surveys conducted 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).

As it can be difficult to find a sufficient number of suitable bores outside the impact area, a more targeted project specific focus on finding sufficient bores inside the expected zone of impact was adopted.

The WA Guidelines allow a Pilot Study approach where it is considered that the likelihood of finding stygofauna is very low (e.g. poor groundwater quality, unsuitable geology, historic sampling of the local area has not recovered stygofauna, lack of groundwater etc.). Whilst Pilot Surveys in WA do allow for a reduced sampling effort, there is a requirement in the Guidelines that in the event of a Pilot Study finding stygofauna, additional survey effort would be required to satisfy the full WA Guideline requirements. In 2011 a Pilot Study approach to surveying stygofauna for the EIS was undertaken to determine if stygofauna were present in groundwater associated with the project, and to determine the range of taxa present, their conservation significance and potential management strategies.

One of the requirements when sampling for stygofauna as defined under the WA Guidelines (2003 & 2007) is the need to sample all hydrogeological units present within the mine lease area, including a focus on shallower alluvial aquifers, if present. A hydrogeological study undertaken as part of the EIS (RLA, 2012) reported no significant alluvial aquifers present on the Byerwen MLA's, so this environment was not sampled as part of the Pilot Study. The RLA study (2012) also identified the Rangal and Fort Cooper Coal measures as the major aquifers within the Byerwen MLA's and the only aquifers likely to be impacted by mining operations. These coal seam aquifers were adequately sampled as part of the Pilot Study.

20.3 Study Methodology

20.3.1 Study Design

In accordance with WA Guidelines (2003 & 2007) for Pilot Studies a single sampling event was undertaken during the 2011 pre-wet season between 30th November and 1st December 2011.

This data was supplemented by stygofauna sampling data from Xstrata's nearby Newlands Mine, (see **Figure 20-1**) as described in **Section 20.3.2**.

Established standard sampling techniques used in Australia and overseas (Hancock and Boulton, 2008; Dumas and Fontanini, 2001) were adopted.

Of the 12 bores selected for stygofauna sampling - eight could be sampled at the time of the surveys. Bore BYGW04 was blocked at around 70 m so was not sampled for either stygofauna or in-situ water quality. Bore BY188 was sampled as an alternative to BYGW04.

Due to a severe wet weather event during the sampling program bores BYGW07(a) and 07(b), BY073 and BYGW09 were not sampled for safety reasons. Information on bore characteristics and bore history is provided in **Appendix 20**.

The basic criteria for selection of groundwater bores for stygofauna sampling were:

- aperture of ≥ 50 mm diameter
- intersect the water table
- if lined - slotted through the water column
- vertical with a total drilled depth (preferably) < 200 m
- geographically spread across the proposed mine lease and include reference bores outside the potential zone of impact (i.e. water drawdown zone)
- coverage of 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)

- include a high number of bores with a salinity less than 5,000 $\mu\text{S}/\text{cm}$ EC (and preferable less than 1,500 $\mu\text{S}/\text{cm}$), a DO concentration >1 mg/L and pH 6.5 to 7.5.

20.3.2 Xstrata Newlands Coal Mine Supplementary Dataset

Xstrata stygofauna data was obtained for the Newlands Mine located immediately to the east of the project comprising Newlands Coal (Mining Lease (ML) 4748 and 4771), Eastern Creek North (ML 4754), and Eastern Creek South (ML 4755 and ML 10176) open-cut mines, and the Newlands Southern (now closed) and Northern (ML 10316, ML 10317, ML 4774 and ML 10322 - operating) underground mines, and Suttor Creek (ML 4761) containing Suttor Creek and Wollombi pits, situated immediately south of the project. Newlands bores from where stygofauna samples were collected are also shown on **Figure 20-1**, and include bores located immediately adjacent to (or in some cases within) the Byerwen project boundary.

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In September 2012, a technical assessment of the suitability of including Newlands Mine stygofauna data in the project EIS was undertaken in 2012 by Rob Lait Associates (RLA). The assessment considered the locations and depths of Newlands Mine bores in relation to the stratigraphy of the region.

