An Investigation of the Stygofauna Community in the Pilliga Area 2016-17.

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Executive Summary

This report and field study was produced as a result of the comments in the Santos 2016 Environmental Impact Statement that "no stygofauna were collected during the sampling regime by Eco Logical" and therefore "there is an uncertainty regarding the presence of stygofauna at the project areas, especially Leewood". The aim of this report is to provide certainty by demonstrating via a more extensive survey of bores across the Pilliga that stygofauna do indeed exist in the shallow aquifers of the Pilliga Forest, are at risk from the current and proposed future development of Coal Seam Gas production and therefore need to be considered and included in the environmental management program.

The current condition of the stygofauna community is considered good, based on available evidence (number and range of species in samples). The occurrence of this community within an unregulated catchment that has had very little water extraction for irrigation is considered to be a contributing factor in its condition. However, the proposed expansion of the coal seam gas exploration within the Pilliga Forest area including the Bohena Creek catchment poses an imminent threat to this community through likely changes in water table levels and water chemistry. The additional disturbances and demands by mining on the groundwater aquifer and potential changes to the aquifer water chemistry from gas exploration in the Pilliga is a serious and demonstrable threat to this GDE community. Potentially these activities, should they proceed, will place the Pilliga groundwater dependent ecosystems that include the endemic stygofauna, baseflow stream communities and the Terrestrial Vegetation community at risk of serious and irreparable environmental damage

Australia is biogeographically distinct in its groundwater fauna (Humphreys, 2002) and the subterranean fauna of NSW is biogeographically distinct from other Australian 'hotspots' (Eberhard and Spate, 1995; Serov, 2002; Thurgate et al, 2001). In addition to the diversity aspect, our ecological perspective of groundwaters has broadened to consider the subsurface system as having a complex and interactive boundary with surface ecosystems at a range of scales. Groundwater fauna, especially stygofauna are extremely sensitive to the environmental characteristics of the water they inhabit and thus potentially are useful indicators of groundwater health (Tomlinson & Boulton, 2008, Serov et al, 2009).

The importance of aquifer ecosystems in terms of biodiversity is that groundwater environments within unconsolidated alluvial and fractured rock aquifers (as well as karstic aquifers) harbour a dynamic and diverse range of invertebrate communities that are composed of most of the major taxonomic groups (i.e. Crustacea, Oligochaete, Mollusca, Insecta) found in the surface water habitats, however, many of the lower (Order to species) are no longer found in surface environments or have surface water relatives (Humphreys, 2002; Marmonier et al,. 1993; Rouch and Danielopol, 1997; Sket 1999b; Danielopol et al., 2000). There is also a marked bias towards the crustacean and oligochaete groups (Marmonier et al,. 1993; Rouch and Danielopol, 1997; Sket 1999b; Danielopol et al., 2000 Tomlinson & Boulton, 2008). Most of these species are new to science.

In 2012 the first surveys were carried out within the Pilliga in order to determine the presence of Stygofauna within the Pilliga Sandstone Aquifer. The initial surveys were conducted on the pastoral property of 'Rockdale' located approximately 20km south of Narrabri, within the Pilliga State Forest. This first survey was in response to the property owner experiencing a rapid decline in water quality from the house bore used for domestic consumption. This was the second recorded change in groundwater condition, with the first occurring in 2006 with the failure of the original house bore. In order to investigate the cause behind the decline in water quality a biological survey of the bores on the property was included as an indicator of the groundwater conditions to compliment the water chemistry analysis conducted in the same period by Divstrat Pty Ltd. to provide advice on the possible cause of the water quality change. This was the first environmental assessment of the aquatic ecosystems of the Pilliga sandstone aquifer within the Pilliga Forest area.

This initial survey identified three taxa of stygofauna belonging to the Annelida and the Acarina. These results were later confirmed in 2013 by repeated and additional surveys that recorded a similar community composition from nearby bores. The aim of this report was to conduct a larger investigation into the distribution and community composition of stygofauna across the Pilliga and to determine the risks to this community from proposed developments as well as to continue the process of providing a benchmark for subterranean ecosystems across the Pilliga. This assessment included a baseline aquifer ecosystem evaluation for stygofauna across the largest aquifer complexes in the area. The difficulty in conducting a comprehensive survey of stygofauna across the Pilliga is the sparsity of bores from which to sample.

The stygofauna baseline survey included one round of surveys in order to identify the presence of stygofauna within the Study Area. The survey was conducted in 2016-17 and included 22 sites separated into 21 bores and one well. The sites were selected to cover as broad a coverage of the Study Area as possible, as well the broadest range of habitat types. The bore types range from shallow alluvial monitoring piezometers accessing groundwater situated in unconsolidated alluvial/colluvial sediments and deeper observation and domestic production bores into the shallow Pilliga Sandstone aquifer from the northeast to the southern margins of the Pilliga Forest as well as one within the Warrumbungles to the south of the Pilliga. A total of eleven taxa of invertebrates were recorded which included ten families from five orders of stygofauna. These orders included: Oligochaete, Acarina, Crustacea, Insecta and Nemertea.

The results showed stygofauna exist across the entire area. The distribution however varies with a low diversity across the Pilliga Sandstone and the Pilliga Colluvial with a higher diversity present within the Namoi Alluvium. Of the 22 sites sampled, 14 bores contained stygofauna species. The community composition included four orders of crustaceans, one order of mites, Oligochaetes and insects and Nemertea. There were no listed threatened species collected, however, as is the case for most assessments in this emerging field, all species are likely to be new to science. The biological and water quality data indicates that the fauna is associated with the Permian Pilliga Sandstone and the Quaternary colluvial and alluvial aquifers. The alluvial aquifer is shallow, composed of coarse to fine sediments with low electrical conductivity and relatively neutral pH water quality. The Pilliga Sandstone is characterised as consisting of fine grained sands, very low electrical conductivity and mildly acidic pH as well as very low turbidity. The relative consistency of the community composition within the bores that recorded stygofauna across the Study Area is an indication of connectivity within the shallow sandstone and alluvial aquifers and of consistency in the environmental conditions of this aquatic ecosystem. For this reason the shallow alluvial aquifer was assessed as having a high ecological value for the purpose of this study. The fine grained nature of the substrates and elevated electrical conductivity of the aquifer are suggested as reasons for the lack of fauna in the other sites.

Stygofauna are potentially threatened by activities that change the quality or quantity of groundwater, disrupt connectivity between the surface and aquifer, or remove living space. Aquifer contamination, drawdown and structural change resulting in connectivity changes are identified as the main risks to stygofauna associated with current and future developments. The potential impacts include changes to:

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

The stygofauna recorded are assessed as having a high risk of mining related impacts based on the modelled drawdown to the three aquifers surveyed from water extraction, the altered chemical composition of the treated waste water, particularly the elevated salinity levels that are proposed to be discharged into Bohena Creek and the highly connected nature of the streams and aquifers. The risks to the surface aquatic groundwater dependent ecosystems from the modelled drawdown are also regarded as high due to the shallow nature of these ecosystems. The risk of impact from water quality changes is regarded as high as any change in water quality parameters outside of the natural range can adversely impact subterranean communities. A risk assessment ranked ecological risk to sites where stygofauna were present as Class C (high value/high risk). The short term management actions relevant to these risk ratings include: protection measures for the aquifers and GDE, continue the ongoing risk monitoring of physicochemical parameters such as water level and water chemistry; periodic biological survey monitoring for the identified hot spot sites; and the exploration of more sites to gain a more complete understanding of community composition and species distributions. This is to be carried out within a long term adaptive management and monitoring program. Also identified is the intergenerational risk of contamination of the Great Artesian Basin via its recharge beds in the Pilliga Sandstone Aquifer.

1. Introduction

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

The Namoi River Valley has been recognised as a subterranean biodiversity hotspot for the East Coast of Australia. There are currently at least five acknowledged stygofauna communities identified along its length with the closest to the Pilliga being the highly diverse community within the Upper Maules Creek subcatchment located to the northeast of the Pilliga and only 25km east of Narrabri.

The Pilliga Forest is located to the south of Narrabri in the Northwest of NSW. It is one of the largest isolated, forested areas remaining in NSW and extends from Narrabri in the North to Coonabarabran and the Warrumbungles in the South. This project aims to confirm the presence of stygofauna across aquifers within and adjacent to the Pilliga Forest area and highlight the stygofauna community composition and distribution. It also aims to examine the environmental factors contributing and possibly controlling the presence of this community.

This study extends the earlier surveys conducted in 2012 and 2013 to cover the three main aquifer units present within the Pilliga. The three main aquifer units include the Quaternary Colluvium, the Namoi Alluvium and the Pilliga Sandstone Aquifer. This investigation also covers two main surface water catchments that include the Namoi River in the North and the Castlereagh River in the South. The area is heavily vegetated with native woodland across the Pilliga with riparian communities within the riparian zones of all the stream sections. The area borders the southern edge of Mount Kaputar in north and the northern boundary of the Warrumbungles in the south.

1.1 Purpose of this Report

The object of this investigation is to determine the extent and composition of subterranean stygofauna communities across the area. Specifically this report assesses whether subterranean groundwater dependent ecosystems (GDEs) occur within the area of the current and proposed development, and if they exist, whether the proposed activities will have an impact on them. This investigation is a baseline aquifer ecosystem evaluation for stygofauna across the Pilliga.

1.2 Impact Assessment Objectives

The aim of this stygofauna baseline survey and impact assessment is to determine the presence of stygofauna within the Pilliga area and to assess the potential impacts of potential future developments on groundwater ecology including aquatic threatened species, populations, communities or their habitats that are dependent on groundwater.

The specific objectives were to:

- ❑ Describe the natural/pre-development characteristics of the groundwater ecology through qualitative surveys of stygofauna;
- ❑ Identify or determine the likelihood of occurrence of threatened species, populations, habitat and/or communities within the Study Area;
- ❑ Assess whether the proposed developments will cause significant adverse effects to groundwater and baseflow stream ecology; and

- Determine whether these impacts will significantly impair any identified threatened species, populations, habitat or communities.

1.3 Legislation, Policy, Criteria and/or Guidelines

Groundwater ecosystem dependence is an increasingly important component of surface and groundwater initiatives in NSW and has been incorporated within Groundwater Management Plans under the Water Reform Agenda. The ecological value and ecological risks to any identified subterranean communities are assessed in accordance with the NSW Government's "Risk Assessment Guidelines for Groundwater Dependent Ecosystems" (Serov et al. 2012) in order to provide a baseline for future planning.

The NSW State Government also has an obligation under the *Water Management Act 2000* (WM Act) and the Groundwater Dependent Ecosystem Policy (2002) to "manage GDEs in such a way that it:

- Applies the principles of ecologically sustainable development;
- Protects, enhances and restores water sources, their associated ecosystem, ecological processes and biological diversity and their water quality;
- Integrates the management of water sources with the management of other aspects of the environment, including the land, its soils, its native vegetation and its native fauna."

The WM Act also provides water management principles that are relevant to the management of GDEs. These include:

- water sources, floodplains and dependent ecosystems (including groundwater and wetlands) should be protected and restored and, where possible, land should not be degraded;
- habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and (in the case of habitats) restored; the quality of all water sources should be protected and, wherever possible, enhanced;
- the cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised;
- The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirement.

The following policies are relevant to the protection and management of GDEs in NSW:

- NSW State Groundwater Policy Framework document, Department of Land and Water Conservation, 1997. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/
- NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/
- NSW Groundwater Quality Protection Policy, Department of Land and Water Conservation, 1998. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/
- NSW Wetlands Management Policy, Department of Environment, Climate Change and Water, 2010a.
- State Environmental Planning Policy No. 14 – Coastal Wetlands, SEPP 14.
- Risk assessment guidelines for groundwater dependent ecosystems – the conceptual framework NSW Office of Water, September 2012
- NSW State Rivers and Estuaries Policy – NSW Water Resources Council NSW Government, 1993. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Keypolicies/
- Water Compliance Policy (NSW Office of Water, 2010a). http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies
- NSW Water Extraction Monitoring Policy. http://www.water.nsw.gov.au/Waterlicensing/Metering/default.aspx

The following legislation and strategies are also considered in this assessment for the protection and management of GDEs in NSW:

- *Threatened Species Conservation Act 1995*. This Act and its listings are used in the determination of the ecological value of a GDE, i.e. if a GDE contains a threatened species as listed under this Act; the GDE is taken to have higher ecological value.
- *Native Vegetation Act 2003*. This Act is relevant to the protection of vegetation which may be or form part of a GDE community.
- *Fisheries Management Act 1994*. This Act is relevant to the determination of the ecological value of a GDE (i.e. if the GDE contains a threatened species as listed under this Act, the GDE is taken to have higher ecological value).
- Draft New South Wales Biodiversity Strategy, Department of Environment, Climate Change and Water NSW and Industry and Investment NSW, 2010. The Strategy is directly relevant as its objectives include the: smarter biodiversity investment and improved partnerships whole of landscape planning effectively managing threats sustainable production environments.
- NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010-2015.

