**From:** Andrea Broughton [redacted]
**Sent:** Sunday, 30 April 2017 7:41 PM
**To:** fracking inquiry
**Subject:** Preliminary submission
**Attachments:** Submission re Santos CSG Pilliga.docx; GSI Recommendations to Federal Environment Department.docx; GSI Submission to Senate Select Committee.docx

To whom it may concern

I am a Principal & Hydrogeologist for Groundwater Solutions International. I actively follow the unconventional gas industry in Australia and NZ (coal seam gas, coal gasification and shale gas) providing submissions to State and Federal departments since 2006 on behalf of clients. Unconventional gas projects I have reviewed and provided submissions on include Santos (Eastern) Pty Ltd Narrabri Gas Project (NSW) and the Lazarus Senate Select Committee on Unconventional Gas Mining (Queensland). I also served on a panel of experts for the NSW Law and Science Forum held at NSW Parliament in 25 March 2014.

I recently read the following ABC report aired on 7 April 2017 on Origin Energy's proposed shale gas project drilling 400-500, 2-3km deep wells in Northern Territory's Beetaloo Basin:

http://www.abc.net.au/news/2017-04-06/nt-fracking-ban-proving-polarising-for-remote-farmers/8417442

I was particularly concerned with the following comments made by Origin Energy's chief geologist and unconventional exploration manager David Close:

"We risk assess. We design. We expect that this will have integrity for the life required of the well, similar to the rock formations around them."

This comment has been made by other unconventional gas proponents and this concerns me. David Close forgets the aquifer and rock formation is in natural equilibrium. A process that has taken millions of years. Steel well casing and concrete grout is not in equilibrium with the aquifer, and its integrity is not equivalent to the rock formations surrounding it. The wells will degrade with time, and possibly with serious consequences.

"Mr Close said Origin would insure farmers against environmental damage for the life of projects and their remediation, but the NT Government will have to decide what happens after that."

So 'life' is an economic term and the money the NT government will earn from the Beetaloo Basin Shale Gas Field may well have to be used to compensate farmers when the ex-shale gas wells' integrity fails decades from now. A big red flag flying here for the NT government.

I am interested in seeing how this progresses and may be interested in putting in a full submission. If you could please advise me if there is any way I can help with the NT Fracking Inquiry? I have attached my CV for your information and a few reports I have written to give you an idea of the sort of work that I do.

All the best.

Kind regards,
Andrea Broughton

**GROUNDWATER SOLUTIONS INTERNATIONAL**

115 Tasman Street, Mt Cook,

Wellington 6021

New Zealand

28 November 2014

Mahani Taylor

Director, New South Wales/ACT Assessment Section

**Department of the Environment**

GPO Box 787, Canberra, ACT, 2601

Australia

Dear Mahani

Santos is required to protect the Environment while supporting the NSW government's goals for CSG supply for the domestic and international market.

In order to achieve this, high quality numerical groundwater modelling is required. A groundwater numerical model is one of many tools that are used to make decisions regarding environmental matters. However, in CSG it has become the main tool which the NSW government uses to make important decisions. The groundwater model also forms the basis for other decision-making tools. The groundwater numerical model needs to be high quality, reliable and representative of the hydrogeological environment. This requires high quality data that takes time to gather.

Regarding Santos' Narrabri Gas Field I would like to put forward my recommendations for what the Commonwealth Assessment Guidelines should include, based on my experience of the hydrogeology of the area. These are outlined below:

**Field Data and Analyses**

*Overall a higher quality database (baseline and monitoring) is required including detailed aquifer field assessments.* Santos has already begun implementing their Groundwater Monitoring Bore Network program, with the guidance of NSW Office of Water. Given the uncertainties to date regarding the characterisation and interrelationships of the shallow and deep groundwater systems, I would suggest Santos undertakes at least the following baseline studies:

1. Full chemistry (including methane), isotopic and physical characteristics (including downhole wireline logging) for each of the following hydrostratigraphic units:

   a. Quaternary Bohena Alluvial Unconsolidated Aquifer
   b. Jurassic Keelindi Bed (Orallo Formation) leaky aquitard
   c. Jurassic Pilliga Sandstone consolidated aquifer (Recharge Beds)
   d. Jurassic Purlawaugh Bed aquitard
   e. Late Triassic-Early Jurassic Garawilla Volcanic fractured rock aquifer
   f. Triassic Deriah formation
   g. Triassic Napperby formation
   h. Triassic Digby Formation leaky aquitard
2. Step drawdown, constant rate (or head) pump tests (3 days minimum plus recovery) to determine good hydraulic parameters (including leakage factors in the lower transmissivity aquitards). This information is essential in developing a sound Conceptual Groundwater Model.
3. Groundwater level trends versus climatic variations (especially for drought conditions).
4. A detailed Water Balance using actual real data collected to determine all sources of groundwater recharge, abstraction and discharge from the Narrabri Gas Field project.
5. Determining the connectivity of the ephemeral Bohena Creek with Bohena Alluvial unconsolidated aquifer, the Keelindi Bed leaky aquitard, and the Pilliga Sandstone consolidated aquifer.

**Well Integrity and Compliance Monitoring**

I have read through the NSW Code of Practice for CSG Wells and it is thorough. However, it is only good if the driller and his team complies with them. The only way to ensure this is for the government to show a firm commitment to active compliance monitoring.

I have also been advised by OCSG they will not be requiring a Hydrogeologist to be present on site. They will have a Petroleum Engineer who can call on a Hydrogeologist if required. In my experience this does not always happen when needed.

My concern is mainly for the first 300m of drilling, i.e. the Shallow Groundwater System consisting of the:

- Quaternary Alluvial unconsolidated aquifer
- Jurassic Pilliga Sandstone consolidated aquifer of the Surat Basin
- Protecting aquitards, the Keelindi and Purlawaugh Beds.

Is there a possibility there could be a guideline requiring an experienced Field Hydrogeologist to be onsite during drilling?

I have spoken to another Hydrogeologist from a Petroleum company drilling CSG wells in Queensland and they were surprised that no Field Hydrogeologist would be onsite during drilling as their expertise is greater than Petroleum Engineers when it comes to deciphering hydrostratigraphic information during drilling. Petroleum Engineers are generally interested in getting to the CSG target beds as quickly and effectively as possible. The Narrabri shallow groundwater system (Alluvial and Pilliga sandstone plus important aquitards) may not be given enough consideration during drilling to effectively protect them.

**Well Completion Reporting**

Santos has six months to report well completion logs to the NSW Office for Coal Seam Gas. This is too long if there is a problem found regarding improper placing of casing and seals.

In this day and age of high level ability to digitally communicate technical information I do not see why Santos can't get this info to OCSG within a week or two. My main concern is ensuring the correct emplacement of casing and the sealing off of the alluvial aquifer and Pilliga sandstone aquifer from each other, and from Triassic and Permian hydrostratigraphic units (including the coal measures).

**Conceptual Groundwater Model**

Santos should develop further or confirm, the existing Narrabri Gas Field Groundwater Conceptual Model by using actual data from the recent drilling activities. Including updated detailed geological maps and cross-sections, hydraulic parameters garnered from downhole wireline logging and pump tests as mentioned above.

**Numerical Groundwater Model**

The numerical groundwater model should include at least two years of high quality groundwater, collected from monitoring bores in the shallow and deep groundwater systems, to allow meaningful calibration for Steady State conditions.

**Cumulative Impact Modelling**

If Santos is looking to explore in other areas of the NSW GAB Recharge Beds then it is critical for the cumulative impacts to be modelled to a high level now.

**Model Peer Review**

The Peer Reviewer (Dr Franz Kalf) has only audited information contained in the Groundwater Modelling Report. It is apparent from his Peer Reviewer's Checklist he has not had access to the Numerical Model data files to ensure these are satisfactory.

The Numerical Model Data Files should be included in the Peer Review/Audit.

Kind regards,

Andrea Broughton

Independent Hydrogeologist

Groundwater Solutions International

Groundwater Solutions International

# Submission to

# Senate Select Committee on

# Unconventional Gas Mining

DESKTOP REVIEW

INTER-AQUIFER LEAKAGE
AND
GROUNDWATER-SURFACE WATER CONNECTIVITY
CONDAMINE RIVER CATCHMENT

AND
POTENTIAL IMPACTS OF COAL SEAM GAS AND COAL GASIFICATION

11 MARCH 2016

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# Executive Summary

The recent investigations carried out by joint research between UNSW Connected Water Initiative Research Centre/Australian Nuclear Science and Technology Organisation/ University of London/ University of East Anglia (2015); CSIRO (June 2014) and the Queensland Government provides evidence of inter-aquifer connectivity between the Walloon Coal Measure and the overlying aquitards and aquifers. Many studies indicate there is evidence of groundwater-surface water connectivity between the Condamine River Alluvial Aquifer and the Condamine River under certain hydraulic conditions downstream of the Chinchilla Weir.

Under the right hydraulic conditions methane gas is able to migrate from the underlying Walloon Coal Measures up into the Condamine River and private bores. The migration pathway is still uncertain although recent studies indicate natural faulting may be a cause, along with depressurisation of the Walloon Coal Seam, and poorly constructed water and coal bores. Inter-aquifer connectivity is complicated by natural faulting and/or by past Coal Seam Gas and Coal Gasification activities. Depressurisation of the Walloon Coal Measures by Australia Pacific LNG and Queensland Gas Company is allowing buoyant methane gas that is not affected by the low pressure zone artificially created at the exploration/production wells, to migrate to other low pressure zones, such as natural faults and boreholes (poorly constructed water and old coal bores).

Coal Gasification activities carried out by Linc Energy Pty Ltd in the past included fracturing of the Walloon Coal Measures and this may have also created preferential pathways for the migration of methane gas into the overlying Springbok Sandstone aquifers. The Queensland Government initiated legal action against Linc Energy in 2013. The Queensland Government has recently renewed Linc Energy's Mineral Development Licence 309 for 10 years, with specific conditions based on environmental requirements to ensure important decommissioning and rehabilitation activities can be completed. This includes groundwater abstraction to 'clean' the underground coal gasification area.

Numerous old coal exploration boreholes lie open at the surface across the Condamine Valley. The locations of the boreholes are not entirely known and pose a real risk by acting as conduits to migratory methane gas from coal seam gas field's groundwater depressurisation activities. Australia Pacific LNG and Queensland Gas Company need to obtain more geological, geochemical, isotopic and hydrogeological data. Their conceptual models need to be revised and the numerical groundwater model re-run for the various migratory path scenarios.

Both the 2009 Queensland Gas Company *Environmental Impact Statement* and the 2010 Australia Pacific LNG *Environmental Impact Statement*, although comprehensive, have not sufficiently considered Groundwater Dependent Ecosystems (GDE). Although the Bureau of Meteorology GDE Atlas was published in 2012, it was largely based on references pre-2010. Australia Pacific LNG and Queensland Gas Company should have undertaken an in-depth GDE investigation, especially for the mid-catchment Condamine River reaches downstream of the Chinchilla Weir. Australia Pacific LNG recognised there are various river reaches in the study area that potentially receive baseflow from the outcropping aquifer systems of the Great Artesian Basin. The mid-catchment reaches are able to receive baseflow from the Gubberamunda Sandstone aquifer where the Condamine River cuts into the exposed sandstone rock down gradient of the Chinchilla Weir. Queensland Gas Company concluded only the Springbok Sandstone Aquifer (or 'the first aquifer above the Walloon Coal Measures') will be impacted and the Condamine River Alluvial Aquifer and the Condamine River itself would not be negatively affected.

The evidence gathered by scientists to date regarding inter-aquifer leakage and groundwater-surface water connectivity suggests neither the Australia Pacific LNG Talinga/Orana Gasfield nor the QGC Argyle Gasfield should be expanded. Relevant, meaningful data needs to be gathered, processed and the next Surat Underground Water Impact Report released with an updated numerical groundwater model before future EIS are considered.

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# 1.0 Brief

I have been contracted by Ms Helen Bender, 'Chinta', to carry out a literature review of published scientific studies detailing groundwater and surface water interactions between the Condamine River Alluvial Aquifer and the Condamine River.

Ms Bender, neighbouring landowners and relevant government scientists have observed methane gas 'bubbling' along the middle reaches of the Condamine River, downgradient of the Chinchilla Weir. Ms Bender's groundwater bore has also experienced gas kicks sending groundwater out of their bore and onto the surrounding grassed area leading to grass die back. Her bore was 'plugged' by Origin Energy (acting on behalf of Australia Pacific LNG) but has since 'kicked' the plug a vertical distance of 30m out of the bore (Ms Bender pers. Comm.). Clearly the groundwater system is being affected by methane gas the source of which is controversial. This report will look at the last five years of research in the Upper-Mid Condamine River Catchment where the groundwater – surface water system is complex.

# 2.0 Introduction

Coal Seam Gas (CSG) fields produce gas by initially pumping groundwater (often referred to as 'produced water'), thereby depressurizing the reservoir until the pressure falls below the critical desorption pressure of the coal seams. That is, depressurising the reservoir enables the coal seam gas and groundwater to move away from the coal fracture surface. Pumping at a water supply bore causes a "cone of depression" in the *water table*, or if the aquifer is under an artesian pressure the *potentiometric surface*, that gradually spreads outwards. Similarly, the zone of depressurization at a producing CSG well propagates outwards and normally has impacts beyond the immediate vicinity of the producing well.

Figure 1 shows the extent of the Coal Seam Gas Fields adjacent to the Bender's property, 'Chinta', and the neighbouring landowner's properties. Australia Pacific LNG (APLNG), a joint venture between Origin, ConocoPhillips and Sinopec, operates the Talinga and Orana Gasfields. Queensland Gas Company (QGC), which is part of the multinational oil and gas company BG Group, which was bought out by Royal Dutch Shell in February 2016, operates the Argyle and Kenya Gasfields.

APLNG proposes to 'develop a world class CSG to liquefied natural gas (LNG) project in Queensland. This includes the development of the Walloons gas fields, the construction of a high pressure gas transmission pipeline from the gas fields to Curtis Island near Gladstone and a LNG facility on Curtis Island. The Project being assessed by this environmental impact statement (EIS, 2010) will be spread over 30 years and has been addressed under the following three main components:

- Gas fields
- Gas pipeline
- LNG facility.

The Walloons gas fields are located in Queensland's Surat Basin on the Western Downs. They cover an area of approximately 570,000 hectares (ha). There are eight development areas in total. This submission details concerns for the Talinga/Orana Gasfield near the town of Chinchilla.


**Figure 1:** APLNG and QGC Coal Seam Gas Fields adjacent to the Bender's property 'Chinta'.

The north-eastern portion of the Talinga/Orana Gasfield covers the confluence of Charley's Creek with the Condamine River and is within a hydrogeologically complex system.

APLNG stated there was little in the way of research, and therefore datasets, on the groundwater – surface water system that was available at the time of their Environmental Impact Statement in 2010. However, since this time landowners have experienced:

- groundwater loss in bores completed in the Walloon Coal Measures (WCM), Gubberamunda and Springbok Sandstone aquifers,
- methane gas 'bubbling' from private bores completed in the Walloon Coal Measures,
- methane gas 'bubbling' up into, and emitting from, the Condamine River downgradient of the Condamine Weir since the 2012 floods.

It became apparent to the Queensland Government the groundwater – surface water system is very complex in the Walloon Coal Measures (WCM) and Condamine River Alluvial Aquifer (CRAA). Further scientific investigations were required to understand the WCM – CRAA interaction.

QGC proposed in 2009 the drilling of 6,000 wells across the study area to extract CSG. In November 2015 the Argyle Gasfield ceased production in 40 wells for 'Operation and Maintenance'. QGC has not ceased CSG production in the remaining wells in the Argyle Gasfield nor in the Kenya Gasfield.