Groundwater occurrence and flow is controlled by the formations in which the aquifers occur and the geological structure of the region. RLA (2012) determined that the regional strike of the formations within the study area was north-west to south-east. The tests used for assessing the suitability of including the NCP stygofauna data in the Byerwen EIS were as follows:

- whether the Xstrata stygofauna monitoring bores are along the regional strike trend so as to be representative of groundwater in that formation, and
- whether the depths of the Xstrata stygofauna monitoring bores are similar to the depths of the Byerwen stygofauna monitoring bores.

The assessment concluded that the two adjoining mining leases (Byerwen and Newlands Mine) share the same hydrogeology, with sufficient conductivity to ensure the movement of stygofauna within the aquifers.

The relevance of this determination is that it is scientifically defensible to include the Newlands Mine stygofauna dataset in the Byerwen Pilot Study data in order to better inform the EIS.

The dataset for assessment now includes both the current Byerwen dataset (i.e. 8 bores sampled in 2011) as well as 67 samples from 20 bores collected for Newlands Mine in 4 sampling events in 2008, 2009, 2010 and 2011. This provides a very comprehensive and significant dataset from which to assess whether stygofauna represent a relevant environmental factor for consideration of impacts from the project.

Stygofauna sampling conducted for the Newlands Mine from 2008 to 2012 used the same sampling methods and sampling equipment as adopted for the Byerwen project and are therefore directly comparable with the Byerwen project dataset.

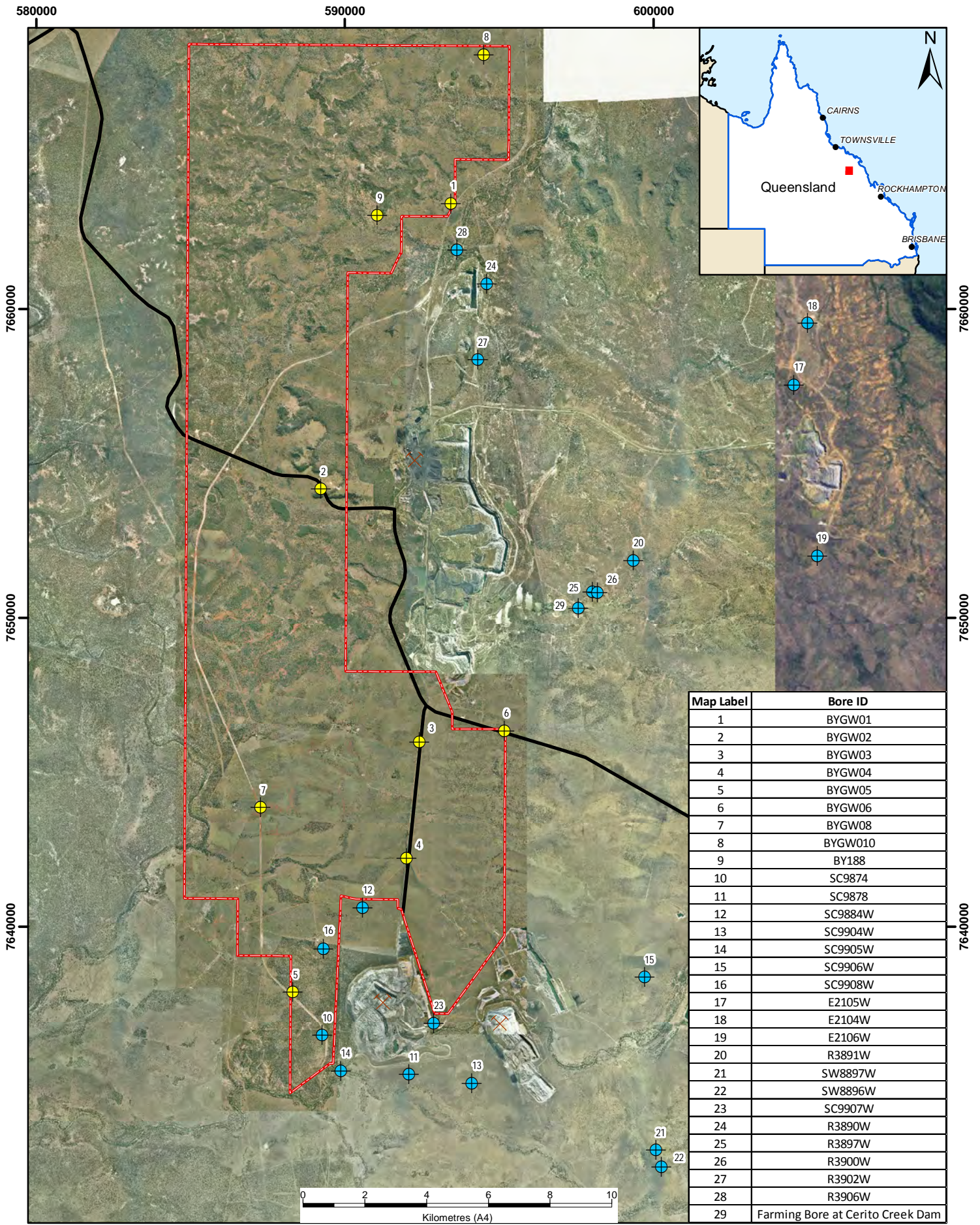
A total of 20 Newlands Mine groundwater bores were sampled for stygofauna on four occasions (December 2008, September 2009, July 2010 and September 2011). The 20 Newlands Mine groundwater bores were located both on Xstrata's leases (7 bores) and off Xstrata's leases (13 bores).