1.4. Stygofauna Ecology

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

Stygofauna are blind, colourless, have slow metabolisms, reduced body size, specialised anatomies and low reproduction rates (Coineau 2000). As there is no photosynthesis below ground, these groundwater environments rely on inputs of organic matter from the surface to provide the basis of the food web on which stygofauna depend (Schneider et al. 2011). Despite their small size, the cumulative effect of stygofauna activity plays an important part in maintaining groundwater quality. This process is evident in alluvial aquifers where water flowing though sediment particles is cleaned during transit by stygofauna, in much the same way as water moving through slow sand filters or trickle filters in water and sewage treatment (Hancock et al. 2005). Stygofauna therefore play a functional role in aquifers and are also considered a direct and sensitive indicator of the quality of an underground water source.

1.4.1 Stygofauna ecological requirements

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

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

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

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

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

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

These ecosystems and organisms have many values including the following:

- Most are rare or unique
- Retain phylogenetic and distributional relictual species and communities;
- And therefore, the ecosystems surviving in aquifers and caves are amongst the oldest surviving on earth.
- High proportion of short range endemics.
- Develop or retain narrow range habitat requirements (i.e. narrow range endemic species). To survive, these species and communities continue to rely on the continuance of certain groundwater levels/pressure and water chemistry; and
- Develop specialised morphological and/or physiological adaptations to survive in groundwater environments.
- They have water quality functions, biodiversity value and add to the ecological diversity in a region.

The other important characteristic of alluvial aquifer communities is that their dispersal capabilities are entirely dependent on the subsurface hydrological connectivity of the aquifer with other aquifers and narrow physiological tolerance ranges in water chemistry. As this community is adapted with specialized morphological features, narrow environmental tolerances (Gibert, et al. 1994; Gibert & Deharveng, 2002; Marmonier et al, 1993; Rouch and Danielopol, 1997; Sket 1999b; Danielopol et al., 2000; Serov, 2002; Serov et al, 2009, Tomlinson & Boulton, 2008), and have no desiccation tolerant life stages (i.e. they cannot disperse via surface rivers and streams or via aerial dispersal of eggs). They are therefore, solely restricted to this environment. Tomlinson & Boulton (2008) outline the characteristics of subsurface aquifer communities. These communities can be isolated by a number of barriers including geological, hydrogeological, climatic and differences in water chemistry. As a result of these barriers to dispersal, subterranean communities in general have a high potential for speciation and very short range endemism and are highly vulnerable to habitat change resulting in local or total extinction of species.

Stygofauna surveys in NSW, and more specifically within and around the Namoi Catchment have identified the alluvial aquifer contains a diverse and highly endemic stygofauna community. This isolation and aerial extent of the community has been identified and confirmed by a broad sampling of the region that includes:
1) The hyporheic zones of the Maules Creek and the Upper Namoi tributaries,
2) A number of government monitoring bores and a number of privately owned wells and bores within the Namoi Catchment both for stygofauna and water chemistry.

Regional sampling has also been conducted in the sub-catchments of the Namoi River including in the Peel and Cockburn River alluviums, Halls Creek near Manilla and east and west along the Namoi River, north-west on the Gwydir River as far as Moree, and south throughout the Hunter River and Upper Hunter River Tributaries including the Pages River. The closest community to the Pilliga area identified within the Namoi River catchment so far is located within Upper Maules Creek, Halls Creek, Peel and Cockburn Rivers west and east of Tamworth, covering 140 km along the river in a straight line. Each community however is isolated hydrologically and each contains separate species. This restricted distribution is delineated by geological and water chemistry barriers (Anderson & Acworth, 2007, Anderson, 2008, Serov et al, 2009). Therefore, it is considered highly unlikely to impossible that the community intergrades with any other subsurface alluvial groundwater dependent ecosystem.

1.4.2 Processes that Threaten Stygofauna

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

1) Stable water quality/physicochemical parameters;

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

2) Surface connectivity;

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

3) Subterranean connectivity.

The third critical factor is 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 restrict their movement. Over time, these natural barriers encourage genetic isolation and ultimately, speciation. Barriers, however, can also be created rapidly by changes in water levels or water chemistry/quality such as an area of lower porosity and sections of poor water quality. If any area is impacted by a disturbance that results in a loss of biodiversity, these new barriers to dispersal may prevent recolonization of the habitat.

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

Stygofauna are potentially threatened by activities that change the quality or quantity of groundwater, disrupt connectivity between the surface and aquifer, or remove living space. These impacts to groundwater and aquifer conditions have become a particular issue for mining proponents over the last decade or so, principally because of the perceived biodiversity value of stygofauna and the fact that little is known of their environmental water requirements.

1.4.3. Effects of mining on stygofauna

Mining operations may incorporate a range of activities in their operations that may result in impacts on water resources, including some or all of the following (Serov et al. 2012):

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

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

- ❑ Quantity (groundwater levels, pressures and fluxes);
- ❑ Quality (changes outside of natural ranges, concentrations of salts, heavy metals 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, compaction of aquifer matrix through dewatering, increase in porosity by blasting, or overburden compaction).

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

1.4.4. Other studies

The National Water Commission (NWC) has reported (RPS 2011) that extensive gaps exist in our knowledge of the distribution, composition and biodiversity value of Australian stygofauna. Despite this incomplete inventory it is apparent that stygofauna are present across a variety of Australian subsurface environments and are generally characterised by high diversity and local-scale endemicity. They are also often of high scientific interest; for example, the occurrence of the only known southern hemisphere representatives of several phylogenetic relict lineages.

In Australia, at least 750 stygofauna species have been described (Humphreys 2008), but this is a conservative estimate of total continental biodiversity as more than 66 % of known species come from just two regions of Western Australia (Humphreys 2008) and large parts of Australia remain un-surveyed. In NSW there are approximately 400 species of stygofauna known, but this estimate is likely to increase as more surveys are conducted and taxonomic knowledge improves.

It is worth mentioning that although the Namoi Valley has one of the richest known communities of stygofauna in NSW, no animals thus far have been collected from coal seams in this catchment. All of the bores that contained stygofauna were in the fractured rock Pilliga Sandstone and alluvial aquifers of the Namoi River and its tributaries.

1.5 Terminology Used in This Report

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

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

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

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

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

1.6 Assumptions and Limitations

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

Groundwater bore sites sampled are assumed to be representative of the groundwater ecosystems present across the Study Areas, temporally and spatially. While every effort was given to maximize the representativeness of the system it does not cover the full extent of the bores and potential subterranean and groundwater dependent habitats in the Study Area. Temporal variations between autumn and spring also cannot be assessed at this stage as there has been no seasonal replication.

2. Study Area and Sampling Sites

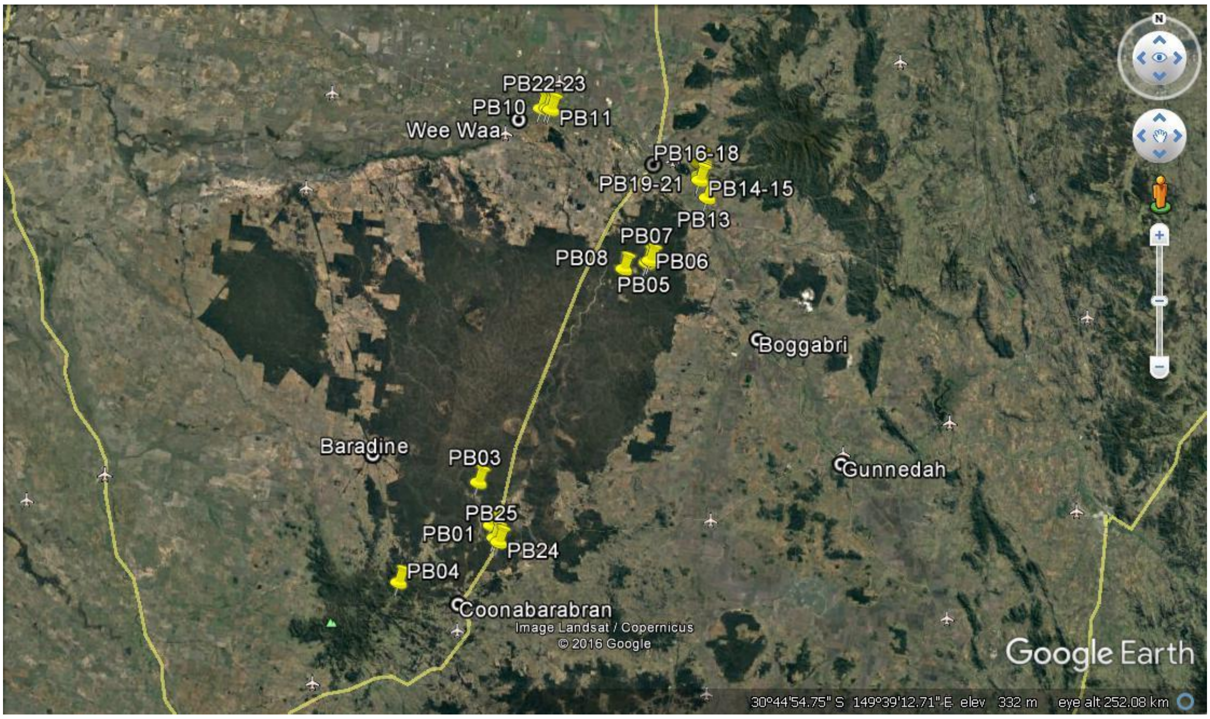
The Study Area for the purposes of this report encompasses the Pilliga Project Area (refer to Map 1) and adjacent alluvial lands to the north east, northwest and south containing groundwater bores and wells.

2.1. General Description

The study area covers Pilliga Forest area and adjacent lands and is located within both the Namoi and Castlereagh River catchments. The Pilliga Forest is located to the south of Narrabri in the Northwest of NSW. It is one of the largest isolated, forested areas remaining in NSW and extends from Narrabri in the North to Coonabarabran and the Warrumbungles in the South. This project aims to confirm the presence of stygofauna across aquifers within and adjacent to the Pilliga Forest area and highlight the stygofauna community composition and distribution. It also aims to examine the environmental factors contributing and possibly controlling the presence of this community.

This investigation also covers two main surface water catchments that include the Namoi River in the North and the Castlereagh River in the South. The area is heavily vegetated with native woodland across the Pilliga with riparian communities within the riparian zones of all the stream sections. The area borders the southern edge of Mount Kaputar in north and the northern boundary of the Warrumbungles in the south.

Map 1. Location of the Pilliga Project Area.



Map 2. Location of all surveyed sites within and adjacent to the Pilliga Project Area.

2.2 Groundwater

This study extends the earlier surveys conducted in 2012 and 2013 to cover the three main aquifer units present within the Pilliga. The three main aquifer units include the Quaternary Colluvium, the Namoi Alluvium and the Pilliga Sandstone Aquifer. The following description of the groundwater and geology is sourced from Santos EIS - Chapter 11. Groundwater and Geology. The Pilliga underlies the Southern Recharge Groundwater Source of the Great Artesian Basin (largely the Pilliga Sandstone).

The Groundwater water sources across the area include:

o Porous Rock Aquifers

- Gunnedah-Oxley Basin (Permo-Triassic Age) MDB Porous Rock Groundwater Source;
- Lower Namoi Groundwater Source
- Upper Namoi Groundwater Source
- Great Artesian Basin (largely the Pilliga Sandstone). The Artesian Water Sources are in the western part of the basin and western side of Pilliga
- The Surat Groundwater Sources - Coonamble Embayment of the Surat Basin (Jurassic-Cretaceous Age).
- Warrego Groundwater Source.
- Central Groundwater Sources.
- the Eastern Recharge Groundwater Sources in the non-artesian eastern fringes of the basin
- Southern Recharge Groundwater Sources in the non-artesian eastern fringes of the basin,

The Great Artesian Basin Shallow Groundwater Source (covers groundwater resources associated with the alluvial formations and all other formations to a maximum depth of 60 metres below the surface of the ground that overlie the NSW GAB formations and are not included in other WSPs (within the boundaries of the NSW Upper and Lower Namoi Groundwater Source WSP).

The Namoi Unregulated and Alluvial Water Sources WSP incorporates twenty-three unregulated water sources upstream and downstream of Keepit Dam, as well as four alluvial groundwater sources to the east of the Namoi River catchment outside of the project area.

- The Fractured Rock Aquifers
- New England Fold Belt MDB,
- Liverpool Ranges Basalt MDB and
- Warrumbungle Basalt.