In November 2015 the water bore on the Bender's 'Chinta' property 'kicked' due to a build-up of thermogenic methane gas pressure in the upper portion of the Walloon Coal Bed aquifer (Ms Bender's conversation with Origin Energy). Given the water bore was closest to Origin Energy's Orana Gasfield they plugged the water bore with 'mud' to allow QGC's decommissioning works to commence. However, once the decommissioning works commenced, there seems to have been a shift in gas flow towards the operating CSG wells in Origin Energy's Orana and/or Talinga

Gasfields, which were continuing to produce gas (Ms Bender pers. comm.). This may be responsible for a large change in the movement of gas increasing the gas pressure in the Chinta water bore because it resulted in the ejecting of the sealing 'mud' plug Origin installed, 30m up and out of the water bore (Ms Bender pers. comm.).

To add further complication, Linc Energy operated the Hopelands Underground Coal Gasification (UCG) plant up until 2013, when it was discovered that irreparable environmental damage had occurred leading to the closure of the Hopelands UCG plant. The environmental damage was caused by subsidence as a result of the UCG process which has led to fractures opening up in the CRAA (the overburden) allowing methane, carbon monoxide and other by products of the process to leak at the ground surface. The Queensland Government initiated legal action against Linc Energy in 2013. Recently the Queensland Government renewed Linc Energy's Mineral Development Licence 309 with specific conditions based on environmental requirements to ensure important decommissioning and rehabilitation activities can be completed.

The Groundwater Dependent Ecosystems Atlas (GDE Atlas) was been published in 2012 is aimed to address the knowledge gap by creating the most complete inventory of the location and characteristics of groundwater dependent ecosystems in Australia. It was developed to:

- collate existing information on groundwater dependent ecosystems
- identify the location and characteristics of groundwater dependent ecosystems that have not previously been identified
- provide a central, web-based portal to present the information

The Groundwater Dependent Ecosystems Atlas is a flagship project under the National Water Commission's Raising National Water Standards Program. It was developed by the National Water Commission, SKM, CSIRO, Cogha and the Bureau of Meteorology with input from every State and Territory as part of the Groundwater Action Plan. The Atlas should have been used by APLNG to consider the requirements of the groundwater dependent ecosystems.

I have completed a literature review of relevant published data, including the GDE Atlas, where significant findings have led me to believe the APLNG EIS (2010) is no longer appropriate to present as an Environmental Impact Statement for the development of the Talinga/Orana Gasfield, based on inadequate information regarding:

- Walloon Coal Measure – Condamine River Alluvial Aquifer connectivity
- Condamine River Alluvial Aquifer – Condamine River connectivity
- GDE requirements

I therefore conclude the expansion of the APLNG Talinga/Orana and QGC Argyle Gasfields should not proceed until further basic hydraulic and geochemical data has been gathered, the numerical groundwater model re-run, and the EIS updated accordingly in light of these findings, including cumulative impacts from other CSG gasfields, underground gasification plants and open former coal exploration boreholes.

No future underground coal gasification plants should operate in this area due to the existing complexity.

# 3.0 Literature Review

## 3.1 Introduction

There have been many studies carried out in the Upper Condamine River Catchment over the last few decades. However there still seems to be a lack of critical hydraulic, geological and geochemical field data to input into sophisticated numerical groundwater models such as those being designed by APLNG, as part of the Environmental Impact Statement process. These models are unable to be become any more sophisticated without the basic data. There is also the possibility that without the critical field data APLNG may have an incorrect conceptual hydrogeological model that forms the basis of the numerical groundwater model.

APLNG's is operating the Talinga/Orana exploration gas field in the far north-western area of the Upper Condamine River Catchment. Landowners in this area are experiencing bores drying up and others 'kicking' from methane gas build-up. The Condamine River in the area below the Chinchilla Weir is also experiencing 'bubbling' methane.

Connectivity between the Walloon Coal Measures, the Springbok Sandstone, Condamine River Alluvial Aquifer (CRAA) and the Condamine River in the APLNG Talinga/Orana Gasfield area needs to be better understood before the exploration gasfield can be expanded and production commence.

Due to the Condamine River Alluvial Aquifer (CRAA) being less than 10m in thickness it is not considered a productive, secure groundwater resource in the north western portion of the Upper Condamine River Catchment. Bores access the underlying Springbok Sandstone aquifer and/or the underlying Walloon Coal Measures. However, the CRAA plays an important role in hydrogeological systems in this area and supports groundwater dependent ecosystems (GDEs) as shown in the GDE Atlas (BoM, 2012). If this review links the underlying fractured Walloon Coal Measures, with the Springbok, the CRAA and the Condamine River, then under certain hyrdraulic conditions methane may be able to migrate upward or laterally into the CRAA and the Condamine River.

If this is the case then APLNG should be required to gather further data and update their 2010 Environmental Impact Statement so better mitigation measures can be planned to protect the CRAA, the exposed Jurassic recharge beds, the Condamine River, and the GDEs. Depressurisation from dewatering the Walloon Coal Measures increases the likelihood of methane gas migrating to the overlying aquifers and the Condamine River.

A critical review of the many hydrogeological studies was given in Dafny & Silburn (2013). A summary of their findings is given in Section 3.2.

The Bureau of Meteorology 'Groundwater Dependent Ecosystems Atlas' (2012) highlights those areas of the Condamine River that are connected to the CRAA, and the Jurassic layers which the Condamine River cuts into and receives baseflow from. These will be discussed in Section 3.3.

The UNSW Connected Water Initiative undertook an intensive study in the mid-Upper Condamine River Catchment investigating whether using a combination of Methane Isotopes, concentrations of dissolved Organic Carbon (DOC) and Tritium concentration could provide an effective tool for determining whether the Walloon Coal Measures are hydraulically connected to the overlying CRAA (Iverach et al., 2015). A discussion of the results of this informative study is discussed in Section 3.4.

## 3.2 Condamine River Alluvial Aquifer (CRAA) – Condamine River Connectivity

A critical review of the many hydrogeological studies was given in Dafny E., Silburn D.M., 2013*. The Hydrogeology of the Condamine River Alluvial Aquifer (Australia) – critical review.* University of Southern Queensland, Toowoomba, Australia*.* References they used are cited in the summary below, however, readers are directed to Dafny & Silburn (2013) for the full reference.

A summary of their findings is outlined as follows:

### 3.2.1 Geology and Geomorphology

The Condamine River Alluvial Aquifer (CRAA) is largely underlain by the Walloon Coal Measures (KCB, 2011c).

The CRAA provides the groundwater resource for landowners further east and in the mid-to upper areas of the Upper Condamine Catchment.

Where the CRAA is a non-existent or is a thin mantle (<10m) in the west of the Upper Condamine Catchment the Walloon Coal Measures are unconformably overlain by the Springbok Sandstone and Westbourne Formation (Scott et al., 2006).

The Walloon Coal Measures and Springbok Sandstone aquifers provide the groundwater resource for properties, such as 'Chinta', in the north western (or lower catchment) area of the Upper Condamine Catchment.

The geomorphological evolution of the Condamine paleo-valley and the CRAA still remains uncertain (Dafny & Silburn, 2013). That is, it is not certain how the old Condamine valley was eroded so that it was deepest around the Dalby area instead of west of Chinchilla township where the present day Condamine River now flows (refer to Figure 5 as reported in Dafny & Silburn (2013)).

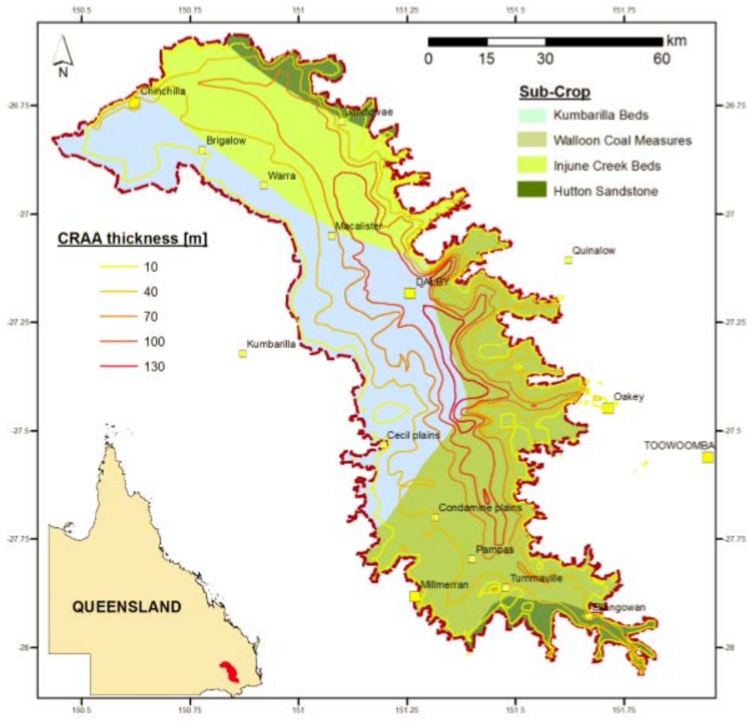



*Figure 5: Sub-crop map of the CRAA (source: GHD, 2012).*

### 3.2.2 Conceptual Geological Model of the CRAA

The Condamine alluvium consists of a mixture of valley-fill deposits and has been described according to two schemes. These schemes are important in understanding the conceptual groundwater flow model for the CRAA to date. The **first scheme is based on depositional environments** (Lane, 1979; Huxley, 1982 as reported in Dafny & Silburn (2013) and the **second scheme are based solely on borehole lithology** (SKM, 1999). These are shown in Figure 4 (as reported in Dafny & Silburn (2013). However, both schemes have suggested there is a low permeability barrier to groundwater flow at the base of the alluvium (or the top of the Walloon Coal Measures).

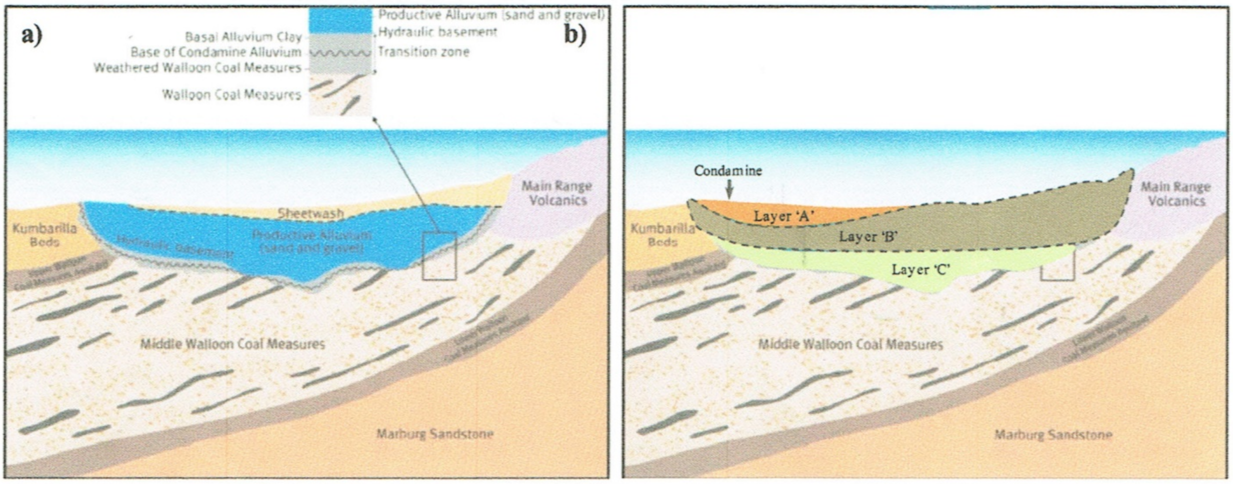



***Figure 4:*** *Schematic geological section across the Condamine Alluvium. (a) After QWC, 2012 (b) the same section adapted to SKM (1999) sub-division of the CRAA.*

**The First Scheme:** As reported in Dafny & Silburn (2013) the 'fluvial alluvium' ('productive alluvium' in KCB reports) is comprised of fine-granular sediments, with a general increase in fine material over granular material in the downstream direction. If formed under varying depositional environments, between riverine high energy to lacustrine low energy. Typical section is comprised of relatively thin (<10metres) fine, mixed or granular horizons, that are difficult to interpret across section.

As reported in Dafny & Silburn (2013) the 'sheetwash alluvium' presents as a wedge of generally fine and/or mixed material abutting the eastern channel wall and overlying the more varied fluvial alluvium. In many places, individual clay and silt horizons are logged as quite thick (over 20m), and there is generally an absence of clean granular horizons.

In Figure 4a the 'fluvial alluvium' dominates the western part of the Upper Condamine Valley and is attributed to floodplain deposition along both strands of the Condamine River. To the east, and generally east of the 'north branch', it is overlaid by the 'sheetwash alluvium' (as reported in Dafny & Silburn, 2013) attributed to transport and sedimentation processes from the eastern tributaries, forming outwash fans.

The boundary between the fluvial and sheetwash alluvium does not coincide with the geological mapping units. Recent studies adopted this scheme while introducing a 'transition layer' at the bottom of the alluvium as a third layer (refer to Figure 4a), as reported in Dafny & Silburn, 2013. Also referred to as the 'transition zone', it is a clayey zone in between the granular/mixed alluvium and the underlying Jurassic formations (including the WCM and Kumbarilla Beds). However, Dafny & Silburn (2013) suggest this interpretation of the clayey zone is also similar to ground-up Jurassic sandy sediments associated with drilling muds (Biggs A., pers comm., 2013).

**The Second Scheme:** is based solely on borehole lithology (SKM, 1999, as reported in Dafny & Silburn, 2013). Accordingly the alluvial sections are divided into three layers as shown in Figure 4b.

Layer A is characterised by a predominance of sand in the uppermost part of the section and has a maximum thickness of 20m. It extends from the western margins of the CRAA as far east as the north branch of the Condamine River and thickens beneath the main branch of the Condamine River.

Layer B accounts for all the sediments that are not included in Layer A or C. It contains sands, clays and some gravel. Its thickness ranges from 20-80m, with the greatest thickness along the thalweg of the paleochannel thinning westwards (a thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel).

Layer C is characterised by the appearance of white sediments in the lower part of the section. Its thickness and extent is determined by the bedrock topography underlying it. Layer C's typical thickness varies between 20m to 60m, with the greater thickness along the thalweg of the paleovalley floor.

Dafny & Silburn (2013) stated that no correlation was made between the sub-surface lithological sub-units and the surficial map units.

Other alluvial units also include the Chinchilla Sands which outcrops near Chinchilla. The floodplain alluvium has also been divided into an 'older floodplain alluvium which is generally found along old fluvial terraces at the valleys rim.

Dafny & Silburn (2013) noted that further work will help with **constructing a comprehensive stratigraphy understanding of the colluvium and alluvial sequences** (Kelly and Merrick, 2007) and **the lack of such work is a major deficiency**.

Recent UNSW Connected Waters research findings (Iverach et al., 2015) suggest if there is a low permeability layer at the base of the alluvium then it may not be as impermeable as previously thought to upward groundwater flow from the Walloon Coal Measures and Kumbarilla Beds or maybe there are other mechanisms allowing methane to migrate from the WCM. This research will be discussed further in Section 3.3.

### 3.2.3 Regional and Local Hydrogeology

The Condamine Plain lies within the eastern margin of the Great Artesian Basin (GAB).

Outcrops of the Jurassic Units (notably the Hutton Sandstone, Walloon Coal Measures, and Kumbarilla Bed's Springbok Sandstone) surrounding the CRAA are part of the 'recharge' area of the GAB. Groundwater flow in the GAB under the Condamine catchment is generally towards the west-south-west (Welsh, 2006; as reported in Dafny & Silburn, 2013).

Generally away from the recharge zones, vertical water leakage is induced by pressure differences, and tends to be upwards, with the deeper artesian aquifers feeding the near surface water table (Welsh, 2006; as reported in Dafny & Silburn, 2013). Groundwater is typified by Na-Cl and Na-HCO3 water types (Huxley, 1982).

At its eastern rims, the CRAA bounds several basaltic aquifers. Groundwater flow within these aquifers generally resembles the topographic relief. Several perched watertables may arise. Groundwater is typically dominated by Mg-HCO3 water types.

The NW area of the Upper Condamine River catchment is dominated by the Kumbarilla Beds and underlain by the Walloon Coal Measures.