20.3.3 Sampling Methodology and Limitations

Detailed sampling and processing methodology is included in **Appendix 20**. Of particular note is that all aquatic animals were removed, identified to Order/Family level (or lower taxonomic rank if possible) in accordance with ToR for the project.

The design of the stygofauna survey conformed to WA Guidelines (2003 & 2007) with the following exceptions:

- Order/Family taxonomic resolution was applied as defined by generic ToR for the project.
- Six hauls (where possible) were undertaken when sampling each bore for stygofauna using a 50 micron mesh net of 40 mm diameter.
- Significant sampling effort was not directed at shallow, quaternary alluvial aquifers.
- Only one field sampling event (comprising 8 bores) located within EPC 614 and EPC 739 has been conducted.



Map Label	Bore ID
1	BYGW01
2	BYGW02
3	BYGW03
4	BYGW04
5	BYGW05
6	BYGW06
7	BYGW08
8	BYGW010
9	BY188
10	SC9874
11	SC9878
12	SC9884W
13	SC9904W
14	SC9905W
15	SC9906W
16	SC9908W
17	E2105W
18	E2104W
19	E2106W
20	R3891W
21	SW8897W
22	SW8896W
23	SC9907W
24	R3890W
25	R3897W
26	R3900W
27	R3902W
28	R3906W
29	Farming Bore at Cerito Creek Dam

Legend

- Project Area
- Existing Mine Site
- Formed Roads
- + Byerwen Pilot Study Locations
- + Newlands Locations

Byerwen Project and Newlands Mine Stygofauna Groundwater Sampling Bore Locations		
Figure 20-1	Byerwen Coal Project	
Date: 5/02/2013 Revision: R1		
Author: Shahram Nasiri Map Scale: 1:160,000 Coordinate System: GDA 1994 MGA Zone 55		
G:\CLIENTS\A-TO-D\BYEGEN - Byerwen EIS\GIS Maps\EIS Chapters\EIS_Chpt_20_Stygofauna\BYEGEN_Stygofauna.mxd		

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20.4 Existing Environment

20.4.1 Geology and Hydrogeology Overview

The stratigraphy of the project area is described in **Table 20-1**. More detailed hydrogeological information is included in **Chapter 18**.