Geology of the project area
From land surface to the basement rocks, the local geology of the project area is characterised by:

- Bohena Creek Alluvial
- Orallo Formations -unconsolidated alluvial and colluvial surface deposits (superficial deposits)
- Surat Basin strata:
- Pilliga Sandstone,
- Purlewaugh Formation and
- The Garawilla Volcanics at the base of the sequence.
- Gunnedah Basin strata of the Bohena Trough
- Meta-volcanic basement rocks.

Transmissivity of Geology
The significant transmissive units (STUs) include the shallow alluvial Gunnedah and Cubbaroo formations within the valley-fill of the Namoi River and its tributaries (Namoi Alluvium), the Pilliga Sandstone of the Great Artesian Basin (GAB), and coal seams within the Black Jack Group and Maules Creek Formation of the Gunnedah Basin.

Overall, the hydrostratigraphic sequence consists of significant transmissive units at depth within the coal seams of the Gunnedah Basin, which are hydrologically isolated from the overlying portion of the Pilliga Sandstone aquifer of the Surat Basin and the shallow Namoi Alluvium aquifer by thick aquitard sequences.

Groundwater Flows
Within the Pilliga Sandstone aquifer of the GAB, artesian groundwater pressure (flowing bores) occurs to the west of the recharge beds and project area. The direction of regional groundwater flow in the Pilliga Sandstone is generally northwest and consistent with the broader northwest flow direction within the Coonamble Embayment from the recharge beds of the Pilliga Sandstone toward the Bogan River Spring Group discharge area. Groundwater pressure in artesian bores where the Pilliga Sandstone subcrops beneath the Lower Namoi alluvium is above the elevation of the water table in the alluvium, which shows a hydraulic potential for upward leakage of groundwater into the alluvium from the underlying GAB aquifer.

Groundwater Quality
Overall, the available data on groundwater quality show that:

- groundwater within alluvium is generally fresh (defined as less than 500 milligrams per litre (mg/L) total dissolved solids (TDS) to brackish (defined as 500 to 3,500 mg/L TDS) and has an alkaline pH (approximately 8)
- groundwater in the Pilliga Sandstone is fresh and has neutral pH (approximately 7)
- groundwater in Permo-Triassic strata of the Gunnedah-Oxley Basin tends to be brackish to saline (defined as 3,500 to 35,000 mg/L TDS) and has alkaline pH (approximately 9)
- groundwater within target coal seams is saline and has alkaline pH (approximately 8).

GW/SW connectivity
Existing studies that were undertaken to assess the degree of connection between surface water and groundwater within the Namoi Catchment have shown that surface drainage lines located within the steeper upland regions, mainly in the eastern part of the catchment tend to be gaining streams, whereas surface drainage in low relief areas tend to be losing streams (Ivkovic 2006).

Connection between the Namoi Alluvium and Pilliga Sandstone aquifer of the GAB occurs 10 to 15 kilometres northeast of the project area but both of these sources are hydrologically isolated from the target coal seam for the project by thick sequences of intervening aquitards.

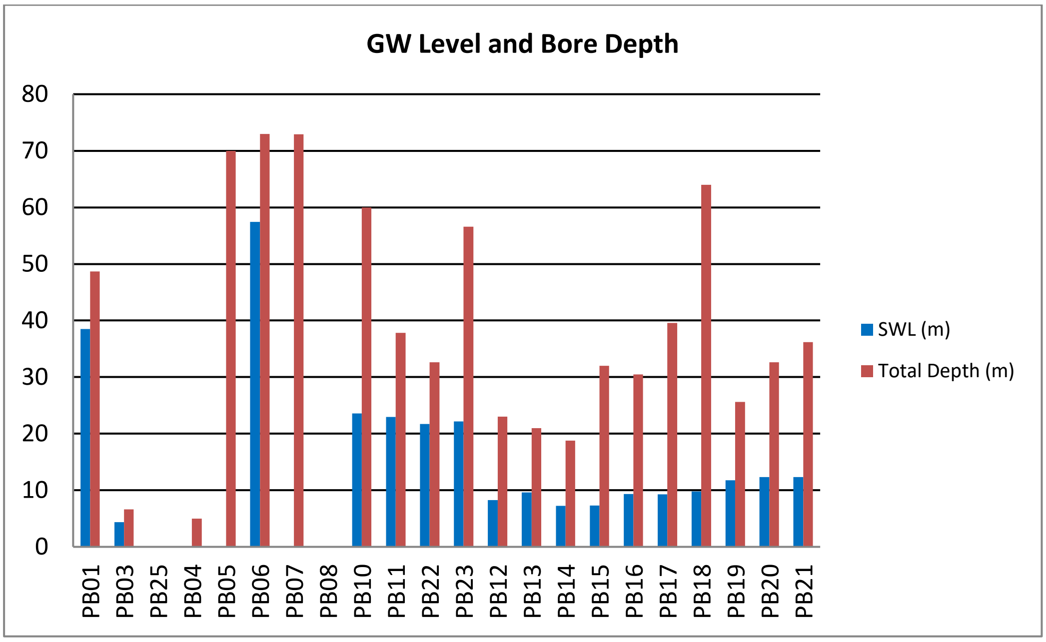


Figure 1. Surface water levels and bore depths recorded at each bore during the survey.

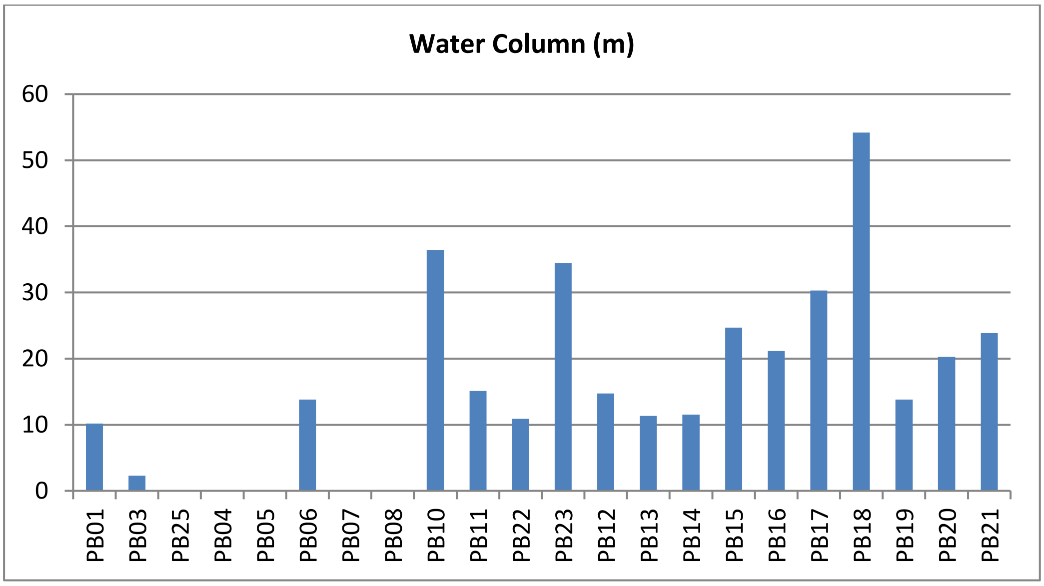


Figure 2. Water column thickness recorded at each bore during the survey.

2.3 Study Sites

As noted in Section 2.1, the Study Area encompasses the Pilliga Project Area and adjacent alluvial lands to the northeast and west containing groundwater bores and wells (refer to Map 4). The sites and bores used for this study have been selected to cover as broad a range of habitats and geographic distribution as possible as well as including where possible bores from both within the Pilliga Forest and outside (Table 1). This allows for comparison between sites and aquifers in similar habitats and depths and the identification of biological hotspots for incorporation into a future ongoing monitoring program. The bores in each area have also been separated into each of the main aquifer systems and catchments in order to determine if any subterranean species are endemic to a specific water shed.

Sites	Site No.
Inspiration Alpaca, Narawah Rd, Coonabarabran	PB01
Pilliga Pottery, Dandry Rd, Coonabarabran	PB03
Dragon Ridge, Newell Hwy, Coonabarabran	PB25
Blackburn Rd, "Mirrorbrook", Timor Rd, Warrumbungles	PB04
GW969324, New House Bore, "Rockdale", Westport Rd, Pilliga	PB05
GW038774, Old House Bore, "Rockdale", Westport Rd, Pilliga	PB06
GW003587, Far Bore, "Rockdale", Westport Rd, Pilliga	PB07
1239 Westport Rd, Pilliga	PB08
Eskdale, Culgoora Rd, Wee Waa	PB10
Eskdale, Culgoora Rd, Wee Waa	PB11
GW036001.1, Culgoora Rd, Wee Waai	PB22
GW036001.2,Culgoora Rd, Wee Waa	PB23
GW030244.1, Pikes Lane, Narrabri	PB12
GW030230, Pikes Lane/Turrawan Rd, Narrabri	PB13
GW030227.1, Pikes Lane/Turrawan Rd, Narrabri	PB14
GW030227.2, Pikes Lane/Turrawan Rd, Narrabri	PB15
GW030308.1, Pikes Lane/Turrawan Rd, Narrabri	PB16
GW030308.2, Pikes Lane/Turrawan Rd, Narrabri	PB17
GW030308.3, Pikes Lane/Turrawan Rd, Narrabri	PB18
GW030226.1, Pikes Lane/Turrawan Rd, Narrabri	PB19
GW030226.2, Pikes Lane/Turrawan Rd, Narrabri	PB20
GW030226.3, Pikes Lane/Turrawan Rd, Narrabri	PB21

Table 1. Bore survey locations.

2.4 Bore Data

Twenty-two bores were selected as representatives of each of the major aquifers that contained monitoring bores (Table 1). All bores sampled are located within the area and selected based on suitability for stygofauna for the following reasons: they were shallow monitoring piezometers or domestic wells with works attached, they accessed groundwater situated in the unconsolidated alluvial sediments as well as the fractured rock aquifers. The bores were surveyed using one to two techniques on one occasion.

Of the 22 bores sampled, eight were in the Pilliga Sandstone, four were in the Quaternary Colluvium and ten were in the Namoi Alluvium. The water bores selected are typically constructed with a short steel casing extending from ground level to approximately 3-6m below the surface which surrounds a 50mm plastic casing extending the length of the bore with a terminal cap to prevent sediment entering from the bottom. The section of the casing that corresponds with the water bearing zone, that is required to be monitored, is equipped with slots to allow the water to enter. The bores did not contain water level loggers however were semi-regularly surveyed for water level. The survey sites are listed below in Table 2.

Site No.	PB01	PB03	PB25	PB04	PB05	PB06	PB07	PB08	PB10	PB11	PB22	PB23
Catchment [3]	CR	CR	CR	CR	NR	NR	NR	NR	NR	NR	NR	NR
Geology [2]	PS	PS	PS	PS	PS	PS	PS	PS	QC	QC	QC	QC
Altitude (mAHD)	518	411	595	698	297.9	297.9	305	270	198	199	197	197
Lat/Long	31.81417/ 149.2058	31.23620/ 149.19675	30.16437/ 149.35860	31.152802/149.64 454	30.342440/1494 50095	30342429/ 149450119	30.340140/ 14945329	30.35524/ 149.413174	30.14327/149.29 2127	30.141303/149.30 4773	30.14269/149.30 2045	30.14269/ 149.302045
Bore Type [1]	MB	Well	DB	DB	DB	DB	DB	DB	IB	IB	MB	MB
Standpipe Height (m)	0.2	1	na	na	0	0	0.5	na	0	0	0.65	0.59
Total Depth (m)	48.7	6.62	nd	5	70	73	72.94	nd	60	37.8	32.6	56.6
SWL (m)	38.5	4.34	na	na	nd	57.44	nd	nd	23.58	22.96	21.69	22.17
Water Column (m)	10.2	2.28	na	na	nd	13.8	nd	nd	36.42	15.11	10.91	34.43
Screen Interval (mBGL)	na	na	na	na	na	na	na	na	na	na	22.8-25	47.5-50.5
Temp (°C)	21.1	19	18.5	16.9	22	21.6	23.4	22.1	22.7	21.6	21.3	21.2
EC (µS/cm)	129.8	5.54	70	177.4	195.9	200.8	447.2	192.8	735	744	619	366
pH (Units)	4.87	6.73	5.18	6.27	5.19	5.41	6.3	5.58	6.58	6.54	6.55	6.93
DO (mg/l)	2.11	1.22	1.9	1.9	1.22	2.34	1.46	1.7	2	2.05	1.42	1.67
Sample Method	Bailer/net	Bailer/net	Sieve	Bailer/net	Sieve	Bailer/net	Bailer/net	Sieve	Bailer/net	Bailer/net	Bailer/net	Bailer/net