### 3.2.4 Existing Hydrogeological Knowledge

Groundwater flow within the CRAA is essentially from south east to north-west, parallel to the elongated axis of the valley and the Condamine River.

The common conception is that the CRAA is fed by lateral flow from the upper Condamine tributaries, with substantial contribution along the flow course of percolated water from the surface (the Condamine River as a 'losing' stream and diffuse recharge), as well as lateral flow from the bounding aquifers. The significance of diffuse recharge is under dispute.

As noted by Dafny & Silburn, in 2013, under the current pumping scheme, several hydraulic sinks exist east of the Condamine River, with the groundwater table lower by ~25m in respect to the un-exploited period.

It is believed by Dafny & Silburn (2013) that as a consequence of this current pumping scheme, fluxes from the bounding aquifers toward the CRAA have intensified (KCB, 2010b). Furthermore, along the western rims of the CRAA, a reverse gradient was formed between the WCM and the CRAA (Hiller, 2010; KCB, 2011c; QWC, 2012). In addition, vertical gradient was noticed in multiple-pipe boreholes toward the central part of the alluvium, at depths where most pumping is concentrated (SKM, 2003).

### 3.2.5 Water Budget

The water budget for the CRAA is far from conclusive.

#### *River contribution*

Overall streambed recharge accounts for the dominant component of the water balance of the CRAA (Lane, 1979; Huxley, 1982; SKM, 2003; Barnett and Muller, 2008; Parsons et al., 2008; KCB, 2010).

The Condamine's North Branch was considered as a detached river, which does not percolate to the groundwater table (Lane, 1979; SKM, 2003; Barnett and Muller, 2008; Parsons et al., 2008).

Induced recharge due to higher surface water levels, i.e., during floods and adjacent to weirs, was reported by Lane (1979). He stated that "significant recharge occurred as a result of stream flooding…in the majority of years (p134)". Induced streambed recharge was not considered implicitly in the later studies water balances primarily because there was no discernible or repeated correlation between flood events and hydrograph responses (KCB, 2011b, p.75).

#### *Fluxes through the western alluvial boundaries – Bedrock Contribution (Jurassic WCM and Springbok Sandstone)*

There is general agreement that groundwater flow occurs from the eastern boundary, however, flow through the western and lower boundary are argued due to the lack of long term, spatially distributed groundwater level data in these units (Hiller, 2010; KCB, 2010b, 2011c; QWC, 2012).

#### *Diffuse recharge*

Following the growing evidence of the feasibility of percolation through cracking clays, several recent researches (Hansen, 1999; SKM, 2003; Kelly and Merrick, 2007; Barnett and Muller, 2008; KCB, 2010b) have included a component of diffuse recharge in their assumptions or models.

#### *Abstraction*

Dafny & Silburn (2013) reported Kelly & Merrick (20017) found actual abstraction exceeds available yield estimations which led to pronounced decline in groundwater levels within the CRAA. Less than one third of the water in use for irrigation is based on groundwater pumping. The rest is from releases from major storages, harvesting stream water and capturing of overland flow (SKM, 2003).

### 3.2.6 Water Quality

A correlation between geochemical properties and concentrations to physical aspects of the aquifer, and to different water sources was identified from compilations by Lane (1979), Huxley (1982) and KCB (2010b).

Overall, low TDS, EC, Cl and Na concentration were correlated with a proximity of 'fresh' recharge sources; mainly the Condamine River and along the south eastern rims of the CRAA.

Increased sodium and chloride concentrations were thought to be the result of mixing/interaction with saltier bedrock water along zones of lower transmissivity, with the tacit assumption that water from these zones has a longer residence time in the aquifer (Huxley, 1982).

Increased influence of groundwater from 'older sediments' was used to explain the trend of increased TDS with depth in several boreholes (Lane, 1979); to explain the increase in the conductivity downstream, towards the northern edge of the CRAA (Huxley, 1982) and; to explain several 'anomalous' geochemical compositions which appear in deep wells, perforated close to the basement rocks (KCB, 2010b).

It was also shown that the upstream part of the CRAA is dominated by Mg-HCO3 water type, the central part by a Na-HCO3 water type, and through the northern part a significant increase in the frequency of Na-Cl water type occurs (Huxley, 1982; KCB, 2010b).

The low salinity magnesium bicarbonate type water in the upstream areas was associated with influence of the Main Range Volcanics (MRV – Tertiary Basalts) and the high salinity sodium-chloride type water in the downstream areas with influence of the Walloon Coal Measures.

### 3.2.7 Hydraulic Properties

The accepted perception was that moderate conductivities (3 m/d < K< 30 m/d) occurs in the most of the CRAA.

'Sheetwash' alluvium was considered less permeable due to its increased clay content; the 'Fluvial or Productive alluvium' had a higher permeability; and the upper sandy layer along the Condamine River was considered relatively permeable.

Storativity was rather homogeneous through the entire CRAA in all studies noted by Dafny & Silburn (2013).

### 3.2.8 Knowledge Gaps

Dafny & Silburn (2013) conclude that there are 'numerous 'grey areas' of significant uncertainty as to the basic elements essential to formulation of numerical models and understanding mechanisms of recharge, flow processes within the aquifer, and interrelations with neighbouring aquifers.'

Some of the knowledge gaps are listed as follows (the reader is referred to Dafny & Silburn (2013) for more detail.

#### *The hydrogeological system*

1. The pumping component is only estimated.
2. The downstream outflux through the northern edge of the CRAA (APLNG Talinga/Orana area) is only roughly constrained due to lack of monitoring data.
3. Lack of thorough understanding of the recharge processes from the upper surface (streams and lands) hamper better recharge estimations (Kelly and Merrick, 2007).
4. Pumping, downstream flux and recharge were identified to have the highest likelihood of affecting the overall accuracy of the water balance (KCB, 2010b).
5. Sub-surface fluxes are only rough estimates.
6. To date, limited fluxes have been considered between the CRAA and all its bounding hydrogeological units due to adjoining low permeability alluvial sub-units. However, there is no certainty as the thickness of this layer, its spatial continuity and conductivity.
7. Only major and continuous flow streams have been included in the water balances. That there is no consideration of the temporal changes in the stream flow. More fieldwork is required to establish and verify recharge rates through both and should also include flooded meanders and weirs.

8. The transition layer should be clarified as to whether it is a weathered part of the WCM, as defined by Lane (1979) or whether it is low permeability basal alluvium clays of the CRAA representing periodically deposited lacustrine sediments at the lake margins during filling the system (KCB, 2010 p.23 in QWC, 2012). This is important as there is a variation in over 40m in thickness. There are also no direct measurements of the permeability of the 'transition' layer.
9. A lack of long-term spatially distributed monitoring well network for the different hydrogeological units is hindering better estimations of vertical hydraulic gradients between units.
10. Diffuse recharge is certainly occurring but is not yet quantified.
11. Two independent pieces of evidence may be used to solve the surface –groundwater connectivity uncertainty:
    a. The lithology along the river and its vicinity
    b. Groundwater geochemistry.
12. It may be appropriate to combine groundwater salinity maps with the thickness of Layer A (refer to Figure 4a) to identify those sections in which streambed recharge occurs, since the Condamine River has a lower TDS than other hydrogeological units.
13. An attempt to identify 'end-members' from which the aquifer water evolved.

### *Model formulation*

14. None of the models Dafny & Silburn (2013) looked at included fluxes from, and to, the underlying WCM, though several include this component in their conceptual model.
15. The model domain should include all zones of perceptible alluvial thickness, since at the rims the alluvium section is usually thin (<5m) and is overlooked and considered un-prospective. A sub-surface inflow should be considered through these boundary sections, as the thin alluvium zones are often saturated.
16. The CRAA north-western boundary is possibly not modelled correctly given they did not consider pre-development times when groundwater may have discharged through natural outlets, such as the down-gradient north-western boundary. If groundwater discharged through the western boundary then an east-west gradient would have occurred. This is not the case and it is assumed the major natural outlet was through the northern boundary. However the alluvial section along this boundary is shallow and narrow, therefore it is possible that the outflow was to the surface water 'gaining streams' and/or through the underlying aquifers. This hypothesis by Dafny & Silburn (2013) needs to be tested.
17. The CRAA lower boundary should be clearly defined and mapped. It should allow influx and outflux between the CRAA and the bounding formations, either aquifers or aquitards, according to the sub-crop map, the prevailing head differences and characterised hydraulic conductivities.
18. All CRAA spatial and vertical boundaries should allow hydraulic inter-connection with the neighbouring aquifers and alluvial tributaries.
19. The CRAA alluvial deposits are highly heterogenic and efforts to enforce internal geological-lithological schemes are hindered by poor descriptions of well logs.
20. Basic data still hinders decisive conclusions.

Dafny & Silburn (2013) conclude that using MODFLOW to predict CSG effects will have inherent problems. As CSG extraction involves dewatering and depressurising of the Jurassic WCM underling the CRAA, two separate groundwater tables might be formulated, one in the CRAA and the other in the underlying formations. MODFLOW cannot model these physical conditions. Therefore models that can handle multiple watertables should be used (e.g. FEFLOW).

### 3.2.9 Summary and Recommendations by Dafny & Silburn (2013)

The CRAA lacks historical measurements with definite 'closed' boundaries complicating the conceptualisation of the aquifer, especially its water balance and hydrogeological processes. Even though the CRAA hydrological, hydrochemical and geological aspects has been studied for over three decades only minor increases in the level of confidence of the modelling outcomes have occurred. This is a direct result of the lack of well-focused field work to support and refine conceptualisation and modelling.

Improvements may include, but are not limited to:

1. A more detailed monitoring scheme which includes frequent monthly monitoring with key bores identified for continuous monitoring to support identification of recharge mechanisms by recording the possible instantaneous responses to precipitation events.
2. A thorough Quality Control process should be carried out to sort invalid records (eg poor ionic balance or samples which represent drilling fluids rather than aquifer water).
3. A systematic sampling campaign for stable and radioactive isotopes, pesticides and other compounds of high priority. At the same time downhole cameras could be used to check/describe the bore screened sections.
4. Publish a detailed sub-crop map for the CRAA to enable better quantification of the inter-formational fluxes by better constraining the contact area. However, this map would benefit from new borehole drilling records where there is a lack of clarity of the true thickness of the CRAA (especially in the area between Dalby and Chinchilla).
5. Achieve better calibration of the hydraulic conductivity of the CRAA, the 'natural' components of the water balance and the inter-connectivity with the bounding aquifers. This could be achieved by determining the initial water balance of the CRAA for the pre-cultivated (pre-developed) period.
6. The current sophisticated models are far ahead of the data reliability. Priority should be given to obtaining superior field data; a better conceptual understanding of the hydrogeological processes; and the use of software that can deal with multiple water tables and integrated surface-sub-surface.
7. As of 2013 there have been no solute transport models calibrated for the CRAA which would help enhance the understanding of the hydrogeological processes and the quantification of incoming and outgoing fluxes.

## 3.3 CCRA Connectivity with the Walloon Coal Measures and/or Springbok Sandstone

### 3.3.1 Introduction

As mentioned in Dafny & Silburn (2013) minimal investigations have been carried out to determine the nature of the fluxes between the CRAA and the underlying WCM and/or Springbok Sandstone.

A co-ordinated investigation was undertaken in 2015 by the Connected Water Initiative Research Centre, UNSW; Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights NSW; Royal Holloway, University of London; and the School of Environmental Sciences, University of East Anglia, United Kingdom (referred to here as the UNSW/ANSTO Methane Study). The research paper was published in Nature journal's *Scientific Reports* (Iverach, C.P. *et al.* Assessing Connectivity between an Overlying Aquifer and a Coal Seam Gas Resource Using Methane Isotopes, Dissolved Organic Carbon and Tritium. *Sci. Rep*. **5**, 15996; doi: 10.1038/srep15996 (2015).

There have been isotopic studies undertaken previously in the Surat Basin, GAB, however this recent study, although limited, is the only study of its kind to have been carried out in the investigation area using multi-geochemical signatures of methane isotopes, dissolved organic carbon and tritium as a tool to determine the source of methane.

### 3.3.2 University of NSW Connected Water Initiative Research Centre – ANSTO – University of London Study

The Methane Study assessed connectivity between the Condamine River Alluvial Aquifer (CRAA) the underlying Walloon Coal Measures (WCM) in the irrigation district to the south of Dalby and east of Cecil Plains. To achieve this they needed to determine the background groundwater chemistry and to map geological pathways of hydraulic connectivity between aquifers. They mapped hydraulic connectivity between the WCM and the overlying CRAA using groundwater methane ($CH_4$) concentration and isotopic composition ($\delta^{13}$ C-$CH_4$), groundwater tritium ($^3H$) and dissolved organic carbon (DOC) concentration. Methane gas and groundwater samples, for isotopic methane-dissolved inorganic carbon, dissolved organic carbon, tritium, sulphate and nitrate were collected from 19 private irrigation boreholes completed in the CRAA. A continuous mobile methane survey adjacent to the CSG developments was used to determine the source signature of methane derived from the WCM.

There are many sources of methane within the Condamine Catchment that could contribute to the measured methane and isotopic methane in the groundwater and air. These include methane from:

**Thermogenic methane**

- The upward migration of gas from the WCM

**Biogenic methane**

- Biological activity in the saturated zone beneath rivers and wetlands
- Biological activity in the saturated zone of the CRAA,
- Biological activity in the vadose zone (methane sink),
- Biological activity within the borehole

**Anthropogenic methane**

- Inputs into the atmosphere

Each of the above sources potentially has a unique isotopic methane signature.

Trends in groundwater of isotopic methane versus methane concentration, in association with dissolved organic carbon concentration and tritium analysis, identified four locations where methane in the groundwater of the Condamine River Alluvial Aquifer most likely originated from the Walloon Coal Measures.

The UNSW/ANSTO Methane Study provides evidence that the CRAA and the underlying WCM are connected in the mid- Upper Condamine River Catchment. This research indicates that if there is a low permeability layer ('transition layer', 'Layer C') then it is not entirely 'intact' and there must be a migratory pathway for groundwater to flow upwards from the WCM and/or Springbok Sandstone into the overlying CRAA.

This investigation proves there is a credible tool that could be utilised to determine CRAA and WCM connectivity in the lower valley of the Upper Condamine River catchment.

### 3.3.3 Grace Denis, Royal Holloway, University of London thesis on 'Faulting in the Surat Basin and the Implications for Hydraulic Connectivity' (8 April 2013)

Grace Denis carried out investigations as part of her thesis, which is part of the UNSW Connected Water Research Centre coal bed methane studies in the Surat Basin. Fault lines are present in the Upper Condamine Catchment area as indicated in her Figure 3.7 below:

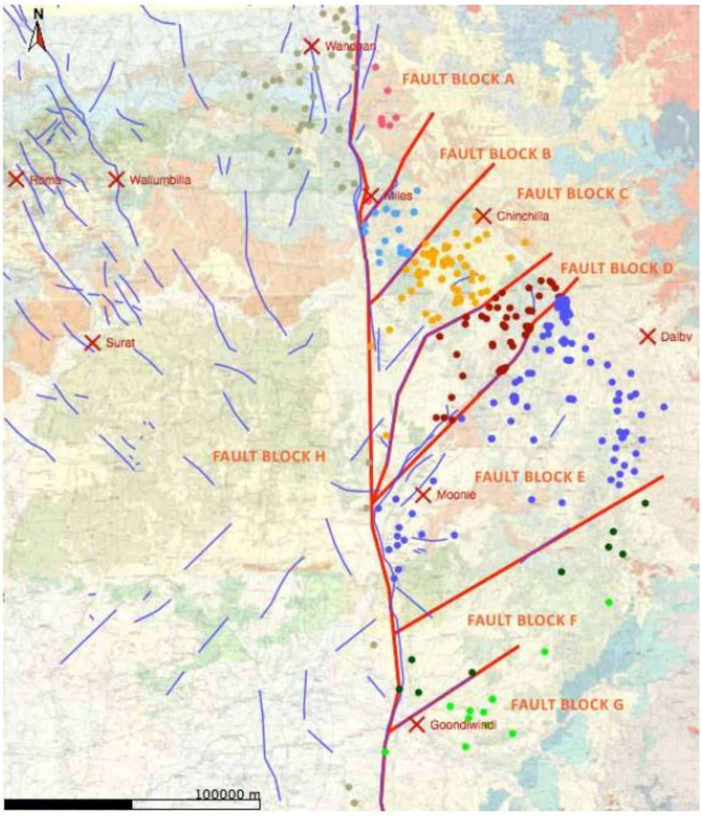



**Figure 3.7:** Simplified fault blocks (red) lettered A to H based on the original SRK polygons (blue) and corresponding wells colour coded to their fault block for the entire regional study area

When compared with the geochemical studies by UNSW/ANSTO her findings indicated three of the four private borehole samples found to be groundwater influenced by Walloon Coal Measures, lie along an extended line of a fault between Fault Block F and Fault Block E in the Dalby-Cecil Plains area (Prof. Bryce Kelly pers comm.).