Table 20-1 Stratigraphy of the Project Area

Age	Unit	Lithology	Topography	
Quaternary		Silt, sand, clay soil.	Occurs on floodplains of major watercourses and as outwash fan deposits.	
Tertiary	Suttor Formation	Sandstone and conglomerate, locally silicified.	Breakaways; table-top mesas.	
	Tertiary Basalt	Olivine basalt, fresh and vesicular in places.	Slightly elevated lands.	
	Sand below Basalt	Unconsolidated sand and minor gravel; lag deposits from formerly exposed topography.	Not exposed at surface.	
Triassic	Moolayember Formation	Micaceous and lithic sandstone and siltstone.	Recessive; flat areas on Clematis Group tablelands.	
	Clematis Group	Medium-coarse quartz sandstone & pebble conglomerate.	Tablelands; steep scarps.	
	Rewan Group	Green lithic sandstone; red, brown and green mottled mudstone.	Recessive.	
Late Permian	Bowen Basin	Blackwater Group Includes: Rangal Coal Measures Fort Cooper Coal Measures Moranbah Coal Measures	Coal; grey, brown, green sandstone; siltstone; shale; chert; minor conglomerate; fossils.	Generally recessive, subdued.
Early Permian		Back Creek Group Includes: Exmoor Formation Lizzie Creek Volcanics	Grey to purple fine sandstone & siltstone; local coarse sandstone; grey carbonaceous shale; cocquinite lenses; fossils. Andesite; subordinate rhyolite and shale.	Generally recessive sandstone ridges. Not exposed in project area. Regarded as basement for the hydrogeological regime.

20.4.2 Xstrata Newlands Coal Mine

Newlands mining operations includes three major mining areas; Suttor Creek, Wollombi and Eastern Creek. Hydrogeological data is only available for the Suttor Creek mining area and is reported in the 'Newlands Coal Mine: Extension into the Wollombi No. 2 Surface Area Environmental Impact Statement'.

In summary, there are three principal aquifers in the Suttor Creek mining area:

- a deep Quaternary alluvium consisting of quartzitic sands and clayey sands with some gravel and clay
- a fractured basalt aquifer
- a discrete fractured zone in the Permian sediments that includes coal seams of the Moranbah Coal Measures

Quaternary sands and gravels occur near Suttor Creek, overlying (approximately 5 to 10 m depth) Tertiary sediments. Shallower alluvial material extends laterally from the creek for approximately 300 m. Water levels have been recorded within bores screened in that material and have been seen to reflect rainfall patterns.

The Tertiary clay, sand, and gravel sediments overly Permian coal measures and contain deep paleochannels to 100 m in some places.

A Tertiary basalt aquifer greater than 80 m thick in places occurs in the southern section of the Suttor Creek mine area and comes to within 500 m of the Suttor Creek pit boundary. Basalt lies along the sedimentary paleodrainage system and contains groundwater in fractures throughout the rock but more frequently near the base and in the weathered uppermost section.

The Permian stratum is made up of sandstones, siltstones, carbonaceous mudstones, tuff beds, and coal seams. Water occurs at the interface between weathered and fresh rock, in fractures of the coal seam, and at the contact zone between sandstone and shale units.

20.4.3 Relationship to the Great Artesian Basin

Project area groundwater has no relevance to the Great Artesian Basin (GAB) Water Resource Plan (WRP) as the project area is many kilometres to the east of the closest section of the GAB.

20.4.4 Groundwater Quality

Stygofauna in Queensland have been found to prefer water tables less than 20 m in depth (Hancock and Boulton, 2008). The water table across the study area averages 38.21 m across the eight Byerwen project monitoring bores. Only one of the eight bores sampled (BYGW01) recorded a standing water level less than 20 m. Groundwater temperatures were generally high and averaged 27.12 °C across all eight bores.

Stygofauna in Queensland prefer groundwater pH in the range of 6.5 to 7.5 (Hancock and Boulton, 2008) - pH varied greatly between the eight bores (possibly a reflection of bore age) averaging 9.4 across all eight bores with a minimum of 6.34 (BYGW03) and a maximum of 12.07 (BTGW08).

Six bores recorded an electrical conductivity (EC) value less than 5,000 µS/cm which is the preferred range for stygofauna (Hancock and Boulton, 2008). Three bores recorded EC values less than 1,700 µS/cm placing them in the 'highly prospective' range for stygofauna.

Indicative dissolved oxygen (DO) concentrations were low to medium for groundwater averaging 1.63 mg/L across the eight bores. Seven of the eight groundwater bores sampled were within the 'ideal' DO range for the presence of stygofauna (i.e. >1 mg/L) (Hancock and Boulton, 2008).

Groundwater quality in the Byerwen project monitoring bores is summarised in **Table 20-2**.