[1] - Bore type: MB - Monitoring Bore, DB - Domestic Bore, IB - Irrigation Bore,

[2] - Geology: PS - Pilliga Sandstone, QC - Quaternary Colluvium, NA - Namoi Alluviur

[3] - Catchment: CR - Casltereagh River, NR - Namoi Ri

PB12	PB13	PB14	PB15	PB16	PB17	PB18	PB19	PB20	PB21
NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
223.5	222.3	222.3	224.74	224.74	224.74	228.8	228.8	228.8	228.8
30.43204085/ 149.9041934	30.39370769/ 149.8858601	30.39370769/ 149.8858601	30.38870770/ 149.8864156	30.38870770/ 149.8864156	30.38870770/ 149.8864156	30.38342993/ 149.8872489	30.38342993/ 149.8872489	30.38342993/ 149.8872489	30.38342993/ 149.8872489
MB	MB	MB	MB	MB	MB	MB	MB	MB	MB
0.7	0.5	0.52	0.52	0.56	0.46	0.56	0.76	0.76	0.76
23	21	18.8	32	30.5	39.6	64	25.6	32.6	36.2
8.29	9.65	7.27	7.33	9.34	9.29	9.8	11.79	12.33	12.32
14.71	11.35	11.53	24.67	21.16	30.31	54.2	13.81	20.27	23.88
16.4-18.5	11.3-15.8	14.8-15.2	28-29	22.9-25.9	30.5-33.5	57.9-61	23.4-23.7	26.8-29.8	32.9-33.2
20.1	22.2	21.3	21.3	21.5	21.4	21.4	21.1	21.1	21.1
242.5	918	551	538	539	547	575	543	516	439.5
6.97	7.05	7.37	7.49	6.88	7	6.92	6.9	6.78	6.7
1.85	1.21	1.25	2.08	1.8	2.02	1.9	2.05	2.17	1.67
Bailer/net	Bailer/net	Bailer/net	Bailer/net	Bailer/net	Bailer/net	Bailer/net	Bailer/net	Bailer/net	Bailer/net

Table 2. Bore survey station list

3. Methodology

In preparing for each round of stygofauna sampling it is necessary to keep in mind the needs of a future monitoring program that will be required to determine if there have been any significant changes to either the water resource or the dependent ecosystems. This is best done by using a BACI (Before/After Control/Impact) experimental design i.e. before and after sampling at experimental and control (reference) sites. The development of any sampling protocol involves:

❒ Selecting sampling location points (bores, wells, piezometers, appropriate hyporheic habitat etc.);

❒ Deciding on an appropriate sampling method (pumps, bailers, plankton nets, Bou Rouche pump etc.);

❒ Determining sample handling procedures (such as filtration, transfer, preservation, etc.); and minimum disturbance to biological specimens.

3.1. Stygofauna Sampling

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

<u>The Phreatic/hypogean zone</u>

The phreatic zone is the subsurface area within an aquifer where voids in the rock are completely filled with water. This is occupied by phreatobites. Phreatobites have adapted to tolerate suboxic conditions (dissolved oxygen concentration (DO) less than 3.0 milligrams per litre) or limited food supply (Malard and Hervant 1999; Hervant and Renault 2002; Datry et al. 2005) and even hypoxia (DO less than 0.01milligrams per litre) (Thomlinson & Boulton, 2008). Dissolved oxygen (DO) concentrations below 1.0 to 0.5 mg/l are the critical threshold for most groundwater fauna (metazoans) (Hahn 2006). The stygofauna community was sampled using three standardised methods and one non-standard method.

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

The second standard method is the use of a groundwater bailer. A bailer is typically used by hydrogeologists to take water samples from bores for water quality/water chemistry analysis. The bailer used for this study is 1 meter long by 40mm clear plastic tube with a running ball valve at the bottom. The advantage of using a bailer is twofold. The main reason for using a bailer is that it is able to sample the bottom sediment of a bore that cannot be sampled by a haul net and therefore enables the collection of cryptic invertebrates that do not inhabit the water column or sides of the bore. The second advantage is that in shallow bores down to 5 meters in sediments with low transitivity porosity, a bailer is able to empty the entire contents of a bore and thereby confidently collect all animals within the bore. The contents of the bailer are emptied into a cleaned bucket from which the water is then decanted through a 150 μm mesh sieve. The contents of the sieve are transferred to a labelled sample jar and preserved with 100% ethanol. Following sampling and preservation of the sample and prior to the next sampling, all equipment including the bailer, net and sieves must be rinsed clean with clean water via a spray bottle to remove any sediment and animals that may have remained attached to the sampling devices. This is to reduce the possibility of cross contamination of organisms (stygofauna or bacteria) or pollutants from one aquifer or bore to another.

The third method was used on domestic bores that have a pump or works installed that would preclude entry to the bore and the use of the other methods. This involved pumping water through the bore pump to the surface for approximately ten minutes. This removed an estimated two bore volumes. The water was drained through a 150µl sieve. The resulting sediment was washed into a container and preserved in 100% ethanol.

3.2. Laboratory Methods

3.2.1. Identification

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

3.2.2. Physico-Chemical Data

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

3.3 Data Analysis

3.3.1. Risk Assessment Methodology

The “Risk Assessment Guidelines for Groundwater Dependent Ecosystems” (Serov et al. 2012) methods were structured to specifically reflect current relevant legislation, as well as to address the Secretary’s Environmental Assessment Requirements for the Project. These methods include monitoring design and impact assessment criteria.
The ecological valuation and risk assessment process used to assess the risk and potential impacts of the proposed development for the identified GDEs is the “Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Serov *et al*, 2012)”.

In summary, GDEs are first identified and classified and the level of dependency on groundwater for individual GDEs inferred. Once the current ecological value of individual aquifers has been determined, the ecological value of the GDEs associated with that aquifer must then be assessed. The individual value of each GDE within the aquifer can also be assessed as a stand-alone unit. Following an assessment of the aquifer and associated GDEs current value, the potential future impact of a proposed activity on the aquifer and associated GDEs must then be determined. The magnitude of risk from that activity to the ecological value of the GDE(s) and aquifer is then determined. Finally, the Risk Matrix is applied to determine the most appropriate management response for a given environmental value. The process is illustrated in Diagram 1 below.

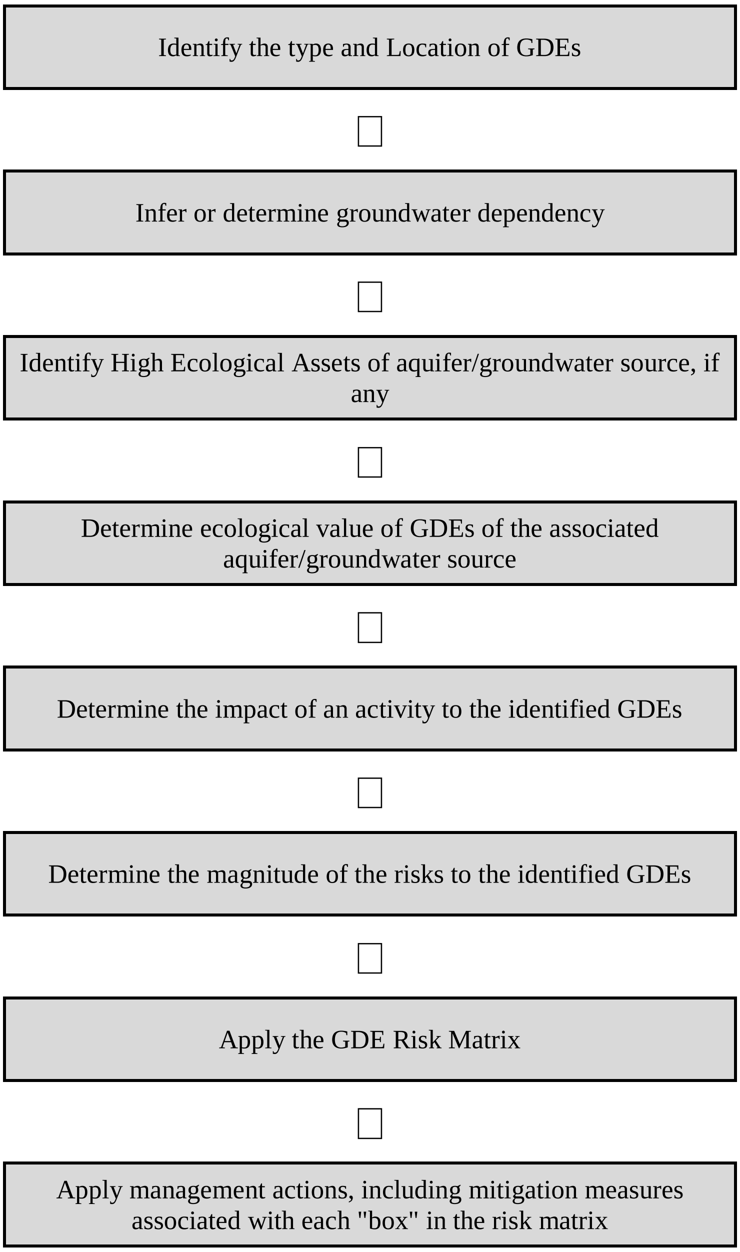


Diagram 1. Ecological valuation and risk assessment process. (Serov et al. 2012).

3.3.2. Aquifer Risk Assessment

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

- Ecological Assets;

- Risk of a change in groundwater levels/pressures on GDEs,
- Risk of a change in the timing of groundwater level fluctuations on GDEs,
- Risk of changing base flow conditions on GDEs.
- Risk of changing aquifer flow paths.

❑ Water Quality Assets;
- Risk of changing the chemical conditions of the water source,
- Risk on the water source by a change in the freshwater/salt water interface, and
- Likelihood of a change in beneficial use of the water source.

❑ Aquifer Integrity Assets;
- Risk of substrate compaction.

3.3.3. The Risk Matrix

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

1. Recommend the most appropriate management strategies for each given scenario at the outset; and
2. Test the effectiveness of the management strategies over a time period by combining a monitoring program with an effective framework for adaptive management (i.e. responding to the monitoring outcomes).

The aim of the management strategies is to:

1. Maintain and/or improve the ecological value of an aquifer and its associated GDEs; and
2. To reduce the level of risk to that aquifer and associated GDEs.

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

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

The Risk Matrix identifies both the level of management action required and the time frame in which this action needs to be implemented (Action Priority) as illustrated in the Risk Matrix Management Actions Table 3. Each component aligns with each of the axes. The management action is aligned with ecological value and does not vary with changes in risk (i.e. the rules for the management of high ecological value ecosystems or aquifers are the same whether the risk is high or low). However, the timing of the management action is aligned and determined by the level of risk. For example, if an ecosystem or aquifer has been identified as of high ecological value and the risk assessment process has identified a proposal or current activity that poses a high risk, the management strategy would require immediate action before the impact occurs, or undertaken with significant protection measures if the activity is unavoidable. If the impact is a current activity, the strategy would be to either immediately stop the activity or commence mitigation works in a short time frame to limit damage to the identified ecological values.

The management strategies for aquifers and GDEs are largely vested in the legislative controls of the Water Management Act (2000). A requirement of Water Sharing Plans is to monitor plan performance using a standard set of Performance Indicators. For the purpose of Section 35 (1) (b) of the Water Management Act, the following broad indicator categories are to be used to determine the performance of each plan against its objectives:

a) Change in ecological condition and value of these groundwater sources and their dependent ecosystems. This includes changes in species/community numbers and composition.
b) Change in groundwater extraction relative to the extraction limit.
c) Change in climate adjusted water levels.

Category 1 **High Ecological Value (HEV)** **Sensitive Environmental Area (SEA)**	**A**	**B**	**C**
Category 2 **Moderate Ecological Value (MEV)** **Sensitive Environmental Area (SEA)**	**D**	**E**	**F**
Category 3 **Low Ecological Value (LEV)**	**G**	**H**	**I**
	Category 1. **Low Risk**	**Category 2.** **Moderate Risk**	**Category 3.** **High Risk**

Table 3. Risk Matrix.