Faultlines and fractures can act as conduits to groundwater flow or could inhibit groundwater flow, depending on whether or not the fault zone is high in clay content.

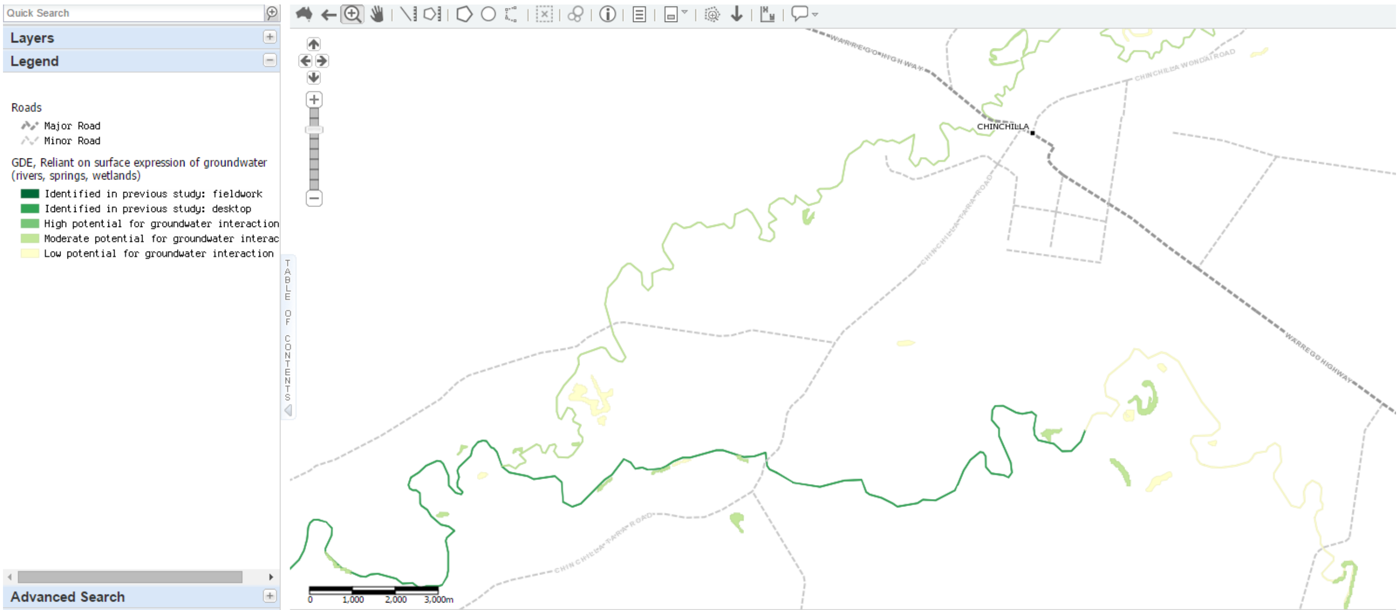
Faultlines and fractures, man-made or naturally occurring, can form preferential flow paths that affect connectivity between the Walloon Coal Measures/Springbok Sandstone formation and the overlying CRAA.

Faultlines and fractures may be partially responsible for the migration of methane gas (Charlotte Iverach & Prof. Bryce Kelly pers. comm.) in the upper Condamine Valley Catchment. Other possibilities are poorly constructed water and old coal bores.

## 3.4 GDE Atlas - Bureau of Meteorology (2012) Atlas of groundwater dependent ecosystems. Bureau of Meteorology, Canberra.

The National Atlas of Groundwater Dependent Ecosystems presents the current knowledge of groundwater dependent ecosystems across Australia. It displays ecological and hydrogeological information on known groundwater dependent ecosystems and ecosystems that potentially use groundwater. The Atlas is a tool to assist the consideration of ecosystem groundwater requirements in natural resource management, including water planning and environmental impact assessment.

APLNG could not include the GDE Atlas (2012) when they were assessing the GDE groundwater requirements in their 2010 Environmental Impact Statement. The GDE Atlas shows GDEs are reliant on a surface expression of groundwater along the Condamine River, based on desk top studies, within the APLNG Talinga/Orana Gasfield as indicated in the following computer screen shot.




Potential areas where GDEs are reliant on a surface expression of groundwater were mapped if the following conditions occurred:

• intersected with existing Queensland floodplain mapping (Geoscience Australia, Dataset 31; Office of Environment and Heritage, Department of Premier and Cabinet, Dataset 32)

• contained wetlands or other surface water features identified in existing Queensland wetland mapping (Queensland Department of Environment and Heritage Protection, Dataset 33; NSW Department of Environment, Climate Change and Water, Dataset 34; Department of Sustainability, Environment, Water, Population and Communities, Dataset 35)

• occurred over shallow groundwater, where shallow groundwater is defined as regions where depth to groundwater is less than 10 m (Geoscience Australia, Dataset 36)

• occurred in regions where depth to groundwater ranged between 10 to 20 m. This second criterion considered those assets that may access groundwater intermittently (Geoscience Australia, Dataset 36)

• contained water-dependent assets already listed in the water-dependent asset register.

## 3.5 Queensland Government LNG Enforcement Unit and Origin Independent Gas Seeps Investigations.

### 3.5.1 Introduction

The Queensland Government (QG) and Origin undertook independent Condamine River Gas Seeps Investigations. The LNG Enforcement Unit coordinated a multi-agency response by Government principally involving the Queensland Department of Environment and Heritage Protection (QDEHP) and the Queensland Department of Natural Resources and Mines (DNRM).

Origin (which holds the tenure on behalf of Australia Pacific) contracted Norwest Energy Consultants to undertake the investigation into the seeps, including an assessment of environmental effects. Norwest subcontracted technical parts of the study to an environmental consulting company FRC Environmental. FRC Environmental undertook a field monitoring program to gather information on water quality and aquatic ecology that might be influenced by the methane gas seeps. FRC Environmental reported their findings in their report 'Condamine River Gas Seep: Preliminary Aquatic Ecology Assessment'. The Norwest 'Draft Condamine River Gas Seep Investigation: Technical Report' relies on this study for information on environmental issues.

The Independent Review Panel was coordinated by Dr Geoff Garrett, Chief Scientist to the Queensland Government. The Panel consisted of Dr Simon Apte (CSIRO Land and Water, Lucas Heights, Sydney, NSW), Prof. Peter McCabe (Queensland University of Technology, Brisbane, QLD), Dr Rod Oliver (CSIRO Land and Water, Waite Campus, Adelaide, SA) and Dr Lincoln Paterson (CSIRO Earth Science and Resource Engineering, Clayton, VIC).

The following technical reports were independently reviewed by the panel:

- Queensland Government's report 'Summary Technical Report – Part 1 Condamine River Gas Seep Investigation (December 2012)'
- Norwest 'Draft Condamine River Gas Seep Investigation: Technical Report'
- FRC Environmental 'Condamine River Gas Seep: Preliminary Aquatic Ecology Assessment'

The following sections present a summary of the main findings by the various parties.

### 3.5.2 Queensland Government

The CSG Compliance unit (formerly the LNG Enforcement Unit) was contacted by a landholder on 17 May 2012, regarding the observation and possible causes on the bubbling in the Condamine River approximately six kilometres downstream of the Chinchilla Weir. Preliminary investigations by the CSG Compliance Unit (CSGCU) concluded the bubbling was unlikely to be caused by CSG activities in the region. However, further information provided by Origin (on behalf of APLNG) indicated that gas bubbling in the Condamine River was occurring at additional sites. In anticipation of further sites or incidences being discovered the Queensland Government implemented a two-phase multi-agency investigation:

Phase 1: immediate focus on ensuring public safety, assessing environmental harm and the extent of the gas seeps.

Phase 2: longer term detailed technical investigation involving Origin (APLNG's agent). The investigation included desktop reviews focussing on CSG activities and tenure, groundwater and geology; targeted ground verification; and an examination of historical documents on gas seep in the region and internationally (and related investigations).

A summary of the Queensland Government's investigation was reported in "Summary Technical Report – Part 1 Condamine River Gas Seep Investigation (December 2012). Origin (which holds tenure on behalf of APLNG) contracted Norwest Energy Consultants to undertake an investigation including an assessment of environmental effects.

The following summarises the findings by CSGCU:

- The gas is predominantly composed of biogenic methane, likely formed through a $CO_2$ reduction pathway, which is consistent with gas originating from Surat Basin geological formations.
- The results do not provide definitive evidence of the source or cause of the Condamine River gas seeps.
- It was recommended that the government undertake:
    - Ongoing water quality monitoring in the Condamine River by DEHP, in order to assess for potential environmental harm.

- Periodic gas safety assessments of nearby landholder water bores by DNRM Petroleum and Gas Inspectorate, in order to ensure public safety.
- Geological Survey of Queensland will revise the geological mapping on the affected area in the Surat Basin.
- Government will keep landholders updated on investigation activities relating to the Condamine River gas seeps.
- Further in-depth review of historical groundwater data of nearby gassy bores, utilising all available departmental records.
- Government will continue to verify Origin's investigation of the gas seeps, in order to make sure that their investigation is rigorous and is independently assessed.

Assisted by the Chief Scientist to the Queensland Government, advance scientific reviews will ensure Origin's investigation, and verification actions by government, achieve a high scientific standard and integrity.

'The report concluded that the source and cause of the Condamine River gas seeps is unlikely to be determined in the short term, and that a long-term approach to find more science-based answers to the phenomenon is needed.'

### 3.5.3 Origin Energy (Norwest Energy Consultants)

The following sections are a summary of important points from the Norwest Energy Consultants' (Norwest) report on the Condamine River seep areas (*Condamine River Gas Seep Investigation: Technical Report* Submitted to: Origin Energy and Queensland CSG Compliance Unit. Date: 28 February 2014. Norwest Energy Consultants Pty. Ltd. Brisbane, QLD,).

These points help form the basis of Norwest's conceptual model for the river seep area.

#### *Geology*

The geologic units of interest in this investigation area, in ascending order, the Walloon Coal Measures (WCM), the Springbok Sandstone, and the Westbourne Formation. Together these range from middle to late Jurassic in age. Both the WCM and the Springbok Sandstone contain coal seams.

Much of the area of investigation is covered by Cainozoic aged alluvium which has been referred to as the "older alluvium" and includes lateritised[1] Tertiary alluvium, including the Chinchilla Sand. A conglomerate, containing silicified sandstone and petrified wood, is found exposed in the Condamine River banks and may be a coarse-grained facies of the Chinchilla Sand. This unit has been mapped as part of the Jurassic-aged Kumbarilla Beds as seen in Chinchilla, Queensland 1:250,000 Map (SG56-9), 1st edition 1971(Bureau of Mineral Resources, Geology, and Geophysics, Canberra, A.C.T); and part of the Jurassic-aged Orallo Formation by previous investigations.

'The upper part of the older alluvium is comprised of black clay and silty clay. The older alluvium is not related to the Condamine River as it exists today.'

#### *Existing boreholes*

'Water bores have been completed in the Westbourne, Springbok Sandstone, WCM, and in the alluvium. Published information indicates that there are approximately 73 existing and 17 abandoned private water bores within 10 km of the seep area. These include bores that supply water for livestock watering or domestic purposes. Water bores completed in the Springbok Sandstone and the WCM tend to produce water of poor quality with concentrations of

[1] Laterite is a soil and rock type rich in iron and aluminium, and is commonly considered to have formed in hot and wet tropical areas.

total dissolved solids (TDS) ranging from 2,000 milligrams per litre (mg/L) up to 6,000 mg/L and in some areas produce large quantities of methane.'

Norwest constructed a map showing the depth to the top of Walloon Coal Measures from CSG wells, seismic surveys, and published information (Figure 4-3 in the Norwest report). In the area of investigation, Norwest approximates the thickness of the WCM to be 300 m thick, with the top of the formation ranging from approximately 20 m to 90 m below the ground surface. The map also shows the location of preliminary geologic cross section A-A' (Figure 4-4 in Norwest report) that was also constructed by Origin geologists. The cross section shows what have been interpreted from seismic data as naturally occurring fractures and faults that extend through the WCM.