Table 20-2 Groundwater Quality Data – Byerwen Project Monitoring Bores

Bore ID	Depth of Drilled Hole (m)	Date Drilled	SWL (m)	pH	EC (µS/cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% satn)	Date Sampled
BYGW01	59.5	17/9/11	10.57	8.33	1,697	26.78	1.39	17.8	30/11/11
BYGW02	59.5	8/9/11	33.47	6.82	9,975	28.42	1.92	25.7	30/11/11
BYGW03	67.0	8/9/11	34.19	6.34	2,302	26.74	0.92	12.2	30/11/11
BYGW04*	119.0	6/9/11	ND	ND	ND	ND	ND	ND	30/11/11
BYGW05	105.0	16/9/11	80.69	10.39	17,058	28.46	1.04	14.3	29/11/11
BYGW06	120.0	14/9/11	55.95	11.77	3,026	24.19	2.01	24.2	1/12/11
BYGW08	66.0	11/9/11	42.70	12.07	4,458	28.35	2.75	36.2	30/11/11
BYGW010	52.0	18/9/11	27.08	11.70	1,477	26.96	1.03	13.1	30/11/11
BY188	56.0	ND	21.03	7.97	1,532	27.02	1.98	24.8	30/11/11
Mean	-	-	38.21	9.40	5,191	27.12	1.63	21.04	-
Range	-	-	10.57 to 80.69	6.34 to 12.07	1,477 to 17,058	24.19 to 28.46	1.03 to 2.75	13.1 to 36.2	-

Notes:

Groundwater samples were collected in November/December 2011 by a hand operated bailer prior to any biological sampling occurring. Bore BYGW04* was blocked at around 70 m and could not be sampled for water quality or stygofauna. Bore BYGW02 contained stygofauna. (ND – No Data) (EC = Electrical Conductivity)

Groundwater quality samples were also collected by QCoal in October 2011 for all bores shown in **Table 20-2** with the exception of BYGW04 and BY188. Data available for pH and EC show similar figures obtained by QCoal to those shown in **Table 20-2**. Groundwater level data, also collected in October 2011 by QCoal, indicates a lower water table across all sites than what was observed by ALS in November/December 2011.

20.4.5 Regional Stygofauna

Queensland has approximately 40 known species of stygofauna. As more surveys are conducted and taxonomic knowledge improves, the number is expected to increase significantly.

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 areas close to Clermont, Collinsville, Glenden, Rolleston, Maryborough and Nebo. These were collected from alluvial/sedimentary aquifers rather than coal seam aquifers, likely due to lower electrical conductivity (EC), porosity and connectivity in alluvial aquifers.

Eight stygofauna taxa have been recorded by GHD (unpublished data) from coal seam aquifers in Queensland, indicating that coal seam aquifers in Queensland contain communities of significance. These included:

- A species of harpacticoid copepod collected from the Bowen Basin in Central Queensland, collected from a shallow coal seam (50 m deep), with low electrical conductivity (< 2 000 $\mu\text{S}/\text{cm}$), 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) collected from a coal seam aquifer (89 m deep with SWL at 38.5m) in the Galilee Basin. The bore recorded high groundwater quality (EC 1,505 $\mu\text{S}/\text{cm}$; pH 6.28 and DO 2.51 mg/L).
- A species of Amphipoda and a species of Cyclopoid copepod collected from one bore from the northern Bowen Basin (i.e. current study). The bore tapped a shallow coal seam aquifer (Fort Cooper Coal Measures 59.5 m deep) with a relatively deep water table at 33.47 m and poor groundwater quality with an EC concentration of 9,975 $\mu\text{S}/\text{cm}$.
- A species of Astigmata (water mite) from a single bore (i.e. 75 m 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.

20.4.6 Byerwen Stygofauna

Stygofauna were present in one (BYGW02) of the eight bores sampled (see **Table 20-3**). The sample comprised two obligate groundwater species and one terrestrial, possibly edaphobitic (soil dwelling) species. The relatively small size (<1 mm) of the species present and small number of specimens of each species indicates a low to moderate connectivity within the aquifer (a coal seam of the Fort Cooper Coal Measures).