Risk Matrix Box	Descriptor	Management action short term	Management action mid term	Management action long term **
A	High value/Low risk	Protection measures for aquifer and GDEs. Baseline Risk monitoring.	Continue protection measures for aquifers and GDEs. Periodic monitoring and assessment.	Adaptive management. Continue monitoring.
B	High value/Moderate Risk	Protection measures for aquifer and GDEs. Baseline Risk monitoring. Mitigation action.	Protection measures for aquifer and GDEs. Monitoring and periodic assessment of mitigation.	Adaptive management. Continue monitoring.
C	High Value/High Risk	Protection measures for aquifer and GDEs. Baseline Risk monitoring. Mitigation.	Protection measures for aquifer and GDEs. Monitoring and annual *assessment of mitigation.	Adaptive management. Continue monitoring.
D	Moderate Value/Low Risk	Protection of hotspots. Baseline Risk monitoring.	Protection of hotspots. Baseline Risk monitoring.	Adaptive management. Continue monitoring.
E	Moderate Value/Moderate Risk	Protection of hotspots. Baseline Risk monitoring. Mitigation action.	Protection of hotspots. Monitoring and periodic assessment of mitigation.	Adaptive management. Continue monitoring.
F	Moderate Value/High Risk	Protection of hotspots. Baseline Risk monitoring. Mitigation Action.	Protection of hotspots. Monitoring and annual *assessment of mitigation.	Adaptive management. Continue monitoring.
G	Low value/Low risk	Protect hotspots (if any). Baseline Risk monitoring.	Protect hotspots (if any). Baseline Risk monitoring.	Adaptive management. Continue monitoring.
H	Low Value/Moderate Risk	Protect hotspots (if any). Baseline Risk monitoring. Mitigation action.	Protect hotspots (if any). Monitoring and periodic assessment of mitigation.	Adaptive management. Continue monitoring.
I	Low Value/High Risk	Protect hotspots (if any). Baseline Risk monitoring. Mitigation Action.	Protect hotspots (if any). Monitoring and annual *assessment of mitigation.	Adaptive management. Continue monitoring.

Table 4. Risk Matrix Management Actions

3.3.4. Comparative Indices (Number of Taxa)

Number of Taxa. All macroinvertebrate taxa are separated and counted. The number of families present generally decreases with decreasing water quality and depth and is used as a comparative measure of community change over time.

4. Results

4.1 Environmental Physico-chemical Conditions

All physico-chemical parameters were remarkably consistent within each of the aquifer units of the Study Area (Table 2). The groundwater chemistry for the sites that recorded stygofauna were broadly within the minimum requirements as set out by the ANZECC and ARMCANZ guidelines (2000) although each aquifer has its own characteristics. At the time of sampling the area was mainly dry with isolated pools occurring along the length of Bohena Creek and the Namoi was flowing.

Sites	**Site No.**	**SWL (m)**	**Total Depth (m)**	**Temp (°C)**	**EC (µS/cm)**	**pH (Units)**	**DO (mg/l)**
Inspiration Alpaca, Narawah Rd, Coonabarabran	PB01	38.5	48.7	21.1	129.8	4.87	2.11
Pilliga Pottery, Dandry Rd, Coonabarabran	PB03	4.34	6.62	19	554	6.73	1.22
Dragon Ridge, Newell Hwy, Coonabarabran	PB25			18.5	70	5.18	1.9
Blackburn Rd, "Mirrorbrook", Timor Rd, Warrumbungles	PB04		5	16.9	177.4	6.27	1.9
GW969324, New House Bore, "Rockdale", Westport Rd, Pilliga	PB05		70	22	195.9	5.19	1.22
GW038774, Old House Bore, "Rockdale", Westport Rd, Pilliga	PB06	57.44	73	216	200.8	5.41	2.34
GW003587, Far Bore, "Rockdale", Westport Rd, Pilliga	PB07		72.94	23.4	447.2	6.3	1.46
1239 Westport Rd, Pilliga	PB08		70	22.1	192.8	5.58	1.7
Eskdale, Culgoora Rd, Wee Waa	PB10	23.58	60	22.7	735	6.58	2
Eskdale, Culgoora Rd, Wee Waa	PB11	22.96	37.8	21.6	744	6.54	2.05
GW036001.1, Culgoora Rd, Wee Waai	PB22	21.69	32.6	21.3	619	6.55	1.42
GW036001.2,Culgoora Rd, Wee Waa	PB23	22.17	56.6	21.2	366	6.93	1.67
GW030244.1, Pikes Lane, Narrabri	PB12	8.29	23	20.1	242.5	6.97	1.85
GW030230, Pikes Lane/Turrawan Rd, Narrabri	PB13	9.65	21	22.2	918	7.05	1.21
GW030227.1, Pikes Lane/Turrawan Rd, Narrabri	PB14	7.27	18.8	21.3	551	7.37	1.25
GW030227.2, Pikes Lane/Turrawan Rd, Narrabri	PB15	7.33	32	21.3	538	7.49	2.08
GW030308.1, Pikes Lane/Turrawan Rd, Narrabri	PB16	9.34	30.5	21.5	539	6.88	1.8
GW030308.2, Pikes Lane/Turrawan Rd, Narrabri	PB17	9.29	39.6	21.4	547	7	2.02
GW030308.3, Pikes Lane/Turrawan Rd, Narrabri	PB18	9.8	64	21.4	575	6.92	1.9
GW030226.1, Pikes Lane/Turrawan Rd, Narrabri	PB19	11.79	25.6	21.1	543	6.9	2.05
GW030226.2, Pikes Lane/Turrawan Rd, Narrabri	PB20	12.33	32.6	21.1	516	6.78	2.17
GW030226.3, Pikes Lane/Turrawan Rd, Narrabri	PB21	12.32	36.2	21.1	439.5	6.7	1.67

Table 5. Physico-chemical data from each site collected.

4.1.1 Conductivity

Figure 3 compares the salinities between the surveyed sites and between the three aquifers and illustrates that there were three salinity ranges; bores within the Pilliga Sandstones with low salinities averaging 245 µS/cm (70-554 µS/cm), bores within the Quaternary Colluvium with high salinities averaging 616 µS/cm (735-366 µS/cm) and bores within the Namoi Alluvium with moderate to higher salinities averaging 540 µS/cm (242.5-918). The large range in the alluvium is attributed to the distance from a waterway. The low value site of PB12 is very close to a streamway where the high value site of PB13 is a greater distance from a streamway. This distinct separation of the bores based on salinity represents the separation of the bores into differing lithologies... This is particularly important as it also delineates the areas occupied by stygofauna from the areas devoid of fauna. Apart from the outlier, PB1, most stygofauna are present in bores with salinity between 195 and 744 µS/cm within an average value of 491.

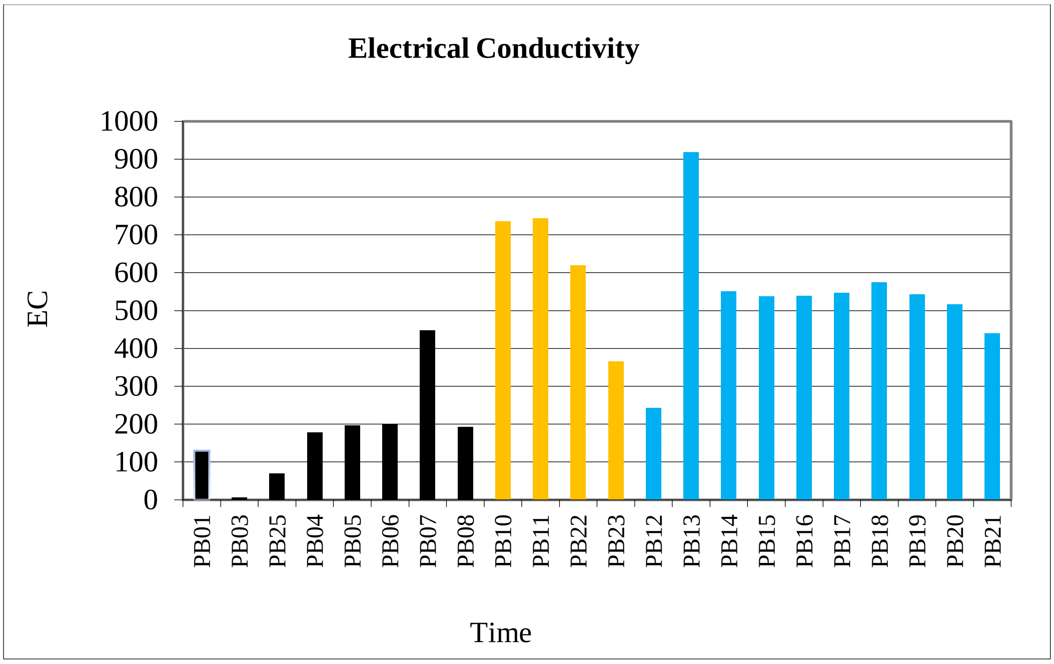


Figure 3. Electrical conductivity of bores within the Study Area.

4.1.2 pH

Figure 4 compares the pH values between the surveyed sites and between the three aquifers and illustrates that there were also three pH ranges; with bores within the Pilliga Sandstones with low pH values averaging 5.69 (4.87-6.73units), bores within the Quaternary Colluvium with higher pH values averaging 665 units (6.55-693 units) and bores within the Namoi Alluvium with near neutral values averaging 7 (6.55-7.49 units). The range is pH sampled insitu (Figure 4) between the sites sampled is small varying from 4.87 at PB01 to 7.49 at PB15. The highest diversity of stygofauna occurs in bores that were essentially neutral. As there has been very little fluctuation of pH throughout the system over time, it is therefore not considered to have any major impact on groundwater biodiversity although the lower values within the southern Pilliga Sandstones aquifer may be influencing the fauna composition that favours the insects and Oligochaetes over the crustaceans. Low pH can inhibit shell formation in crustaceans.

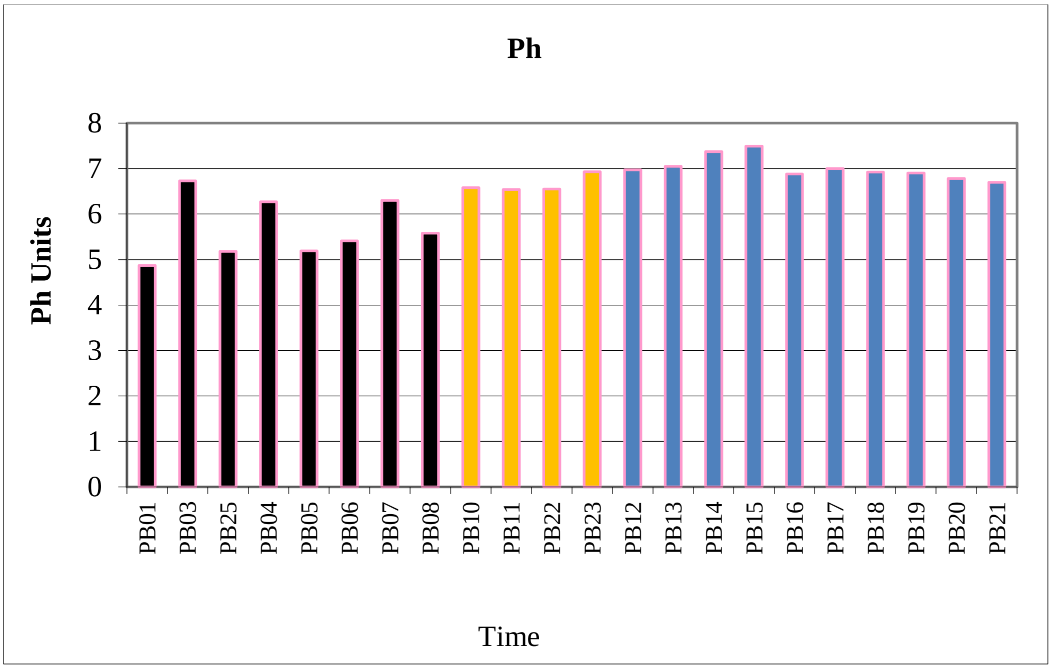


Figure 4. pH of the bores within the Study Area.