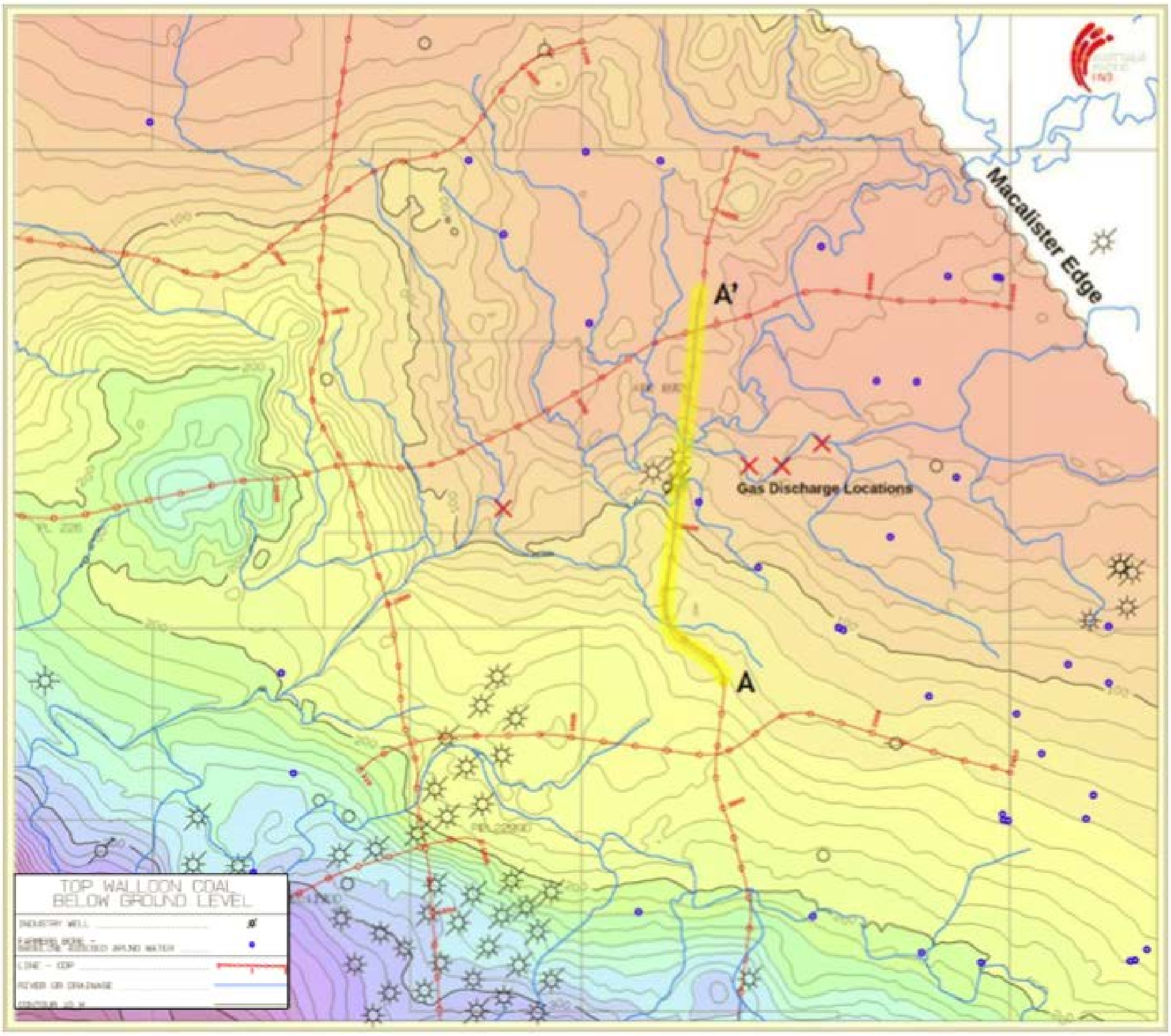
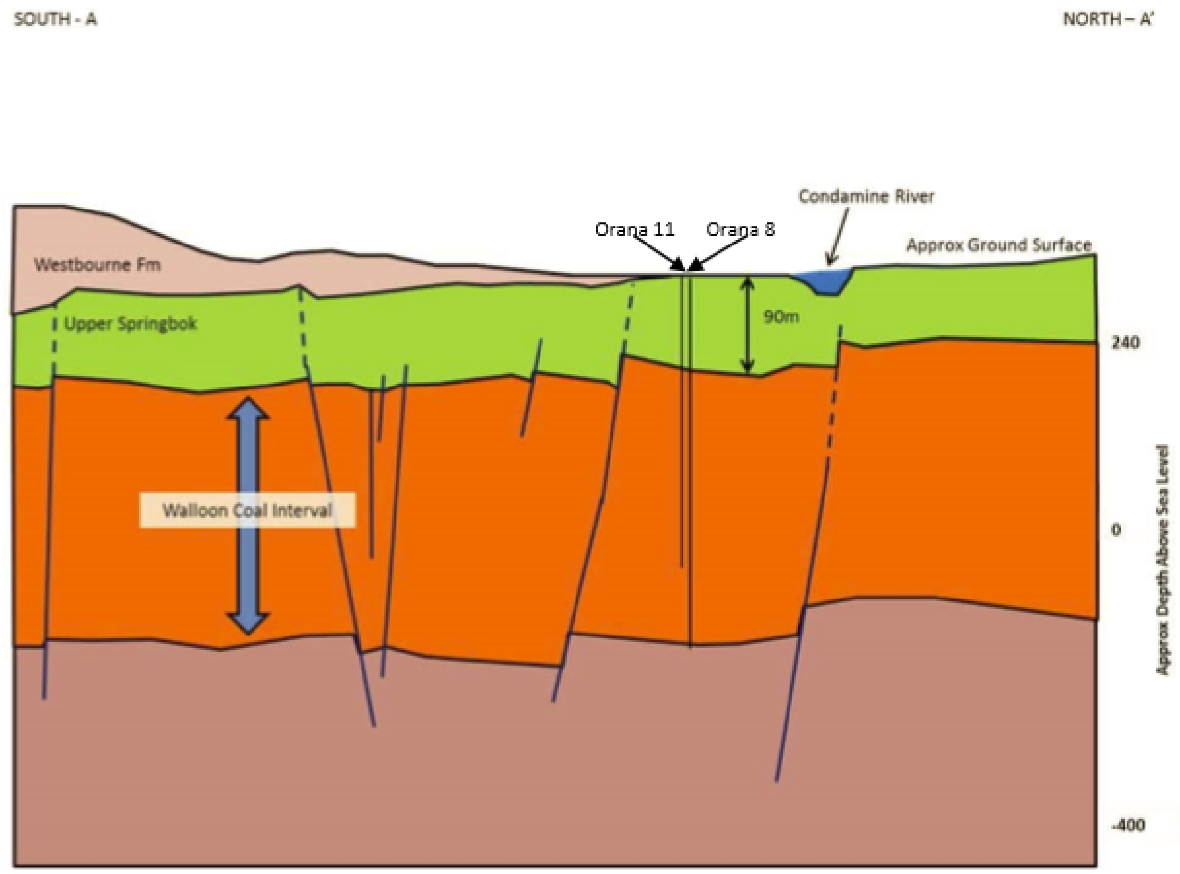



FIGURE 4-3
DEPTH BELOW GROUND LEVEL TO TOP OF WALLOON COAL MEASURES
Source: Origin Energy.
Line A-A' is the location of the N-S cross section shown in Figure 4-4.




Note:
This is a simplified cross section based on one interpretation of complex seismic data.

**FIGURE 4-4**
**PRELIMINARY GEOLOGIC CROSS SECTION**
**Source: Origin Energy.**
**The location of N-S cross section A-A' is shown on Figure 4-3**

Norwest state that 'although resolution above the WCM is poor, the seismic data may indicate that some of the fractures and faults extend up into the Springbok Sandstone. Site specific geologic conditions determine whether faults and fractures act as conduits for or barriers to the migration of gas and other fluids that are under pressure.'

### *Orana CSG Pilot Wells*

In 2008 Origin drilled four CSG pilot wells (Orana 8, Orana 9, Orana 10, and Orana 11) at locations approximately 1.25 km west of the Camping Ground seep (adapted from Figure 1-1 in the Norwest report). CSG pilot wells are drilled to obtain information about the nature, extent, and variability of the coal seams and the gas they contain. The four Orana pilot wells have not produced nor are they equipped to produce gas or water and they are not connected to production pipelines.

Norwest conducted a thorough and intensive investigation into Origin's CSG exploration pilot wells Orana 8, Orana 9, Orana 10, and Orana 11. Based upon the information reviewed and test results, Norwest conclude that it does not appear that the Orana 8, Orana 9, Orana 10, or Orana 11 wells are currently acting as conduits for gas migration to the ground surface (as of February 2014). Readers are referred to Norwest's (2014) report for full details.


Charleys Creek
Condamine River
Chinchilla Weir
Pump Hole
Camping Ground
Fenceline
Orana 9
Orana 10
Orana 8
Orana 11
Rock Hole
Condamine River

### *Coal Gas Bearing Units*

The two most likely sources of the methane discharging at the Condamine River seeps are the coal and gas bearing units of the Springbok Sandstone and the WCM.

The overlying Springbok Sandstone is lithologically heterogeneous and comprised of interfingering and interbedded sandstones, siltstones, and mudstone with some coals that were deposited in a variety of fluvial environments. In general the lower portion of the Springbok Sandstone contains more coarse grained rocks (fluvial sandstones) and less coal and fine grained rocks (overbank mudstones and coals) than the upper portion. Methane that is adsorbed onto coals in the Springbok Sandstone can desorb and become free gas when the hydrostatic pressure is reduced by water removal.

In places the base of the Springbok Sandstone contains sandstones that were deposited in fluvial channels that had eroded into the WCM. Scott et al. (2006) describe how these channel sandstones in the lower Springbok Sandstone can become charged with methane from the underlying WCM.

Permeability data from drill stem tests provided by Origin and QGC to Norwest indicate:

- Taroom (lower WCM) Coal Measures (up to 6,000 md)
- Jundah (upper WCM) Coal Measures (4 md to <1,000 md)
- Springbok Sandstone (0.1 md to 800 md). The coarser grained sandstone facies can be aquifers exhibiting higher permeability while the finer grained mudstones and siltstones can have very low permeability and act as aquitards.

### *Condamine River Hydrology and Climatic Factors*

Historical flooding, stream flow data, and water quality were obtained from Queensland Government, Department of Natural Resources and Mines (DNRM) website.

Norwest note that since the construction of the Chinchilla Weir in 1973 the Condamine River exhibits no-flow conditions approximately 25 percent of the time, and the reach of the river included in this investigation is considered to be ephemeral.

Historical stream flow record provided by APLNG to Norwest indicate that an average of 45% of the flow in the Condamine River occurs during the summer, 30% of the average annual flow occurs in autumn, and the remaining 25% of the flow occurs in winter and spring (Australia Pacific LNG. March 2010. *Australia Pacific LNG Project EIS*. Volume 2, Section 11.3.9: "Existing stream flow.").

Starting in December 2010 and culminating in January 2011, following heavy rainfall, the Condamine River overflowed its banks and caused excessive flood damage. High water levels occurred in the summer of 2011-2012 and summer flooding occurred again 2012-2013. The Pump Hole, Fenceline, and Camping Ground seeps were observed following the 2011-2012 flood events.

Site-specific factors may influence how precipitation and recharge affect methane seepage. Gas seeps may be related to high rainfall through several mechanisms, described in more detail in Section 10. These included erosion of the river bed removing a confining cap and allowing release of previously-trapped gas, and a number of other mechanisms related to the rise in the water table in the Springbok Sandstone due to direct infiltration from the River, and/or associated high recharge along the Springbok Sandstone outcrop.

While the data from the two Chinchilla weather stations (41017 and 42048) indicate local rainfall conditions in and around the 2010-2011 flood events, the driver for the flooding in the seep area of the Condamine River is the rainfall further up-catchment in the Condamine River basin.

### *Origins of Methane Gas*

Norwest discussed how methane is produced in two main ways, as follows:

1. By thermal breakdown and decomposition of deeply buried organic matter, under the influence of heat and pressure, and
2. By methanogenic microbes in anaerobic environments.

Methane produced by thermal breakdown is referred to as “thermogenic” methane.

Methane produced by methanogenic microbes is referred to as “biogenic” methane, which has two subsets. Methanogenic bacteria produce methane either (i) decomposition and fermentation of organic material or (ii) by reduction of $CO^2$ derived from respiration or dissolved bicarbonate.

Methane produced from these three processes is the same. Nonetheless methane produced by these different processes can be differentiated using the stable isotopes. This involves analysing gas samples from different sources, comparing the results, and identifying the stable isotope ratios that are typical of each source.

### *Initial Conceptual Model*

The Norwest ‘Draft Condamine River Gas Seep Investigation: Technical Report (28 February 2014) draws on experience with methane seeps in Colorado where methane emissions associated with coal bearing strata and CSG development has been studied for several decades. Norwest suggested established technology used in Colorado would be applicable for Queensland. Experience gained in the Colorado studies was used to help develop the strategy for investigating the Condamine River gas seeps and to develop the initial site conceptual model, as shown in Figure 5-1 below:

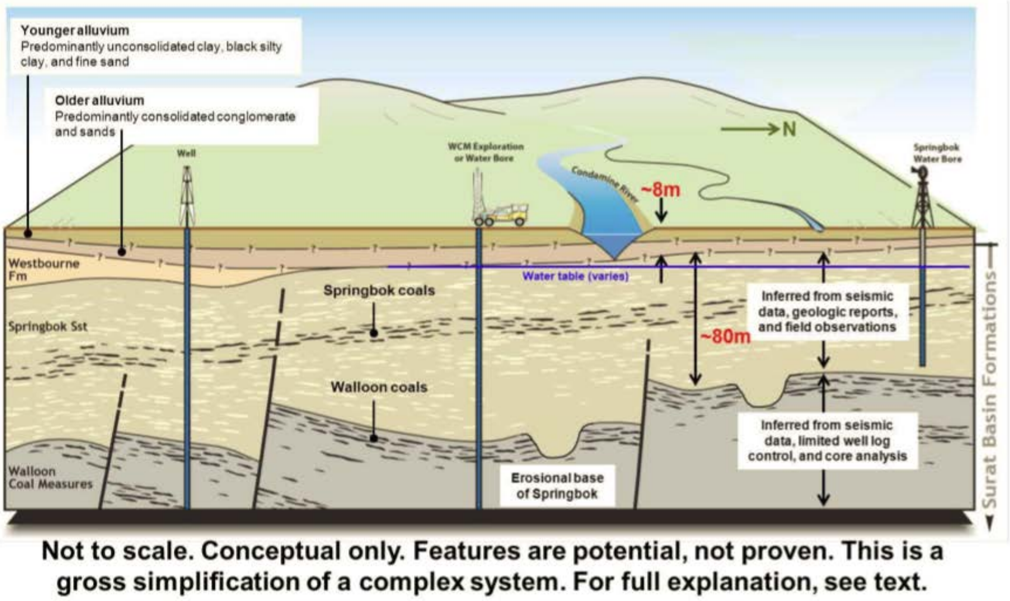



FIGURE 5-1
SITE CONCEPTUAL MODEL – GEOLOGY AND HYDROLOGY

ORIGIN ENERGY – 588-1
CONDAMINE RIVER GAS SEEP INVESTIGATION: TECHNICAL REPORT
5-2

Key elements of the initial site conceptual model (Figure 5-1) are:

1. The Springbok Sandstone overlies the WCM.

2. Coals within the WCM and Springbok Sandstone are the presumed primary source of the gas. The greater abundance of coals (and hence the main exploration target for CSG development) is in the WCM.

3. The widespread presence of free gas in the shallow geology within the study area has been observed for many decades as noted in water bores and coal exploration bores during drilling and under static conditions.

4. Because the Springbok Sandstone and WCM formations outcrop at the surface in this location and they are in part overlain by the Condamine River and associated alluvium, the study area represents part of the “intake beds” or recharge area for these formations.  This is the location in the Surat Basin where the outcrop of these can receive inflow of water which then infiltrates into the basin.  These formations are close to or at the surface and are therefore susceptible to water level/and pressure variations from rainfall and flooding events.

5. The study area has been subjected to historical and multiple recent substantial flooding events (4 times in 4 years).

6. The potentiometric head in the WCM at the Orana 8 well in 2008 was close to normally-pressured, that is, the water level in this CSG well would be close to the ground surface.

7. Water levels in the Springbok Sandstone are approximately 25 m below the ground surface. There is in some areas an unsaturated zone above the water table in which gas, air, or a mixture could be present.

8. The strata are gently-dipping (approximately1 degree), but not perfectly flat. As a result of the gentle dip to the southwest, the Springbok Sandstone outcrops and can be observed within the Condamine River channel near the upstream Pump Hole seep, whereas it is mapped as subcropping (near the regional edge of the Westbourne Formation) vertically below the downstream Rock Hole seep.

9. Variations in permeability, overall dip and stratigraphic thickness, and displacements across steep faults, present the potential for classic "gas traps".

10. Near-surface older alluvium, of two types: the upper unconsolidated clays and fine sands, and a lower consolidated conglomerate.

11. The Condamine River channel is deeply and steeply incised (~8 m) below its flood plain.

12. The consolidated conglomerate is exposed in large areas of the Condamine River channel, due to the down cutting river.

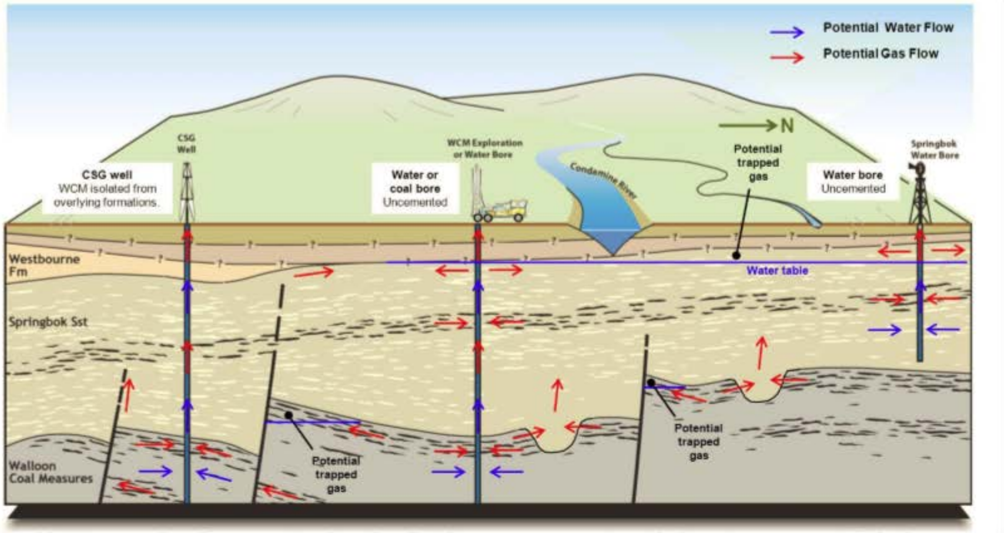
13. High-angle faults that could be flow barriers, or conduits.