20.4.6.1 Stygobites / Stygophiles

The obligate groundwater fauna was characterised by one Amphipod order and one Copepod order. These two species can be found in the hypogean (true groundwater ecosystem), which is characterised by relatively low DO, permanent darkness and highly stable water quality (Gilbert *et al*, 1994).

The Amphipoda are predominantly detrital feeders consuming sediment, alga and diatoms, whereas the Copepoda are predatory on zooplankton and phytoplankton.

Although subterranean, these two 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 deep sand and gravel beds associated with areas of groundwater discharge (Gilbert *et al*, 1994). They typically characterise the transition zone between the permanent shallow hyporheic ecozone and the groundwater hypogean environment (Gilbert *et al*, 1994).

Table 20-3 Byerwen Groundwater Fauna

Bore ID	Order	Family	Species	No. Animals	Habitus	Collection Method	Collection Date
BYGW01	-	-	-	0	-	50 µ Net	30/11/11
BYGW02	Amphipoda	Not Determined #	<i>sp.</i>	1	Stygobite	50 µ Net	30/11/11
BYGW02	Copepoda	Cyclopoida	<i>sp.</i>	1	Stygophile	50 µ Net	30/11/11
BYGW02	Psocoptera	Trogiomorpha	<i>sp.</i>	1	Edaphobite	50 µ Net	30/11/11
BYGW03	-	-	-	0	-	50 µ Net	30/11/11
BYGW04	-	-	-	0	-	50 µ Net	30/11/11
BYGW05	-	-	-	0	-	50 µ Net	29/11/11
BYGW06	-	-	-	0	-	50 µ Net	1/12/11
BYGW08	-	-	-	0	-	50 µ Net	30/11/11
BYGW010	-	-	-	0	-	50 µ Net	30/11/11
BY188	-	-	-	0	-	50 µ Net	30/11/11

Note: Shaded rows show true stygofauna (# the Amphipod specimen was immature and damaged so could not be identified beyond Order level).

20.4.6.2 Edaphobite

The third species belongs to the insect group Psocoptera or Book Lice/Bark Lice. They are typically detrital or fungal feeders associated with the ground litter layer and tree bark. Their presence in the sample is most likely coincidental either by falling in or occupying the vegetation adjacent to the bore or living within the bore above the water table, as they have a preference for humid environments.

Details of this animal are provided in this report as they were collected as part of the Pilot Study, however, as they are not aquatic and groundwater dependent they have no specific relevance to this study other than scientific interest, and they will not be considered further in this report.

20.4.7 Newlands Stygofauna

Twenty groundwater bores were sampled within and adjoining the Newlands mine in September 2011 (GHD, 2011). High quality samples were collected from all 20 groundwater bores. A standard six net hauls were collected from each groundwater bore with the exception of two bores where 4 net hauls were collected due to clay clogging the net and sieve. Three sites registered the presence of aquatic fauna in September 2011. Only one bore recorded stygofauna (two obligate groundwater species) as shown in **Table 20-4**.

The same 20 groundwater bores were sampled in December 2008, September 2009 and July 2010. No stygofauna were recovered from these sampling events.

Table 20-4 Newlands Groundwater Fauna - September 2011

Bore ID	Order	Family	Genus	No. of Animals	Habitus	Collection Method	Collection Date
SW8896W	Oligochaeta	Naididae	Not determined	11	Stygobite	50 µ Net	15/9/11
SW8896W	Syncarida	Parabathynellidae	c.f. Notobathynella	53	Stygobite	50 µ Net	15/9/11
SC9907W	Hempitera	Amphidoidea	Not determined	2	Stygoxene	50 µ Net	13/9/11
SC9874	Coleoptera	Not determined	Not determined	1	Stygoxene	50 µ Net	13/9/11
SC9878	-	-	-	0	-	50 µ Net	13/9/11
SC9884W	-	-	-	0	-	50 µ Net	14/9/11
SC9904W	-	-	-	0	-	50 µ Net	13/9/11
SC9905W	-	-	-	0	-	50 µ Net	13/9/11
SC9906W	-	-	-	0	-	50 µ Net	15/9/11
SC9908W	-	-	-	0	-	50 µ Net	13/9/11
E2105W	-	-	-	0	-	50 µ Net	16/9/11
E2104W	-	-	-	0	-	50 µ Net	16/9/11
E2106W	-	-	-	0	-	50 µ Net	16/9/11
R3891W	-	-	-	0	-	50 µ Net	17/9/11
SW8897W	-	-	-	0	-	50 µ Net	15/9/11
R3890W	-	-	-	0	-	50 µ Net	19/9/11
R3897W	-	-	-	0	-	50 µ Net	17/9/11
R3900W	-	-	-	0	-	50 µ Net	17/9/11
R3902W	-	-	-	0	-	50 µ Net	17/9/11