4.1.3 Temperature

During the current round of sampling the water temperatures (Figure 5) for the sites were very similar across the Study Area. The values were very consistent throughout the system ranging from 16.9ºC at PB04 to 22.7 ºC at PB10 with all others below 21 ºC. As there has been very little fluctuation of temperature throughout the system, it is therefore not considered to have any major impact on groundwater biodiversity

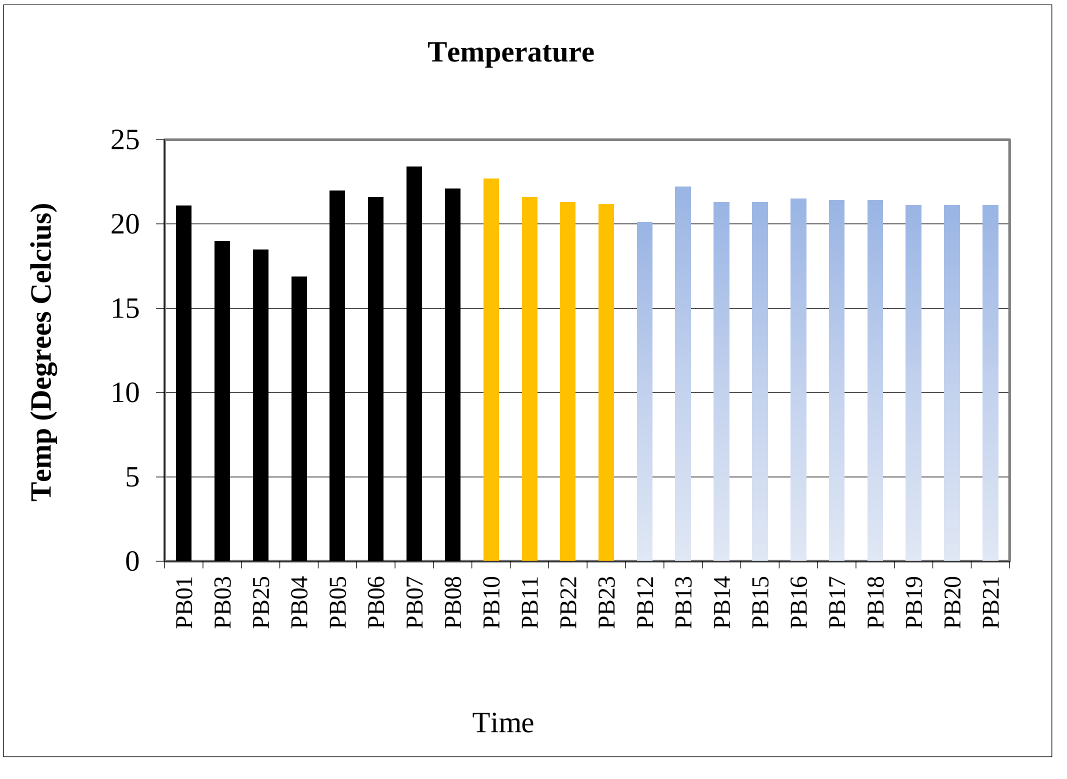


Figure 5. Water temperature of the bores within the Study Area.

4.2 Ecological Response - Stygofauna Data

4.2.1 Community Structure

The survey sampled 22 sites separated into 21 bores and 1 well across the Study area and recorded 14 bores that contained a total of 11 stygofauna species. The full species list is presented below in Table 6. The species list for each site is listed in Table 6 below. The stygofauna were present within each of the three aquifer types with a higher diversity being recorded within the shallower Namoi Alluvium. Stygofauna were collected from bores with total depths of between 6.6-72.9m. The most ecologically productive horizons within the alluvials appear to be in the depth range of 6-32m although there were a number of outliers. The community composition included four orders of crustaceans, one order of mites, Oligochaetes and Nemertea. There were no listed threatened species collected, however, as is the case with most assessments in this emerging field, most if not all species are likely to be new to science and restricted in distribution due to the short range endemic nature of stygofauna species

Most species collected are morphologically specialised, which includes total lack of eyes i.e. blind and unpigmented including the insect order Collembola. Although the species have not been identified to species level as yet, the significant taxa include the Syncarida Family Psammaspididae and Parabathynellidae, the new record of subterranean Oligochaete families Enchytraeidae and Haplotaxidae as well as the microcrustaceans, the Ostracoda and Copepoda. Descriptions of the recorded families are presented below.

The aquifers can be delineated by the fauna present. The Pilliga sandstone is characterised by the presence of the Oligochaete, Acarina and the microcrustaceans, Ostracoda and two orders of the Copepoda. The Quaternary Colluvium is similar to the sandstone with the presence of the Oligochaete, Acarina and the microcrustacean, Copepoda. The Namoi Alluvium is characterised by a richer diversity consisting of all of the above with the addition of Amphipoda and two families of Syncarida.

The depth of bores and therefore the depth of the aquifer also appear to play a significant role of separating the community. The shallower depths between 6 -25m are occupied by the greatest diversity of fauna including the Ostracoda, Copepoda, Psammaspididae Syncarida and the Amphipoda. The Parabathynellidae Syncarida range from 30-39m. The Oligochaeta have the greatest range extending from 6-70m whereas the highest abundance occurs from 32-70m. The deepest fauna collected were the Collembola occurring at 70-72 only. Although the Collembola are regarded as Edaphobites or soil fauna they have been repeatedly collected from only two bores and at depth. Morphologically they have the characteristics of groundwater fauna in being colourless and appearing to be blind. Therefore it is highly likely these species are indeed stygofauna.

Class	Order	Family	Genus	PB01	PB03	PB25	PB04	PB05	PB06	PB07	PB08	PB10	PB11	PB22	PB23	PB12	PB13	PB14	PB15	PB16	PB17	PB18	PB19	PB20	PB21
Annelida	Oligochaeta	Enchytraeidae	*Enchytraeus*		*			*				*	*								*	*	*	*	
Acarina	Prostigmata	Halacaridae	*TBD*					*				*											*	*	
Crustacea	Ostracoda	Candonidae	*TBD*		*	*				*						*		*			*		*		
Crustacea	Copepoda/Cycl	Cyclopidae	*Eucyclops c.f.*			*						*				*		*		*					
Crustacea	Copepoda/Harp	Canthocamptidae	*Canthocamptus c.f.*		*																				
Crustacea	Amphipoda	Neoniphargidae	*Neoniphargus n.sp.*															*	*						
Crustacea	Syncarida	Psammaspididae	*Psammspides n.sp.*													*									
Crustacea	Syncarida	Parabathynellidae	*Notobathynella n.sp.*																	*	*				
Insecta	Collembola	Isotomidae	*Isotomodes c.f*									*													
Insecta	Collembola	Sminthuridae	*Sminthura c.f.*							*															
Nemertea	Anopla	Heteronemertea	*TBD*		*					*															
	Totals No. of Taxa	**11**	**11**	**0**	**3**	2	**0**	**2**	**0**	**3**	**0**	4	1	0	0	3	0	3	1	1	3	1	3	2	0

Table 6. Species List by site

The majority of fauna recorded during the survey were crustaceans and worms. The number of taxa and specimens collected at each site indicates that there is a richer fauna within the alluvial aquifers than in the other aquifers. The commonality of particular taxa indicates a high level of hydrological connectivity within the aquifer and possibly between the aquifers. It is acknowledged within the Santos EIS that the Pilliga sandstone aquifer and the Namoi Alluvium are likely to be hydrologically connected 10-15km to the Northeast of the Pilliga, possibly through unconsolidated sand lenses or fractures. The similarity in fauna may also indicate connectivity through a series of palaeochannels present within the alluvium and colluvium.

The relative consistency of the faunal composition across the bores sampled suggests that the subterranean community diversity is naturally low to moderate with the high potential for biodiversity hotspots that may be comparable with other regions in NSW such as the Peel River in the upper catchment of the Namoi River and certainly comparable with the fauna within the Hunter River. The fauna composition indicates a consistent shallow groundwater system which is directly connected to the river system. The fact that sections of Bohena Creek and the Namoi contain water while other sections are dry indicates a variable gaining/loosing flow situation whereby the groundwater is partly feeding into the river.

There are in fact a number of permanent pools that have been identified along Bohena Creek that have consistent water levels. These pools have recently been found to contain large populations of freshwater mussels, freshwater sponges and large crustaceans such as crayfish and shrimps by the author. These large freshwater mussels and decapod fauna have also been recorded recently by Murphy (2011) and Murphy & Shea (2013). There are no records of the Freshwater Sponges which will likely be new records for this group. These faunas however were not identified at all within the Santos EIS. The significance of the occurrence of the mussels and sponges, in particular, in a waterhole is that as they have very long lifespans that exceeds decades, have no drought tolerance and are unable to migrate or disperse once water levels or water quality declines their presence is indicating that the waterholes must be permanent. In addition, as the mussels and sponges were collected in very shallow depths of only 10-20cm any significant decline in water tables exceeding these levels would leave them exposed and they would perish. Therefore their presence strongly indicates that the groundwater sustains these permanent pool levels and the fauna within them. The same principle would apply to the level of baseflow within the streams and within the aquifer.

The variability of the porosity of the aquifer substrate appears to be one of the significant factors in determining the fauna composition as well as the presence or absence of fauna from bores. The porosity varies from low porosity in the clays and finer alluvial sediment zones and high porosity in the coarser unconsolidated sands sediments close to the river. The relative small size of the phreatic fauna collected is also an indication that the sediments are generally fine in nature.

The fourteen sites that recorded the presence of stygofauna are characterised by the community of obligate groundwater fauna. The significance of each major order is described below.

Syncarida

The Division Syncarida is one of the most common invertebrate groups found in Australian groundwaters. They are an ancient group that branched off from the main stream of the Eumalacostraca or higher Crustacea at a very early period perhaps as far back as the Late Devonian (about 400-380mya), with today's extant taxa still retaining a primitive body structure (Schram, 1984).

Plate 1. Syncarida, Psammaspididae. (©P.Serov 2015).

Plate 2. Syncarida, Parabathynellidae. (©P.Serov 2015).

The current classification of the Syncarida is broken up into: the minute, interstitial Bathynellacea, which have a world-wide distribution and are suggested to be the most primitive; the fossil Palaeocaridacea which were restricted to North America and Europe during the Carboniferous to Permian (approximately 360-250mya) and the Anaspidacea. The Anaspidacea have a distinctly Gondwana distribution from NZ, Australia and South America and include the shrimp like *Anaspides* and *Allanaspides*, found only in Tasmania. The Psammaspididae, known currently from 10 undescribed species in caves in NSW (Eberhard and Spate, 1995) and one described hyporheic species *Psammaspides williamsi* Schminke 1974, in northern NSW (Schminke, 1974) and one in Northern Tasmania.

The syncarids have always been indicators of cool temperate permanently wet habitats as they have no stage in their life cycle that can tolerate desiccation. The syncarid fauna collected from the alluvial aquifer represent the main group of obligate groundwater fauna. All species collected will be undescribed as there have been no described species from this area except for *Psammaspides williamsi* from a subcatchment of the upper Namoi River. The syncarids collected belong to the Family Parabathynellidae were collected from two bores and, the Psammaspididae was collected from the one lower site.

The importance of the discoveries of this obligate groundwater fauna is that they represent relics of a bygone era and give us a glimpse of another time before the browning of Australia, to a time when Australia was covered in lush, wet, rainforest with numerous waterways, alluviums and deltas. The fact the groundwater habitats have served as refuges and centres of speciation in fluctuating environments of generally increasing and spreading aridity, particularly in the Pleistocene, provides tools for studying the past history of particular taxa. The syncarids are one of these groups. They have a wide distribution at the family and generic level but appear to be highly restricted at the species level as they can only disperse through hydrologic pathways due to their inability to withstand any degree of desiccation in any stage of their life cycle and have narrow environmental requirements. In effect they represent biological time capsules and are very useful as bioindicators (Serov, 2002).

Amphipoda

Within eastern Australia, Amphipoda (followed closely by Syncarida), are the dominant and most widespread of the stygofauna (Thurgate *et al.*, (2001)). They are common in karsts in NSW and Tasmania and are the only described stygofauna so far from North Queensland (Thurgate *et al.*, (2001)). The two main families in eastern Australia and NSW are the Paramelitidae and Neoniphargidae. The highest diversity of Amphipoda in Eastern Australia belongs to the Paramelitidae, which includes 35 stygobite species from eight genera, however, the vast majority of these species occur in Tasmania. The Neoniphargidae, however, is the most diverse family in NSW with 87% of stygal species being restricted to the karsts of NSW, where most species are restricted to a single karst (Thurgate *et al.*, (2001)). These figures will also be reflected within alluvial aquifers.

Plate 3. Amphipoda, Neoniphargidae n. sp. (©P.Serov 2015)

Ostracoda

Ostracods are present in all groundwater habitats from fractured rock aquifers, to karst and alluvial aquifer systems, as well as in hyporheic and parafluvial habitats within rivers.

Research indicates that species have quite distinct distributions and, apparently, habitat preferences, with highest biodiversity adjacent to rivers and lower diversity in alluvial aquifers more distant from surface rivers (Ward et al. 1994). Other studies indicate that proximity to running water rich in organic matter is important (Rouche & Danielopol 1997). Their distributions are more complicated than simple proximity to rivers or concentration of organic content. There appear to be few meaningful correlations between ostracod abundances and individual physical factors (organic content, alkalinity, calcium, oxygen concentration). Instead, differences in habitat stability in terms of complexes of physico-chemical factors (e.g., water temperature and organic content) and the upwelling or downwelling nature of interstitial flows seem important, with some taxa more common in variable habitats and others more abundant where conditions are more constant (Ward & Palmer 1994).

The seven bore sites characterised by the presence of the Candonidae Ostracoda (Seed Shrimp) indicate connectivity between these sites as these fauna can only disperse via hydrological connectivity. Further examination of these taxa is necessary to determine if these represent one species or more separate, short range endemic species. This will also be the case for the other fauna as well.