14. Man-made conduits: CSG wells, water bores, and coal exploration bores. Typically CSG wells are cemented in formations above the producing zone, whereas water and coal exploration bores may be un-cemented.

15. Water bores may produce from single formations, or may penetrate two or more formations, thereby connecting them.

After investigations were carried out, Norwest subsequently refined the initial site conceptual model, as seen in Figure 11.1 of the Norwest report. It poses hypothesis regarding the potential sources, mechanisms, and migration pathways of the gas seeps in the Condamine River.

NORWEST
CORPORATION




Not to scale. Conceptual only. Pathways are potential, not proven. This is a gross simplification of a complex system. For full explanation, see text.

FIGURE 11-1
REVISED SITE CONCEPTUAL MODEL – SOURCES AND PATHWAYS

ORIGIN ENERGY – 588-1
CONDAMINE RIVER GAS SEEP INVESTIGATION: TECHNICAL REPORT
11-2

## *Summary and Recommendations by Norwest*

The following is a summary of the reports important points:

- There is very low overall formation dip (approximately 1 degree), minor variation in structure can create areas in which gas can be concentrated or trapped.
- A number of steeply dipping faults have been interpreted from existing 2D seismic data, but their vertical extent and their potential to act as barriers to, or pathways for, gas and fluid migration is not known.
- The Springbok Sandstone is partially confined and partially unconfined, with a water table ~25m below ground surface.
- Above the water table is an unsaturated zone that contains air and/or gas.
- The Springbok Sandstone and WCM are displaced across steep faults, creating potential classic 'gas traps', or alternatively acting as pathways.
- A consolidated conglomerate outcrops along large areas of the Condamine River channel, and has been cut through by river erosion.
- Gas samples from nearby water bores completed in the Springbok Sandstone and the WCM have similar stable isotope character as the gas samples taken from the Surat Basin.
- Prior to the observations of gas seeps in the Condamine River, methane had been encountered during the drilling and subsequent use of many water and coal exploration bores in the investigation area.
- There are known to be coal exploration bores in the area that are not always recorded, and generally these bores were not plugged (however, the locations for many of these bores are unknown).
- Origin performed downhole video inspections of eight gassy water bores. Due to obstructions in the bores it was not possible to clearly identify the formation from which the gas was entering the bore.
- CSIRO was engaged to develop methods to quantify the gas flux from the river.

- A bathymetric survey did not show a correlation between gas seeps and deeper or shallower sections of the river bed.
- Both Springbok Sandstone and WCM coals are potential sources for the gas observed at the seeps based on two QGC CSG wells. However there was uncertainty as to which formations, WCM or Springbok, the bores were accessing or whether the two sources were comingling.
- If the source of methane gas is the Springbok Sandstone, little migration would be required, as the Springbok subcrops directly beneath the alluvium, and in some cases outcrops in the bed of the river.
- Forty five water bores were identified, of which 25 were located and inspected. Methane was detected in 17 of the 25 bores, which are considered to have high potential to act as conduits for gas migration into the overlying aquifers and the atmosphere.
- There was a lack of methane detected at or around the CSG pilot wells in the Orana field. This indicated that gas was not migrating via these wells to the ground surface. These pilot wells have not produced water or gas.
- The main mechanism that can cause gas to migrate is depressurisation.

  Man-made depressurisation could be done by:

  a. Historic and ongoing water bore pumping.
  b. Coal exploration bores that were converted to water bores or that are allowed to flow gas.
  c. Connection of two formations by water or coal exploration bores.
  d. CSG production pumping.

  (Note: there is no mention here of fracking)

- Natural depressurisation could occur due to typical seasonal alternation of dry/drought and wet/flood conditions, sometimes extreme, provides a set of natural mechanisms that could also affect gas migration.
  a. Displacement of trapped gas due to falling or rising water tables.
  b. Dissolution of gas due to increased water pressure and release when pressures reduce.
  c. Release of dissolved and free gas at springs.
  d. Trapping of gas by capillary forces released at higher pressures that reduce gas bubble size.
  e. Erosion of a potential low permeability alluvium 'cap' due to stream bed erosion or shifting sediment.
- The primary data gap identified is subsurface data.
- Monitoring bore installation is a key recommendation.

No discussions on groundwater-surface water connectivity were given in the Norwest Technical Report (28 February 2014), nor were any references made to the GDE Atlas (Bureau of Meteorology, 2012).

### 3.5.4 Independent Review

The Review Panel commended the authors of the technical documents saying the studies were comprehensive and rigorous using appropriate methodologies. The results were well documented and the overall conclusions appear to be scientifically sound.

The panel were agreeable with the conceptual model developed by Norwest and the rigorous way in which the data gaps had been identified. They were happy with the detailed recommendations for future work.

The Review Panel were 'somewhat disappointed by the volume of investigations conducted to date (e.g. only one snapshot biological survey). General progress seems slow.'

The Panel supported the following conclusions:

- The gas seeping from the Condamine River is derived either from the underlying Walloon Coal Measures and/or the Springbok Sandstone.
- The release of gas from its natural habitat is primarily caused by depressurisation of the coals within the geologic formations. This may be related to anthropogenic withdrawal of water (i.e. by CSG and/or Coal Gasification activities), leakage of deep water upwards in abandoned bores that have been drilled for water extraction for coal exploration, or by natural variations in the water table.
- The gas is flowing to the surface by a variety of pathways including natural geologic pathways (such as faults and permeable layers), water wells and old coal exploration wells.
- Methane emissions from various sources occurred before CSG development in the region though perhaps not as vigorously as in recent years.
- There is currently insufficient information to identify the causes of the recent gas seepages in the Condamine River area. Further investigations are warranted.

The Review Panel comment on the Queensland Government report stated 'Water quality parameters alone (e.g. metal concentrations) are unlikely to give an indication of the potential impact of methane seeps on aquatic ecosystems'.

The Panel thought the Norwest report was interesting in that they agreed the established technology for monitoring methane seeps is applicable to Queensland and they regarded the Colorado approaches as the current scientific standard for studying onshore methane seeps of the type encountered in areas of coal bearing strata.

Most of the comments on the Norwest and the FRC Environmental reports were mostly to do with ecological studies, the lack of data submitted when reporting other studies and the lack of a sampling over different periods of time in the Condamine River, etc.

The Review Panel commented that 'a much better understanding of seeps on a regional basis is needed especially in terms of providing a baseline for changes over time that may be related to CSG development or groundwater withdrawal. A broad regional study of fugitive emissions is needed to understand the current methane flux and a system established to monitor variations over time….'

The Review Panel concluded with the following Recommendations:

1. The relative role of the various pathways is still poorly understood. The scale and location of faults needs to be documented. The nature of the contact between the Walloon Coal Measures and overlying Springbok Sandstone needs to be clarified.
2. Given the source of the gas is the shallow Walloon Coal Measures, natural variations in the water table would be expected to impact on emission rates as pressure in the coal will also change. The hydrogeological model would need to be superimposed on the geological model when it is ready.
3. The bathymetric study shows that there are certain rock layers that are preferentially leaking methane gas. However the nature of these strata is not recorded. Fractures are mentioned but are not clear if these are faults, true geologic fractures or bedding planes. Visual examination of the rocks would be very useful as it is unclear at the moment as to whether the migration of gas through strata (as opposed to wells/bores) is related to permeable strata or fractures and faults.
4. Water quality and gas data is compiled in a centralised geo-referenced database on an ongoing basis.
5. The methane is biogenic in origin and from geologic sources – not swamp gas. The study was not able to determine if the gas was from the Walloon Coal Measures or Springbok Sandstones. Detailed analysis of gases from various Walloon coal seams and the Springbok Sandstone in newly drilled wells elsewhere in the Surat Basin could be used to determine if geochemical signatures can be used to discriminate the source

especially after migration and potential mixing. This could be undertaken before any long-term monitoring of gas composition is planned.

6. Obtain broader spatial scale information on terrestrial and aquatic methane emissions from this region using appropriate mobile sensing methods for mapping across the landscape.
7. Further ecological studies should be conducted.
8. Further analysis of the seeps would require extensive monitoring of a range of parameters over a lengthy time period (several years).
9. Detailed recommendations provided by Norwest are critiqued in a workshop and a roadmap for future investigations developed.

## 3.6 Department of Environment 'Aquifer connectivity within the Great Artesian Basin, and the Surat, Bowen and Galilee Basins, Background review, Commonwealth of Australia 2014'

### 3.6.1 Introduction

This background review, published in June 2014, was commissioned by the Department of the Environment on the advice of the Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining. The review was prepared by the CSIRO and revised by the Department of the Environment following peer review. The following organisations contributed to the review:

- CSIRO Water for a Healthy Country National Research Flagship:
- Sinclair Knight Merz Pty Ltd (now Jacobs SKM)
- National Centre for Groundwater Research and Training
- Queensland University of Technology

The primary objective of this review is to document the range of scientific methods that have been developed to measure and model connectivity in any hydrogeological setting, and the specific knowledge of aquifer connectivity for the GAB, Surat Basin, Bowen Basin and Galilee Basin. The review captures expert knowledge from each of the primary authors and their respective organisations, as well as published material from text books and international peer-reviewed journals.

Important extracts from the review are given in the next sections.

### 3.6.2 Aquifer Connectivity

Aquifer connectivity is a term that describes the groundwater interaction between aquifers that are separated by an aquitard (often termed inter-aquifer leakage), or between different parts of the same aquifer (intra-aquifer connectivity). It is dependent upon the lithology of aquitards and aquifers, and their integrity and spatial continuity. Fractures, faults and open or inadequately-sealed boreholes can form preferential flow paths that also affect connectivity. The degree of connectivity and the rate of water and solute transfer between aquifers are strongly influenced by local and regional hydraulic pressure and dissolved mineral concentration gradients. As aquifer systems are dynamic, these gradients are constantly changing with time, as groundwater is recharged or removed from the system.

Any large-scale groundwater development, including that required for coal seam gas (CSG) production and dewatering of coal mines, needs to be managed with the best available information about aquifer connectivity. This is because prolonged groundwater pumping from multi-layered aquifer systems within the coal measures will affect other water bearing aquifers being used by other groundwater users (eg landowners, local shire councils, GDEs), depending on aquifer connectivity.

Potential impacts beyond the pumped aquifer can include:

- enhanced leakage of water from overlying and underlying aquifers and aquitards
- mobilisation of natural salts from overlying and underlying aquifers and aquitards, and deterioration of water quality in the pumped aquifer
- mobilisation of anthropogenic contaminants from overlying and underlying aquifers and aquitards
- changes in the nature and fluxes between surface water and groundwater systems near the ground surface
- declining water levels in shallow aquifers, leading to changes in the recharge and/or discharge rates.

### 3.6.3 Key Points

- Aquifer connectivity is a major determining factor in how groundwater pumping will affect other aquifers.
- There are many techniques available to investigate and evaluate aquifer connectivity that provide information at different spatial and temporal scales.
- Natural features (e.g. fractures and faults) and manmade structures (e.g. boreholes) and activities (e.g. longwall coal mining) can influence aquifer connectivity by providing preferential pathways for flow and contaminant transport.
- Few studies explicitly focus on connectivity and inter-aquifer leakage between the Great Artesian Basin (a major groundwater basin), the Surat (geological) Basin and the linked Bowen and Galilee (geological) Basins (of which the latter three have significant coal seam gas resources).
- Most existing groundwater models that claim to address aquifer connectivity via implementation of measured, site-specific hydraulic conductivity data will under-predict the magnitude of inter-aquifer leakage. This may be the case for the groundwater model used for drawdown predictions in the Surat Underground Water Impact Report (18 July, 2012).
- Priorities for future work include:
    - development of an agreed methodology for determining formation-scale hydraulic conductivity of aquitards and a consistent approach for modelling inter-aquifer leakage
    - understanding dual-phase flow (i.e the flow of both gas and water within coal seams) and the conditions under which it needs to be incorporated into groundwater flow predictions
    - understanding how desorption of coal bed methane may alter the hydraulic properties of the surrounding formations

### 3.6.4 Changes in Aquifer Connectivity

Natural (e.g. fractures and faults) and manmade (e.g. boreholes) structures can significantly influence aquifer connectivity because they can act as preferential pathways for flow and contaminant transport. In addition, they can cause changes to connectivity over time. Mechanical deformation of geological formations due to either depressurisation of aquifers by pumping, reinjection of co-produced water or hydraulic fracturing (commonly termed 'fracking') can enhance fracture connectivity and thus bulk hydraulic properties of the formation. In these instances, most of the induced fractures are propagated extensions of the natural fracture network, with characteristics determined by the geomechanical properties of the formation.

Aquifer connectivity, expressed in terms of flux (i.e. the amount of groundwater that flows through a unit area of the aquifer each second), can change from natural conditions solely by changing the hydraulic gradient. Mine dewatering, coal seam depressurisation, pumping for groundwater supply and co-produced water reinjection are all examples of how the hydraulic gradient can be changed. Uncertainty lies in what happens to the natural system as multiple operations come online over time (cumulative impact) and after the resources have been exhausted and the infrastructure is decommissioned. This is particularly the case for the situation where aquifer connectivity has been enhanced by the creation of new preferential pathways (e.g. fractures in aquitards, leaking borehole seals, reactivated faults) that will remain in place post-production.

The review states: 'A better understanding of the interplay between changing hydraulic conditions, in situ stress, mechanical deformation, fluid properties and hydrogeological characteristics and the subsequent implications for changes in aquifer connectivity is needed.'

### 3.6.5 Measurement and Modelling of Aquifer Connectivity

The review states: 'There is no single method by which aquifer connectivity can be measured or modelled. Rather, the hydraulic characterisation of the subsurface is done through measurement of properties on various time and spatial scales, from core samples in the laboratory to large scale field tests. Together these tests provide valuable and necessary information for the construction of models which may be used as predictive tools or for hypothesis testing.'

'In a 2010 state-of-the-science report entitled Management and Effects of Coalbed Methane Produced Water in the Western United States (NRC 2010), the National Research Council (NRC) identified the measurement of surface water and groundwater connectivity as a major data gap and uncertainty (in the USA). Geochemical, geological, geophysical, hydrological and other data are identified as key components in the necessary scientific evaluation and prediction of subsurface and subsurface-surface connectivity (NRC 2010).' Likewise in Queensland there is also major field data gaps and uncertainty in surface water – groundwater connectivity.

'Where laboratory tests provide estimates of hydraulic properties for the small scale core sized sample, field hydraulic tests can provide information on a scale from tens to hundreds of metres. Airborne and surface geophysical methods are best used to interpret the geological structure of the subsurface (layering of strata, identification of faults) and salinity distribution, and can cover large areas. Borehole geophysical methods are line measurements, but they can provide quantitative information on porosity, permeability thickness of permeable layers. Geochemical methods can provide insights into connectivity at a range of scales, from well-to-well using artificial tracers, right up to formation and regional scales using environmental tracers. Regardless, the use of a particular method will depend on the question being asked, and how best to address it. In order to evaluate and predict aquifer connectivity, the NRC (2010) recommends the use of many different measurement methods together, which is rarely done.'

### 3.6.6 Aquifer Connectivity in the Surat Basin

A detailed discussion is given by the authors in the review. An extract which was relevant to the Condamine River Catchment is as follows:

'Based upon comparisons of water levels and hydrochemistry, Hillier (2010) concluded that the Walloon Coal Measures and Alluvium of the Condamine River (CRAA) are currently hydraulically connected. The author presented hydrographs from bores sited in each formation and highlighted correlations in gradually decreasing water levels over time. Hillier also stated that a negative hydraulic gradient exists between the Condamine Alluvium and the Walloon Coal Measures. Similarly, the author proposed that elevated salinities in the Condamine Alluvium indicate input of lower quality groundwater from the underlying Walloon Coal Measures.'

The authors of the review concluded: 'Currently, there have been no significant studies of stress-induced connectivity in the Surat Basin. Similarly, no significant studies of diffuse leakage from aquifers in the Surat Basin have been undertaken. Borehole leakage in the Surat Basin was identified in a limited study by Habermehl (2009). Studies of groundwater discharge in the Surat Basin have identified the role of faults and fractures as preferential paths for vertical groundwater flow (Habermehl 1982).'