Bore ID	Order	Family	Genus	No. of Animals	Habitus	Collection Method	Collection Date
R3906W	-	-	-	0	-	50 µ Net	14/9/11
Farming Bore at Cerito Creek Dam	-	-	-	0	-	50 µ Net	17/9/11

Note:

Shaded rows show true stygofauna.

The remaining 17 bores did not record stygofauna.

Bore SW8896W was sampled using a phreatobiological net and was located off-lease (to the east of Suttor Creek ML 4761) in the southern region of the survey area. The relatively small size (2-3 mm) and diameter of the species present and the relatively large number of specimens of each species (i.e. 53 Notobathynellids and 11 Oligochaetes) suggest a moderate connectivity within the aquifer (a coal seam of the Fort Cooper Coal Measures).

Bore SW8896W was seen to have SWL of 12.91 m and EoH Depth 42m), pH was 7.44, EC was 2,966 $\mu\text{S}/\text{cm}$ and DO was high at 4.07 mg/L. It would be expected, based on this result, that other local groundwater bores with similar physical and water quality characteristics would most likely contain stygofauna.

20.4.7.1 Stygobites

The obligate groundwater fauna is characterised by Syncarida (Crustacea) and Oligochaeta (Worms). Both groups contain a large number of short range endemic species with a large biodiversity along the continental marginal areas, particular in the southwest and eastern seaboard.

The Syncarida Family, Parabathynellidae, as with other Syncarida, are predominantly detrital feeders. The species collected belongs to the Genus Notobathynella. To date this genus has only been described from NSW, Victoria, Tasmania and New Zealand, and may therefore belong to a new but related genus. (Undescribed species have also been collected in WA and north-west Queensland).

The Oligochaete Family, Naididae, is a common aquatic family of freshwater worms, which currently contains approximately 23 genera and 59 species. The Family is usually associated with high water quality environments and typically swim in the water column just above the substratum, (whereas other aquatic oligochaetes that do not burrow, crawl along the substratum). Most aquatic oligochaetes ingest detritus and sediments, some species may be carnivorous, or parasitic (Pinder & Brinkhurst, 1994).

The Australian Naidid fauna consists mostly of cosmopolitan species, although there are indications of greater endemism 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 (P. Serov, pers. comm.).

Although primarily stygobites, Syncarida and Oligochaeta can also be found within the riverine hyporheic zones in areas of groundwater discharge where the discharge can be either point source springs or diffuse discharge, through a moderate to coarse grained substrate such as sand or gravel (Gilbert *et al*, 1994).

20.4.7.2 Stygoxenes

Two bores (SC9907W and SC9874) recorded two species of stygoxenes (species that are not adapted to living within the groundwater environment and usually occur in this environment by accident). The recorded taxa were aphids (SC9907W) and a terrestrial beetle (SC9874). Both showed signs of decomposition indicating they were not alive when collected. Their presence in the sample is most likely coincidental, either by falling in, or occupying the vegetation adjacent to the bore. Bore SC9874 was also uncapped so it is possible the coleopteran was washed into the bore following recent flooding. The occurrence of these animals is of no direct relevance or significance to this study.

20.5 Potential Impacts

20.5.1 Stygofauna Ecological Requirements

Stygofauna are ecologically and physiologically dependant on the aquifer environment and are adapted to the relative stability of their surroundings. Stygofaunal communities can be impacted by a range of factors that alter groundwater levels, water pressure, water chemistry and aquifer structure.