Plate 4. Ostracoda, Candonidae. (©P.Serov 2015)

Copepoda

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

The Copepoda Cyclopidae is normally associated with fine to course sandy substrates of still water environments of rivers, wetlands, the hyporheic zone and shallow groundwaters. Although they are a ubiquitous component of these habitats, their small size means that they are often overlooked and undercounted. In terms of management, therefore, they are potentially very useful bioindicators, particularly of base flow fed streams or alluvial aquifers or flow through wetlands, as they are sensitive to changes in the environment (Tomlinson & Boulton, 2008). The Cyclopidae were collected at five sites and in each of the three aquifers. The conductivity levels however vary considerably from low to high suggesting that the fauna is either very tolerant of salinity changes or composed of different taxa. It is suggested that fauna is composed of different species with differing salinity tolerance ranges.

Oligochaeta

In Australasia, the Oligochaeta are represented in freshwaters by the families Haplotaxidae, Aeolosomatidae, Lumbriculidae, Phreodrilidae, Naididae, and Tubificidae (Brinkhurst 1971). The obligate groundwater fauna is characterised by the two Oligochaete Families, the Enchytraeidae and Naididae. The Enchytraeidae are a small family of aquatic worms that are poorly known although they have been found in freshwater environments in Victoria, NSW and recently in groundwaters in Queensland. They are a poorly known group that requires further taxonomic work (Pinder & Brinkhurst, 1994). In terms of their use within current environmental sensitivity indices such as the SIGNAL Index ranking, they can only be assessed at the Order level of Oligochaeta which has a ranking of 2. This equates to a family which is quite tolerant of environmental disturbance. This, however, is misleading as the family is usually associated with high water quality environments.

In a review of the stygobitic oligochaete fauna of the world, Juget & Dumnicka (1986) noted 66 species in seven families (Aeolosomatidae, Potamodrilidae, Haplotaxidae, Lumbriculidae, Dorydrilidae, Tubificidae, and Enchytraeidae). More recently, Giani et al. (2001) reported 57 species that can be classified as stygobites in southern Europe alone, suggesting the global diversity far exceeds initial estimates (e.g., Juget & Dumnicka 1936). Indeed, Giani et al. (2001) estimated that, when records from other areas of the world (e.g., North America, Africa, Europe) are added, a total of 96 stygobitic freshwater oligochaetes are known in the world (they excluded Australasia from their estimate for some reason). It should be noted that it is often difficult to make a clear separation between stygobitic and stygophilic oligochaetes. For example, the features that distinguish stygobitic crustaceans from epigean forms, such as absence of eyes, lack of pigmentation, and elongation of body, do not distinguish between stygobitic and epigean oligochaetes. Giani et al. (2001) noted that very few species of Naididae are stygobites.

The presence of Oligochaete worms in eight of the fourteen bores recorded indicates that the water quality is characterised by elevated organic carbon, and possibly high levels of dissolved iron. The relatively small size (1-3mm) of the Oligochaete (worm) species present indicates a low to moderate hydraulic connectivity within the river/aquifer environment. The shallow water table levels within the alluvial phreatic zone and the presence of the two families of worms suggests a direct association/connectivity with a slow base flow river system with a shallow alluvial aquifer. There is very little known about the diversity and distribution of freshwater Oligochaeta, therefore the identification can only be given to the family level. Subterranean Oligochaetes are an increasingly 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, particularly in the southwest and eastern seaboards.

Acarina (Water mites)

The other species of stygofauna collected from one site (P111) belongs to the Acarina or water mites. There is at least one species of water mite present belonging to the Family Halacaridae. Although subterranean water mites are classed as phreatobites they have their highest biodiversity within the riverine, hyporheic zones and are also classed as members of the “permanent hyporheos or the community that occurs within the deep sand and gravel beds associated with areas of groundwater discharge (Gilbert, 1994). They typically characterize the transition zone between the temporary or shallow hyporheic ecozone and the groundwater hypogean environment. *(Boulton* & *Hancock, 2006,* Gilbert, 1994, Humphreys. 2006, Serov, *et al*, 2011.). It is therefore not unusual to find this group within the shallow phreatic zone (groundwater). It is another indication that the Pilliga Sandstone aquifer is or has been connected to surface water sources as a discharge source where the discharge can be either point source springs or diffuse discharge through a moderate to course grained substrate such as sand or gravels (Gilbert, 1994). The presence of these species/groups within the phreatic or shallow groundwater zone is therefore a direct indicator of groundwater connectivity between the local river systems and shallow unconfined aquifers.

Plate 5. Acarina or water mites. (©P.Serov 2015)

Collembola

The dominant group collected belonged to the primitive Families Isotomidae and Sminthuridae. These are large families of Collembola, with all subfamilies occurring in Australia. They are common in leaf litter. They are typically detrital or fungal feeders associated with the ground litter layer and tree bark. Their presence in the samples is most likely coincidental either by falling in or occupying the vegetation adjacent to the bore or living within the bore above the water table, as they have a preference for humid environments. As they are terrestrial soil and leaf litter fauna and not associated with groundwater environments, no further description will be given. It is however possible as mentioned earlier that they could be stygofauna. Their presence in only a small number of bores at depth while exhibiting modified morphological characteristics (i.e. reduced pigmentation and appearing to be blind) as well as the specimens being alive when collected (no degradation of the bodies) does firmly suggest they are phreatobites rather than stygoxenes. Further work will be needed to confirm this.

5.0 Ecological Value and Risk Assessment

The assessment of the ecological value and risk value the stygofauna community at each of the sites surveyed as well as an overall assessment of the shallow aquifers that supply the water to the identified GDEs is presented below. The ecological value and risk value assessment undertaken for the Project was based on current data which is a snapshot of the current condition of the subterranean environments as of 2016. The valuation recorded in tables 7 and 8 of both high ecological value and high ecological risk registers a Class C within the Risk Matrix.

An overall value and risk assessment was conducted by focusing on the shallow aquifers of the Study Area as a whole in order to place the sites into a landscape perspective and to demonstrate the condition and ecosystem function performed by these aquifers. The results of this assessment demonstrated that currently the aquifers in general are in very good condition in regards to water levels, water quality, as well as supporting a range of GDE types.

The sites that registered stygofauna were assessed as having high ecological value due to importance of the fauna and the high water quality and consistent water levels within the aquifer. They are also classified as of High Ecological Value (HEV) as the area is covered by the Lowland Darling aquatic EEC listed under the Fisheries Management Act. This does not seem to have been included in either the surface aquatic ecosystem assessment or the GDE assessments by the Santos EIS. Within the NSW Office of Water GDE Risk Assessment Guidelines (2012) the first stage of assigning ecological value asks if the GDE occurs within a recognised area of high ecological value and if it is then all GDE's that occur there are automatically assigned as HEV - High Ecological Value. Therefore all GDE's listed within the Pilliga are of High Ecological Value. In addition the Pilliga area and its waterways have been acknowledged recently by the CSIRO (November 2016) in the 'Namoi Bioregional Assessments' to be a unique and separate ecosystem within the region due to its quite unique geomorphology. The "Upland Riverine Landscape Class in the Pillaga region" was addressed with a separate modelling exercise due to streams in this region having a unique set of conditions. These streams were characterized as having sandy beds, temporary flow with some permanent pools above highly stratified sandstone. Therefore the streams and aquatic biodiversity cannot be compared with the surrounding region. For this reason alone these aquatic ecosystems should be recorded as having high ecological value. These sites and aquifers also have intact groundwater habitat, the presence of indicator species and potentially endemic stygofauna within the aquifer, as well as ecosystem services the aquifer provides as a water purifier and via the seepage of groundwater from the unconfined alluvial aquifers into baseflows and the riparian and terrestrial vegetation communities associated with the alluvium.

Those bores that did not contain fauna were not assessed as they typically contained similar water quality to the bores that recorded fauna. The reason for the fauna absence is most likely to involve the substrate porosity that precluded the migration of fauna. These sites recorded a high ecological value compared with the other sites due to the higher water quality. The Study Area recorded an overall high to moderate risk value for the ecological risk assessment for those sites that recorded stygofauna, as there was a high to moderate potential for impact from the Santos proposed CSG development as a result of the modelled drawdown levels as well as the potential for aquifer contamination via inter-aquifer connectivity, and the disposal of waste water in the Bohena Creek. This risk value also recognizes that the stygofauna populations are sensitive to changes in water chemistry.

In summary, in terms of the stygofauna community across the Study Area, the following points are noted:

- ❑ A moderate to high diversity of subterranean ecosystems exist in the shallow, unconfined alluvial aquifers of the Namoi Alluvium and the Quaternary Colluvium as well as the Fracture Rock aquifer of the Pilliga Sandstone. None of these species are currently **listed** as endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under the TSC Act, FM Act or the Commonwealth EPBC Act. They do however have a very high potential to be short range endemic, relictual and rare species.
- ❑ The ecological values of the sites that contain stygofauna are classified as high within the NSW Office of Water GDE Risk Assessment Guidelines (2012) due to the presence of the fauna as well as the high ecological condition of the aquifers and occurring within the area the Lowland Darling aquatic EEC listed under the Fisheries Management Act.

- In addition the CSIRO Namoi Bioregional Assessments (November 2016) 'describes the streams of the Pilliga "to be a unique and separate ecosystem within the region due to its quite unique geomorphology".
- The presence of the same or similar species in all aquifer types indicate a direct connectivity between the shallow alluvial aquifers and the aquifers in the underlying sandstones.
- The risk of the proposed development to these subterranean ecosystems was rated as high based on the modelled drawdown and the proposed water quality changes to Bohena Creek as the fauna is indicating a direct connection between surface and groundwater sources.
- There was insufficient long term data to determine whether past land use practices have impacted aquifers and associated GDEs however as the fauna and water quality were relatively consistent across the Pilliga it is a strong indication that the aquifers were in good condition. As a result, the confidence of the overall risk assessment is moderate to high.

Another issue that has not previously been discussed is the risk of the proposed extensive CSG development to the Great Artesian Basin. The Pilliga Forest area and in particular the area delegated for the Santos CSG development is situated on the recharge zone of the Great Artesian Basin via the Pilliga Sandstone Aquifer. It must be seriously considered that any impact on the groundwater quantity and water quality of the receiving waters of the GAB would have significant intergenerational impacts to the dependent human community and the highly sensitive and significant groundwater dependent ecological communities in northwestern NSW such as the Mound Springs of Western NSW, southern Queensland and North Eastern South Australia. Due to the slow movement of water through the GAB these impacts would take 10s to 100s of years to be detected, would be impossible to remediate and would affect many future generations reliant on the quantity and quality of this groundwater for stock, domestic and agricultural uses. It is suggested here that all GAB recharge areas should be given a protection status equivalent to 'National Parks and Wilderness Reserves' that would ban aquifer interfering developments such as coal and CSG in these areas in order to protect the groundwater of the GAB from the high likelihood of contamination from Coal and CSG mining.

6.0 Management

This baseline stygofauna assessment has identified the presence of subterranean fauna within the shallow alluvial, colluvial and Pilliga Sandstone aquifers in the Study Area. Since the numbers of animals and diversity was moderate to high they indicate good water quality and a strong connectivity between the river and groundwater system (Serov et al. 2012.). The broad distribution of the stygobitic fauna recorded would strongly suggest that there is strong connectivity within and between the Fractured Rock aquifer and alluvial aquifers and the associated streams. The fauna should be considered however as short range endemics (SREs) species that is associated with this area. From a management perspective stygobites (phreatobites) usually face a higher risk of extinction than other invertebrate communities as they live only in small geographical areas and typically have narrow physiological tolerance ranges.

The risk assessment presented in Tables 7and 8 identified the overall Study Area to have a Class C risk ranking (High Ecological Value and High Ecological Risk) for the current ecological conditions and the risk from the current and proposed development. As this community is of 'High Ecological value' they should also be classified as 'High Priority GDE's' under the NSW GDE Policy 2002 and as described within the. Risk assessment guidelines for groundwater dependent ecosystems Serov et al, 2012. This Class stipulates that "Protection measures are required for the aquifer and GDEs" and "Baseline Risk monitoring" is required over the life of the development. This also indicates that the ecological values of the aquifers and the stygofauna community where present in the Study Area are high, however the potential for detrimental impacts from the current and proposed developments is also high. The current controls to manage GDEs are largely vested in the legislative controls of the *Water Management Act 2000*. A requirement of Water Sharing Plans (WSPs) is to monitor plan performance using a standard set of performance indicators as set out by the *Water Management Act 2000*. There are five main types of relevant rules which operate to protect GDEs in NSW WSPs, which are summarised as follows:

Distance Rules

- Rules for water supply works located near sensitive environmental areas. This rule specifies the distance restriction for new bores from high priority GDEs, karsts (Karst Rule), escarpments (Scarp Rule) and rivers. This rule is designed to minimise the impacts of extraction on these environments.
- Rules for the use of water supply works located within restricted distances. This rule specifies the maximum amount of water that may be taken on a yearly basis from existing water supply works that are located within the restricted distance from a high priority GDE, karst, escarpment or river. This rule is designed to minimise the impacts of extraction on these systems.