### 3.6.7 Knowledge Gaps in the Surat Basin

The authors of the review stated a number of knowledge gaps including the following:

- 'In-depth studies of the geomechanical properties of Surat Basin units have not been undertaken. Consequently, the potential for changes in hydraulic properties due to changes in stress regimes has not been studied in the Surat Basin. National-scale datasets of horizontal stress directions and magnitudes are available; however, for the purposes of addressing groundwater management issues, regional- or local-scale studies of the stress regimes associated with major faults and fractures in the Surat Basin would need to be undertaken.'
- 'Other than Habermehl (2009), no other published studies have investigated the occurrence of borehole leakage in the Surat Basin.'
- 'Numerical models of groundwater flow in the Surat Basin have historically focused on single-phase flow; consequently, no published studies of multi-phase flow modelling currently exist. This type of modelling would be particularly pertinent to future impact assessments involving mixed-phase flow (e.g. water and gas) in the Surat Basin. Similarly, geomechanical modelling of the potential effects induced by changes in stress fields in the Surat Basin (e.g. due to fluid and gas extraction or injection) is not publicly available. This type of modelling could assist impact assessments in the vicinity of tectonic stress features such as faults and fractures.'

### 3.6.8 Conclusions

The following components of work would assist in addressing aquifer connectivity knowledge gaps:

- research to develop improved methods for identifying fractures and faults and for determining formation-scale hydraulic conductivity of aquitards
- field data collection from the relevant geological formations to enable determination of effective hydraulic conductivity, which can then be fed into existing and future groundwater models
- development of a consolidated, cross-jurisdictional groundwater database that contains corrected hydraulic head data for assessment of potential areas of preferential inter-aquifer leakage
- research into the interplay between changing hydraulic conditions, in situ stress, mechanical deformation, fluid properties and hydrogeological characteristics and the subsequent implications for changes in aquifer connectivity
- establish an ambient earthquake baseline, using information from current active faults, to assess new and/or induced seismicity.

## 4.0 Linc Energy Underground Coal Gasification Plant (Hopeland)

Linc Energy developed a demonstration Underground Coal Gasification plant 20km south east of Chinchilla as shown below (Figure 1 Linc Energy Regional Site Location from Sinclair Knight Merz (March 2007).

Linc Energy UCG & GTL Project (Chinchilla) Terms of Reference for an EIS


Underground Coal Gasification (UCG) is the conversion of solid coal to a gas in-situ by heating the coal and introducing a mix of oxidants (air/oxygen and steam) to cause gasification rather than combustion of the coal. Typically, two wells are drilled into the coal seam, one to inject the oxidants, the other to extract the resultant synthesis gas, or syngas (principally hydrogen and carbon monoxide). The gasification rate is controlled by airflow pressure and temperature.

Linc Energy operated the Hopeland Underground Coal Gasification (UCG) plant up from 2007 until 2013, when the Queensland Government Department of Environment and Heritage Protection discovered serious irreparable environmental damage had occurred leading to the closure of the Hopeland UCG plant. The environmental damage was caused by subsidence as a result of the UCG process which had led to fractures opening up in the CRAA (the overburden) allowing methane, carbon monoxide and other by products of the UCG process to leak up to the ground surface. The Queensland Government is currently undertaking legal action against Linc Energy.

The Queensland Government has recently renewed Linc Energy's Mineral Development Licence 309 for 10 years, with specific conditions based on environmental requirements to ensure important decommissioning and rehabilitation activities can be completed. This includes groundwater abstraction to 'clean' the underground coal gasification area.

In their 'Initial Advice Statement' as part of Linc Energy's *Underground Coal Gasification, Gas to Liquids and Power Project - Referral of Proposed Action*, Sinclair Knight Merz (2006) noted the geology of the region suggested there was no direct hydraulic connectivity between the coal seam and the near surface alluvium or the seam and deeper aquifers (Golder and Associates 2006 as reported in 'Linc Energy UCG/CTL and Power Generation Project Chinchilla - Initial advice statement' (SKM, 2006)).

SKM (2006) stated groundwater studies suggested that although groundwater is impacted upon through the underground coal gasification process, current information and monitoring suggests that groundwater has no direct hydraulic connection above or below aquifers. SKM (2006) suggested as part of the EIS further investigations into the connectivity and movement of groundwater should be undertaken.

SKM (2006) stated that pollutant sampling in the groundwater, at that time, was of poor quality prior to site operation. Operation of the pilot burn resulted in increased levels of phenol benzene and PAH in the condensate (Golder Associates Pty Ltd 2006 as stated in SKM, 2006).

Linc Energy's Environmental Impact Statement was not available for the public to view in February 2016. However, it is possible the UCG process could have impacted on sub-surface environment beneath the Condamine River along the mid-reach areas. Migratory pathways may have been created from hydraulically fracturing the WCM and the overlying Kumbarilla Beds (specifically the Springbok Sandstone aquifer). Any natural fractures or cleats in the coal may have propagated vertically towards the surface. Given the right hydraulic conditions the shallow groundwater environment may have become hydraulically connected with the contaminated groundwater from the Linc Energy Hopeland UCG Plant.

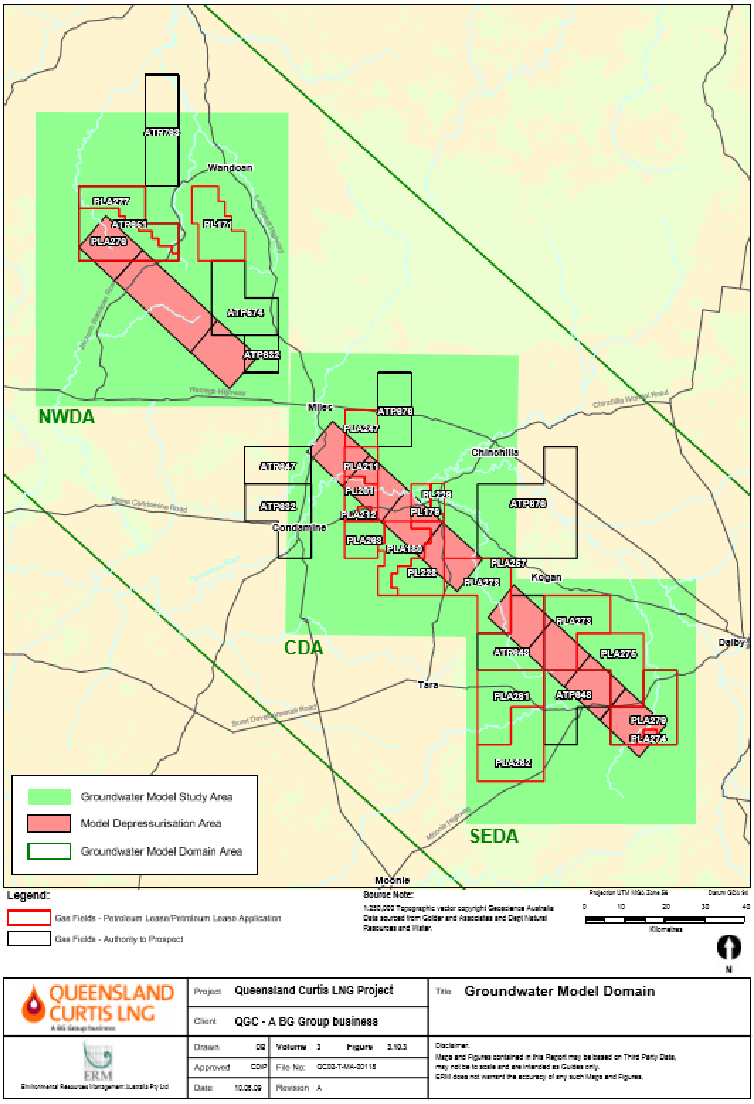
Coal seam gas exploration and production activities in Hopeland area may exacerbate the existing environmental damage Linc Energy has caused.

# 5.0 Queensland Gas Company Environmental Impact Statement

## 5.1 Introduction

In August 2009, Queensland Gas Company (QGC) lodged a draft EIS (Environmental Impact Statement) to describe the potential impacts and benefits of the Queensland Curtis LNG Project on the environment. QGC submitted a Supplementary Environmental Impact Statement in response to submissions from government agencies and the interested public. The supplementary environment impact statement and the draft environmental impact statement constitute the final environmental impact assessment for the Queensland Curtis LNG Project and describe the potential environmental impacts of QCLNG and ways to avoid, minimise or mitigate these impacts.

QGC are drilling 6,000 wells across their North Western Development Area (NWDA), Central Development Area (CDA) and South Eastern Development Area (SEDA). The three coal seam gas (CSG) development areas were conceptually and numerically modelled separately as shown below in Figure 3.10.3 of their QGC EIS (August, 2009) report. The Argyle and Kenya Gasfields are the closest to the Chinchilla farming region and form part of QGC's Central Development Area (CDA). The Argyle Gasfield is closest to those reaches of the Condamine River which are affected by migratory methane gas.




The purpose of this review is to determine whether adequate hydraulic data was collected as part of the QGC EIS (August 2009), to determine the nature of inter-aquifer flow and groundwater-surface water connectivity and whether there would be impacts to the Groundwater Dependent Ecosystems (GDEs). This review also determines whether cumulative impacts were determined as part of this project, and whether these included other operators in the area such as Linc Energy and APLNG/Origin.

The following sections quote pertinent information presented in QGC's 'Queensland Curtis LNG Volume 3: Environmental Impacts of Gasfields Chapter 10: Groundwater (August 2009)'. To assist in the development of the EIS, Golder Associates Pty Ltd (Golder) was commissioned by QGC to examine the effects of the CSG Field component of the Project on groundwater. This report is presented in Appendix 3.4 of the QGC EIS and is titled 'Coal Seam Gas Field Component for Environmental Impact Statement, QGC Groundwater Study Surat Basin, Queensland (June 2009)'.

QGC subsequently published its Supplementary EIS: Queensland Curtis LNG Volume 3 Gas Field Component: Chapter 10 (January, 2010) in response to submissions from government agencies and the interested public.

## 5.2 Inter-formation and aquifer leakage

Desktop and targeted field data was gathered as part of the Golder study. The modelling was carried out on an idealised rectangular shaped production well field layout; conceptualised to represent an irregularly distributed array of tenements (Golder, June 2009). Golder notes this layout only approximates the actual situation in the field and does not take into account the existence of other (adjacent) coal seam gas (CSG) producers bordering on, or in close proximity to, the Gas Field. No quantitative cumulative impact study has been carried out as part of the QGC EIS (2009).

The Conceptual Groundwater Model is over simplified, as was stated by Golder, but was an attempt to assist the assessment process and develop a meaningful model to assess potential impacts. However, in order to assess potential impacts in the vicinity of the CSG site, the model needs to represent the actual dynamics in that area. The lack of field data does not allow the CSG area to be meaningfully represented by this oversimplified conceptual and numerical groundwater model.

The following extracts from Golder (June, 2009) summarise the general hydraulic conditions in the Surat Basin sequence:

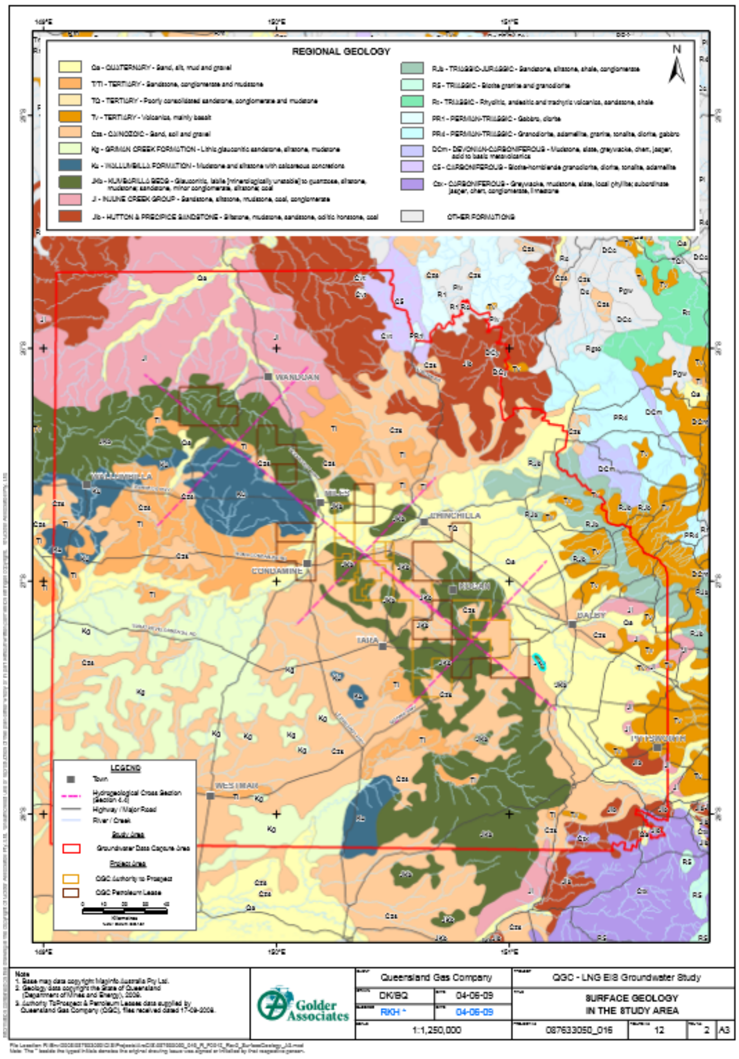
'Groundwater movement within the Surat Basin sequence is dominated by sub-horizontal flow which is largely controlled by the shallow dipping nature of the layered sequence, their hydrogeological parameters (primarily hydraulic conductivity) and structural overprints. Groundwater is inferred to flow, under the prevailing hydraulic heads, along the plane of the layers, parallel with their bedding and contacts. This translates to water flow down-gradient (effectively down the dip of the formations) toward the centre of the Surat Basin. Limited groundwater flow will likely take place perpendicular to the bedding plane, i.e. in the vertical direction or along strike.'

'Cross- or inter-formational flow (from bed-to-bed, layer-to-layer and unit-to-unit, in a vertical direction) is restricted by the natural bedding plane alignment of the sedimentary particles parallel to the bedding plane. In this way, limited flow is anticipated between the various units in the sedimentary sequence (as reflected in the high ratio of vertical conductivity to horizontal conductivity values (Kv/Kh)).'

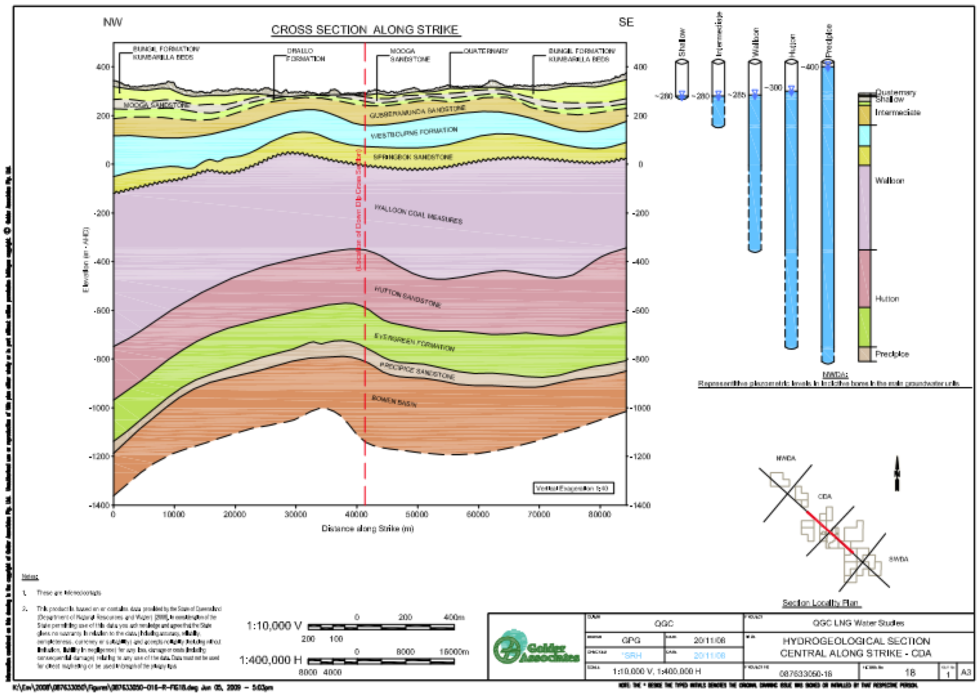
'It is noted that, within the GAB, inter-aquifer flows occur naturally where there is direct aquifer connectivity and where favourable hydrogeological conditions exist. This situation frequently occurs at the margins of the GAB or locally in association with existing faults. Inter-aquifer flow can be enhanced or changed as a consequence of groundwater abstraction.'