Critical factors that make stygofauna communities in aquifers vulnerable to the impacts of human activity are as follows:

- **Stable water quality/physicochemical conditions.** Stygofauna are able to tolerate natural fluctuations in water parameters such as water level, electrical conductivity, and temperature. However, changes outside the natural range of water quality (e.g. a pollution plume) and water drawdown (e.g. rapid drawdown) can impact on the composition, biodiversity and overall sustainability of the community.
- **Surface connectivity.** Groundwater communities require surface connectivity to provide organic matter and oxygen. If linkage is disrupted, communities can be impacted.
- **Subterranean connectivity.** Stygofauna do not have aerially dispersing life stages. To migrate between areas, they 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 can restrict their movement. These barriers encourage genetic isolation and ultimately, speciation. Barriers can also be created rapidly by changes in water levels or water chemistry/quality. If any area is impacted by a disturbance that results in a loss of biodiversity, these new barriers to dispersal may prevent re-colonisation of the habitat.

Many species of stygofauna are restricted to small geographical areas particularly in non-alluvial aquifers and calcrete aquifers, where one or more species are known only from a single aquifer, or part of an aquifer (Humphreys, 2002).

20.5.2 Factors that Threaten Stygofauna

In general, mining operations that have the potential to cause some degree of change in natural water regimes (surface and groundwater) include:

- below water table mining
- water supply development (e.g. groundwater, dewatering, surface water)
- dust suppression
- seepage
- tailings disposal
- waste rock storages
- backfilling and rehabilitation works
- water diversions and surface sealing
- hazardous and dangerous goods storage
- water storages including waste water ponds

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)
- physical disruption of aquifers (excavation of mining pits and underground workings).

The existence and extent of these activities, and their potential impact on groundwater dependent ecosystems (including 'obligate' groundwater dependent fauna) depends on the scale of the operation,

mining methods, and process water requirements. Effects would also be influenced by climatic conditions and geological settings.

20.6 Mitigation Measures

The stygobite/stygophile taxa collected from bore BYGW02 in November/December 2011 have been identified as belonging to the Orders Amphipoda and Copepoda (Family Cyclopoida). Order/Family level taxonomic analysis was undertaken as this is the level of taxonomic resolution specified by the ToR for the project.

To satisfy the ToR, endemism needs to be disproved at the Family or Order level for stygofauna, in which case the Amphipod and Copepod collected from BYGW02 are not endemic, because the Order/Family they belong to (i.e. Amphipoda and Cyclopoida) occur in all Australian States (Serov, 2002). Any proposed mining activities associated with the Byerwen Project will not threaten or put at risk the survival of the amphipod and copepod taxa at the Order/Family level of taxonomic resolution.

Based on these results, no mitigation measures are required.

20.7 Conclusions

The Pilot Study, conducted in accordance with WA Guidelines 54 and 54a (2003 & 2007) identified the presence of stygofauna in groundwater associated with the Byerwen project.

Two adjoining mining leases (the project site and Newlands Mine) share the same hydrogeology, with common aquifers hydraulically connected with sufficient conductivity to allow the movement of stygofauna within the aquifers. The project site and Newlands Mine stygofauna datasets were, therefore, combined to generate a comprehensive stygofauna dataset encompassing 75 individual samples collected from 28 bores over a 4 year timeframe (2008 to 2011) in order to better inform the EIS.

Only two stygofaunal taxa were recovered from one of 20 Newlands Mine bores sampled annually for four years. It is evident from the Newlands Mine data that stygofauna are low in diversity and abundance from this locality. The Byerwen Pilot Study also failed to identify significant stygofaunal communities. Collectively, these data suggest that stygofauna (i.e. stygophiles, stygobites and phreatobites) are poorly represented within the Byerwen and Newlands Mine mining lease areas.

In Queensland, to satisfy the ToR for the Byerwen EIS, endemism needs to be disproved at the Family or Order level for stygofauna, in which case obligate stygofauna collected from both the Newlands Mine and the project specific surveys are not endemic, because the Order/Family they belong to occur in all Australian States (Serov, 2002). Any proposed mining activities associated with the project will not threaten or put at risk the survival of the amphipod and copepod taxa at the Order/Family level of taxonomic resolution (i.e. impacts will be negligible). Therefore no mitigations or further survey work is proposed for stygofauna.