Drawdown Rule:

- Drawdown rules apply to minimise the negative effects of extraction on water levels. No drawdown is permitted to occur at the outside edge of the perimeter of any high priority GDE listed in the WSP. This rule is designed to minimise the impacts of extraction on high priority GDEs.

Cease to Pump Rule:

- Base flows in streams are protected by cease to pump rules. Most licensed users are required to cease pumping when there are no visible flows in the river or when flows are less than the 95^{th} percentile.

Dealing (trading) Rules:

- Dealing (trading) rules are intended to promote trade of entitlement, including for new development, while minimising environmental impacts. Ideally, dealing arrangements result in environmental improvement rather than harm, for example, by avoiding the concentration of extraction in a particular area. In most groundwater sources covered by macro plans, trade is allowed within a groundwater source but not into or out of the groundwater source. This recognises that groundwater sources as defined in WSPs represent discreet aquifer systems.

Local Impact Rules:

- All macro groundwater sharing plans include local impact management rules. These rules are intended to ensure that water levels in a groundwater source are not depleted detrimentally, beyond seasonal variations. Water quality can also decline as a resulting of excessive extraction. All the macro groundwater sharing plans include local impact management rules to manage water quality across a groundwater source. Water quality changes resulting from extraction are to be managed consistently with the designated category.

6.1. Cumulative and Flow-on Impacts

Cumulative effects may result from a number of activities interacting with the environment. The nature and scale of these effects can vary depending on factors such as the type of activity performed, the proximity of activities to each other and the characteristics of the surrounding natural, social and economic environments. They may also be caused by the synergistic and antagonistic effects of different individual activities, as well as the temporal or spatial characteristics of the activities. Importantly, cumulative effects are not necessarily just additive. The implication of multiple mining actives in one region, as proposed within the Study Area i.e. 850 CSG wells, is that impacts may overlap and result in larger impacts than would be expected for a single mining operation (cumulative effects).

Another type of impact that appears not to have been discussed in the Santos EIS is the Flow-on impacts. In addition to cumulative impact the flow-on impact occurs downstream along the flow paths for groundwater and surface waters. All waters flow dispersing both contaminants and depressions in groundwater levels as plumes. The groundwater and surface waters originating in the Pilliga and the area of development will transport any contamination and drawdown impacts along a flow path to the north and northwest of the Pilliga. Therefore the area of highest risk of flow-on impacts is the lands, streams and groundwater sources to the north and northwest of the Pilliga. This area therefore should have a high priority for monitoring.

6.2. Suggested Management Actions

Further work suggested for future stygofauna monitoring includes:

- ❑ The stygofauna and the other GDE's within the Pilliga should be nominated as High Conservation Value GDE's and High Priority GDE's under NSW Office of Water GDE valuation process and given the appropriate protections and management regimes of this grading
- ❑ Identify stygofauna to species (particularly those listed as phreatobites) to determine levels of endemicity of the stygofauna community within each aquifer, particularly between the community within the Namoi River. The determination of whether these populations contain the same species or are isolated, separate species is an important consideration particularly as stygofauna are known to be highly localised and endemic with several species often occurring in the same aquifer.
- ❑ Continue surveying bores across the Pilliga in order to refine the findings of this report and to create a higher resolution distribution map of the stygofauna community.
- ❑ Conduct annual biodiversity surveys in line with monthly water quality monitoring program to monitor potential changes/impacts to the stygofauna community;
- ❑ Continue ongoing monthly monitoring of water levels, and water chemistry, with the addition of water temperature.

7.0. Conclusions

The baseline sampling and assessment of the groundwater ecosystems that exist in the Study Area has demonstrated that:

- ❑ Stygofauna were present within all three major aquifers across the Pilliga;
- ❑ The biodiversity of the stygofauna community within the Pilliga Sandstone is moderate while the diversity within the shallow alluvial aquifers is higher with hotspots of biodiversity which will have a high degree of endemism.
- ❑ Stygofauna were present within the groundwater drawdown zone of the Project (i.e. the impact zone) and within both the surface water and groundwater flow path of any contamination event downstream of the development as well as outside the impact zone of the Project i.e. the control sites;
- ❑ There is an apparent connectivity within and between aquifers and the associated watercourses;
- ❑ There are new species of stygofauna present within the aquifers of the Pilliga:
- ❑ There are a number of vulnerable surface water macroinvertebrate species that will be impacted by the proposed levels of drawdown including a rich crustacean diversity that is much higher than the surrounding region, two species of mussels with one that occurs at the south edge of its range, and a freshwater sponge community and its associated fauna;
- ❑ The ecological value of the stygofauna community GDE is classed as high;
- ❑ The ecological risk from the Santos CSG development is classed as high with the main risk being from contamination of the groundwaters;
- ❑ The ecological value of the permanent waterholes and the baseflow stream is considered high with the main risk to ecological condition and species diversity is drawdown and contamination by the discharge of treated CSG waste water:
- ❑ There is an intergenerational risk to the water quality of the Great Artesian Basin Groundwater Source due to the location of the development occurring within its recharge zone
- ❑ The groundwater fauna of the hypogean (groundwater) environments/sites are quite rich as result of the
    - Water chemistry, i.e. low levels of salinity, mildly acidic to neutral pH levels ranging from approximately 5-7.5 pH units; and
    - Fine to moderate grained nature of the geology and sediments;

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Appendix 1 - Risk Assessment Tables

Locality	**Pilliga Bores (PB03 PB14 PB12 PB19 PB16 PB15 PB20 PB11 PB17 PB10 PB18 PB05 PB07)**			
GDE ENVIRONMENT	**High**	**Moderate**	**Low**	**Comments**
GDE or part thereof occurs or is reserved in National Estates, listed wetlands, SEPP 26 etc.	Yes			Pilliga State Forest, Upper Murray/ Darling Basin EEC
Presence of exotic flora or fauna within GDE	None exist			
Removal or alteration of GDE type or subtype	No detectable change in physical structure, species composition or size in GDE type or subtype.			
AQUIFER				
Water quantity parameters	**High**	**Moderate**	**Low**	**Comments**
Alteration of the frequency and/or magnitude and/or timing of watertable level fluctuations.	No detectable change from natural seasonal variation.			
Alteration to direction of hydraulic gradients	No detectable change from natural seasonal variation.			
Alteration of base flow conditions	No detectable change from natural seasonal variation.			
Water quality parameters	**High**	**Moderate**	**Low**	**Comments**
Degree of acid runoff or acidification of groundwater source.	No detectable change from natural seasonal variation.			
Degree of nutrient load.	No detectable change from natural seasonal variation.			
Degree of groundwater salinity.	No detectable change from natural seasonal variation.			

Degree of bioaccumulation i.e. heavy metal contamination	No detectable change from natural seasonal variation.			
Aquifer structure	**High**	**Moderate**	**Low**	**Comme nts**
Degree of alteration of aquifer structure (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction, compaction of aquifer, etc.).	No detectable change in aquifer structure			
BIODIVERSITY				
Rarity within catchment/groundwater source	**High**	**Moderate**	**Low**	**Comme nts**
Presence of Threatened, Rare, Vulnerable or Endangered species, population or ecological community within GDE.	Yes			
Presence of indicator, keystone, flagship, endemic or significant species, populations or communities within GDE ***	Yes			
Patch size rank of GDE relative to other patches of the same GDE type/subtype (as appropriate)	>50			
Patch size % of GDE relative to original/historic extent	>50%			
Diversity within catchment/groundwater source	**High**	**Moderate**	**Low**	**Comme nts**
Diversity of groundwater dependent native flora and fauna species within a GDE.	Presence of 5 or more species or >80% number of species relative to a reference site			
SPECIAL FEATURES WITHIN CATCHMENT/GROUNDWATER SOURCE	**High**	**Moderate**	**Low**	**Comme nts**

Presence of rare physical/physico-chemical features or environments (e.g. karsts, mound springs, natural saline wetlands, peat swamps etc.)	Occurs only within the aquifer	\		There are recognised springs and permanent waterholes associated with each of the three aquifer types.
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation through aquifer connectivity	Unconfined aquifer with connection to terrestrial and aquatic ecosystems.			
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation relating to aquifer structure and porosity	Unconsolidated aquifer with connection to terrestrial and aquatic ecosystems.	Fractured Rock/semi-consolidated aquifer connected to terrestrial and aquatic ecosystems.	Consolidated aquifer connected to terrestrial and aquatic ecosystems	All three options appear to be present.
TOTAL NUMBER OF ATTRIBUTES	**19**	1	1	
OVERALL VALUE	High			
COMMENTS	All three aquifer types have recorded the presence of a stygofauna community in this round of surveys and the sites that had previously recorded fauna have also remained stable in terms of fauna present, water levels, pH and salinity. The presence of stygofauna both upstream and downstream of Santos development is a strong indication that the aquifer environment has been stable and is in good ecological condition over time. Therefore the high ecological value is justified.			

Table 7. Overall ecological value assessment for Study Area.

Locality	**Pilliga Bores (PB03 PB14 PB12 PB19 PB16 PB15 PB20 PB11 PB17 PB10 PB18 PB05 PB07)**			
Water Quantity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What will be the risk of a change in groundwater levels/pressure on GDEs?	Reduction in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in permanent loss or alteration of defined habitat type.			
What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?			No change in timing of water level fluctuations.	

What will be the risk of changing base flow conditions on GDEs?			No change in direction of flow.	
Water Quality Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of changing the chemical conditions of the groundwater source?	Permanent change (e.g. in pH, DO, nutrients, temperature and/or turbidity)			
What is the risk on the groundwater source by a change in the freshwater/salt water interface?	Permanent change in location or gradient of salt/freshwater interface			
What is the likelihood of a change in beneficial use (BU) of the groundwater source?		Reduction in water quality within designated BU category (for identified trigger parameters)		
Aquifer Integrity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of damage to the geologic structure?		Temporary adjustment to the aquifer matrix. Minor cracking/fracturing of the bedrock/stream bed leading to partial dewatering of the GDE		
Biological Integrity Asset	**High**	**Moderate**	**Low**	**Insufficient data or unknown**
What is the risk of alterations to the number of native species within the groundwater dependent communities (fauna and flora)?	>10% reduction in No. of species.			
What is the risk of alterations to the species composition of the groundwater dependent communities (fauna and flora)?	>10% change in species composition.			
What is the risk of increasing the presence of exotic flora or fauna?			None exist.	
What is the risk of removing or altering a GDE subtype habitat (e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction)?			No removal or alteration of habitat.	
Risk Valuation	5	2	4	

Risk	The risks identified with the proposed Santos CSG development are high in terms of the potential impacts on the identified stygofauna community as a result of drawdown, changes in salinity within Bohena Creek and the potential for contamination of aquifers through either cross aquifer contamination or via direct contamination of waste water spillage. It is acknowledged that there are a number of low impact attributes listed above however as stygofauna are sensitive to changes in water chemistry and the other GDE aquatic fauna within the baseflow waterways across the Pilliga and the Namoi River downstream of the development are sensitive to water level changes through long-term drawdown it is predicted that the impacts will have permanent effects. The ecological risk of the Santos CSG development on the subterranean communities is considered to be high in terms of water chemistry change.

Table 9. Overall risk assessment for the Study Area

APPENDIX 2
Brief Curriculum Vitae of Author

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FIELD OF EXPERTISE

Peter is an Aquatic Ecologist, and Invertebrate Taxonomist who has worked in a range of environments including surface aquatic ecosystems (Rivers, Wetlands), groundwater ecosystems, marine, and terrestrial ecosystems for over 30 years. He specialises in the identification of aquatic macroinvertebrates and stygofauna (groundwater fauna) with a particular interest in the ecological condition assessments and management of Aquatic Ecosystems including rivers, wetlands and Groundwater Dependent Ecosystems. Peter has been a significant contributor in the early development of the NSW Sharing Plans process and recognition of Groundwater Dependent Ecosystems (GDE's) in NSW government. He has been intrinsically involved in the development and implementation of NSW legislation involving High Conservation Value Rivers (HCV) Groundwater Dependent Ecosystems including actioning the NSW GDE Policy by developing and being the principle author of the NSW GDE Risk Assessment Guidelines (2012). As a private consultant Peter has been involved in the assessment, reporting and review of aquatic ecology for both groundwater and surface water components of a number of State Significant Projects in NSW and Queensland.

ACADEMIC QUALIFICATIONS

1986 - Bachelor of Science. Majoring in biology and geology at the University of Wollongong.
1988 - Bachelor of Science. Honours at the University of Tasmania.
2014 - PhD, the University of New England.

PUBLICATIONS,

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