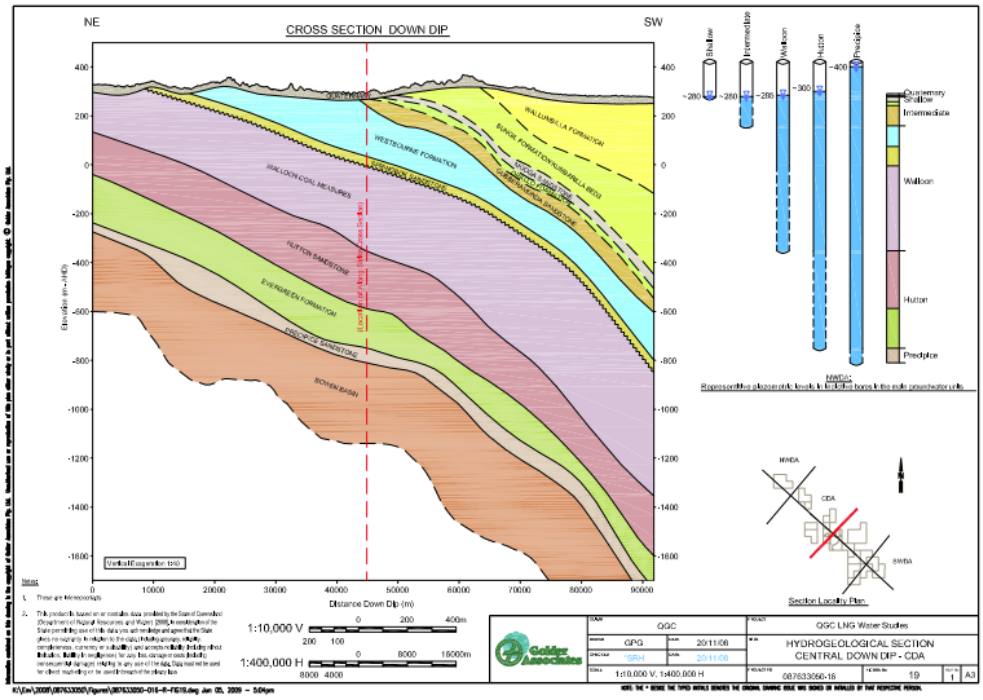
Inter-aquifer leakage is discussed in more detail in the supporting Golder document 'Coal Seam Gas Field Component for Environmental Impact Statement, QGC Groundwater Study Surat Basin, Queensland (June, 2009). This is found in Appendix 3.4 of the QGC EIS (August, 2010).

Figures 12 from Golder's report 'Coal Seam Gas Field Component for Environmental Impact Statement, QGC Groundwater Study Surat Basin, Queensland (June, 2009) shows the surface geology in the study area and the position of the cross and longitudinal sections.




Figures 18 and 19 from Golder (June, 2009) show the cross and longitudinal sections through the Central Development Area where the QGC Argyle and Kenya coal seam gas fields are located. Figures 18 and 19 also illustrate representative aquifer pressure levels (piezometric levels) in indicative bores in the main groundwater units. Groundwater pressure in these formations is weakly upwards. Depending on the connectedness of the aquifers, and the ability for fractures and faulting to act as conduits to groundwater flow there is a possibility for groundwater to flow upwards from the WCM into the CRAA. Therefore there is also an ability for methane gas dissolved in the WCM groundwater to also move upwards into the CRAA. When the depressurisation of the WCM/Springbok Sandstone aquifers occur the aquifer hydraulic gradient is reversed so there would be no longer groundwater flowing, with dissolved methane gas, upwards into the CRAA. However, migratory methane gas could move upwards into the CRAA via conduits such as faultlines, fractures, poorly constructed water bores and open 'old' coal exploration boreholes.




It was reported in Golder (June, 2009) that the three major development areas are separated by fault/s, fold/s or monocline/s (structural features). Within the development areas structural features also exist. In the Argyle and Kenya Gasfields are, the Central Development Area, there appears to be a feature Golder (June, 2009) refer to as the "Undulla Nose". They state:

'the "Undulla Nose" is believed to structurally affect the CDA WCM geology in a way that *enhances its permeability and porosity, inter-formational connectivity and groundwater availability*, as well as CSG resources and extractability.'

'The uplift tectonic forces that caused the nose structure to form also resulted *in a fractured environment developing though the sedimentary layers* above the nose (the coal measures are draped over the fault lineaments). The fractured environment of this sedimentary sequence has resulted in an *overall higher hydraulic conductivity (as has been observed in drill stem testing undertaken by QGC), porosity and storativity in all the lithological units (both aquifer and aquitard units) which comprise the sequence.* As a result, it is also ***possible that hydraulic connection of previously vertically isolated aquifers and aquitards has occurred, giving rise to the potential for of intra-formational groundwater flow under suitable hydraulic gradient conditions.***'

'Outside of the Central Development Area in the northwest and southeast; measurements of hydraulic conductivity fall considerably, by up to two orders of magnitude.'

It may be possible that at least some of this fracturing and faulting may play a role in the migration of methane gas into the overlying shallow, unconsolidated, CRAA unit that unconformably overlies the Surat Basin Formations (including the WCM, Springbok Sandstone and Kumbarilla Beds).

Recent faulting investigations were carried out by Grace Denis as part of a thesis (Royal Holloway, University of London thesis on 'Faulting in the Surat Basin and the Implications for Hydraulic Connectivity' (8 April 2013). As discussed in Section 3.3.2 and Section 3.3.3 of this review Denis (2015) suggested faulting may also be acting as conduit to migrant methane seepages.

In the lower portion of the Upper Condamine Catchment the river cuts into the consolidated Tertiary conglomerates deposited by the 'old' Condamine River which formed the paleochannel. It is possible that these consolidated conglomerates and the underlying Kumbarilla Beds are fractured along the faulting planes.

Golder (August, 2009) noted that the undulations observed in their piezometric head surface maps and water quality suggested hydraulic connection via favourable hydrogeological conditions (e.g. coincident areas of higher hydraulic conductivity in adjacent layers) does occur, to varying degrees, across the study area.

The limitations of the numerical groundwater model are outline in the Golder (August, 2009) report as follows:

- The model provides a simplified representation of actual conditions, with homogeneous isotropic conditions within the model layers, and assumptions related to the applied constant head boundaries.
- The lack of a significant data-set of site specific model input parameters, i.e. hydraulic conductivity (vertical and horizontal), Kv/Kh ratios, transmissivity and storativity values, means that the model outcomes are approximate and are able to provide indicative level estimates of groundwater head declines arising from CSG and groundwater extraction. They are considered suitable to provide the basis for developing guidance level decision-making tools for deciding precautionary management and monitoring practices. Conducting a pumping test program to estimate hydraulic parameters for every aquifer is vital. This data would provide a solid foundation for increasing the confidence in model predictions.
- The models have not been formally calibrated for steady-state or transient state due to the absence of appropriate long-term groundwater level monitoring data, and the absence of quantitative information on the amount of rainfall recharge occurring to areas where significant aquifers outcrop at ground surface.
- The model applies average (bulk) hydraulic parameters for the layers, however in reality, there is likely to be variability in hydraulic parameters within the model domain.
- The potential influence of residual drawdown from previous activities is uncertain because the three development areas were modelled independently.
- The model did not consider the influence that may occur from other neighbouring CSG extraction operations. That is, there is no cumulative impact assessment in the QGC EIS (2010).

- The sophistication of model predictions is necessarily limited because the extent of information available on the hydraulic properties of the various hydrogeological units is limited.

## 5.3 Groundwater-surface water connectivity

Groundwater is further discussed in the QGC Supplementary EIS (Volume 3 Gas Field Component: Chapter 10 Groundwater, Jan 2010).

In *Section 10.2.2.1 Groundwater Resources* the groundwater modelling predicted that QGC's CSG activities were unlikely to affect the groundwater contributions to baseflow and springs (QGC Supplementary EIS, Jan 2010). Golder's groundwater modelling predictions indicated that 'groundwater aquifer depressurisation resulting from inter-formational flow did not measurably impact on the shallow groundwater systems within the Project area'. They attribute this to 'the significant distance between the resources and the CSG wellfields and/or the minimal degree of potential impact predicted where the aquifers' outcrop or subcrop (e.g. the Springbok Sandstone).

Golder (June, 2009) discuss a reduction or loss of spring flow or baseflow contribution to rivers and creeks, as a result of CSG activities, could potentially affect the aquatic ecology of surface water ecosystems. They state that for this occur inter-aquifer leakage associated with coal seam depressurisation would have to propagate through a thick stratigraphic sequence of overburden formations above the coal seams to affect the shallow 'water table' aquifers.

The numerical modelling undertaken by Golder (June, 2009) for these groundwater systems suggest that the effects of inter-aquifer leakage are likely to be limited to the first significant aquifer overlying the depressurised coal measures, and the shallow groundwater resources are unlikely to be affected. Golder (June, 2009) predicted there will be no measurable reduction or loss of baseflow contribution to rivers or creeks as a result of the Project operations. However, the numerical model was not formally calibrated for steady state or transient conditions. As such any predictions the numerical model makes are questionable.

No quantitative studies were carried out on inter-aquifer leakage; and the simplified numerical groundwater model is based on a very limited dataset, with no detailed studies undertaken on the role of possible fracture and faultline increasing the permeability of the overlying formations. The Golder (June, 2009) investigations have not taken existing open old coal boreholes into account in the conceptual and numerical groundwater modelling. These would alter the groundwater system they are trying to make groundwater-surface water connectivity predictions. Golder (June, 2009) have also not taken into account the likelihood of increased permeability resulting from subsidence fractures from Linc Energy's coal gasification processes.

QGC EIS (2010) did not discuss groundwater-surface water connectivity nor did it discuss migratory methane gas in relation to existing unsealed old coal boreholes or water bores completed in the WCM and Springbok Sandstone aquifers.

## 5.4 Cumulative Impacts

In QGC Supplementary EIS (Volume 3 Gas Field Component: Chapter 10 Groundwater, Jan 2010) cumulative impacts were discussed. In '*Section 10.2.2.3 Cumulative Impacts'* Golder discussed:

'While the model provides a representation of aquifer behaviour in the NWDA region, it does not directly take into account the cumulative impacts which might result from groundwater extraction or dewatering associated with neighbouring CSG, UCG or coal mining activities in the same region. The exact details of these proposed activities are not currently known and as such have been treated here in a qualitative manner based on the inferred impacts presented by the proponents for each project.'

'In relation to cumulative effects of other CSG production….it is anticipated that the interference effect between QGC and Arrow and Origin CSG fields will be considerable but of the order (with respect to the magnitude of drawdown) of that predicted in the EIS.'

However, the QGC numerical groundwater used to predict the magnitude of drawdown is oversimplified and based on minimal field data. The numerical model was not calibrated for either steady state or transient conditions. As such it is uncertain whether the numerical model is fit to make predictions.

There was no mention of the cumulative effects of QGC with Linc Energy UCG plant and the existing open old coal boreholes.

## 5.5 Discussion

The previous sections have highlighted that the lack of field data for the numerical groundwater model and the inability for the model to be formally calibrated for steady state and transient conditions puts the predicting ability of the model into doubt.

QGC (August, 2009 and Jan, 2010) and Golder (June, 2009) did not have adequate data to characterise aquifer leakage/connectivity. Nor did they adequately discuss groundwater-surface water connectivity and the effect this has on GDEs.

Cumulative impacts with APLNG, Linc Energy and existing open old coal boreholes have not been addressed.

Golder (June, 2009) stated that:

'A potential adverse side effect of coal seam depressurisation is CSG production in water supply bores and wells screened within the coal measures targeted by CSG operations.'

Golder (2009) discussed that within the range of predicted drawdowns from the indicative numerical modelling, these effects are considered unlikely. However, this has occurred on the Bender family property 'Chinta'.

Golder (2009) stated:

'The degree of depressurisation is of such a magnitude as to induce desorption of CSG from such wells located outside of the perimeters of the CSG wellfields. Wells screened within the coal measures within the wellfield may be impacted by CSG release in these bores.'

Golder (2009) recommended QGC should monitor for methane and other CSG gases in water supply bores and wells screened within the coal measures of the CSG operations.

# 6.0 Australia Pacific LNG Environmental Impact Statement

## 6.1 Introduction

One purpose of this review was to determine whether inter-aquifer flow and groundwater-surface water connectivity was adequately discussed in the APLNG EIS (2010). This was to determine whether there was a risk pathway into the Condamine River Alluvial Aquifer and the Condamine River which will impact on Groundwater Dependent Ecosystems, including those landowners who are affected.

The other purpose was to determine whether there has been research carried out since the APLNG EIS was published that highlights the need for further investigations to be undertaken before the APLNG CSG activities are expanded in the Talinga and Orana CSG Gasfields.

The following sections summarise pertinent information presented by APLNG EIS (2010) in 'Volume 2: Gasfields Chapter 10: Groundwater' which was supported by detailed investigations and discussions by WorleyParsons Pty Ltd presented in 'Volume 5: Attachment 21: Ground Water Technical Report – Gas Fields'.

## 6.2 Inter-aquifer leakage

APLNG/WorleyParsons based there conceptual model mostly on studies by **Habermehl (1980)** *The Great Artesian Basin, Australia*. BMR Journal of Australian Geology and Geophysics, 5, p.9-38; and **Habermehl (2002)** *Hydrogeology, Hydrochemistry and Isotope Hydrology of the Great Artesian Basin*. Bureau of Rural Sciences, Water Science Program, Canberra, ACT; and **Hennig (2005)** *A Summary of the Hydrogeology of the Southern Eromanga and Surat Basins of the Great Artesian Basin*. CO2CRC Report No. RPT05-0024.

The following are extracts from APLNG EIS Volume 2: Gas Fields Chapter 10: Ground Water (March 2010 Page 17 Australia Pacific LNG Project EIS):

'It is expected that vertical hydraulic gradients vary across the study area and between units. Habermehl (1980, 2002) suggests that vertical movement between the aquifers is limited by the low vertical hydraulic conductivities of the confining beds (usually two or more orders of magnitude lower than the horizontal values). Despite the low hydraulic conductivities, the inter-aquifer leakage is estimated to constitute a significant portion of the water balance of the GAB (Habermehl 2002). '

'Geological features such as faults may also provide a pathway for groundwater movement between aquifers, specifically where faults connect aquifers (Hennig 2005), assuming that they are open and provide a pathway for fluid movement.'

No aquifer testing was reported investigating inter-aquifer leakage.

## 6.3 Groundwater-surface water connectivity

The following are extracts from APLNG EIS Volume 2: Gas Fields Chapter 10: Ground Water (March 2010 Page 17 Australia Pacific LNG Project EIS) on groundwater-surface water connectivity.

'The study area is principally located in the Condamine-Balonne River Catchment. Groundwater and surface water connectivity relationships in the catchment area have been assessed in numerous studies (e.g. CSIRO 2008; AGE 2005; Huxley 1982; Lane 1979).'

'The studies indicate that the Condamine River is variably connected to the watertable aquifer, with rates of interaction contingent on a range of factors including groundwater extraction, surface water storages in the Chinchilla Weir, river bed and aquifer permeability, geomorphology and climatic conditions.'

'Tributaries of the Condamine-Balonne River system in and around the study area are ephemeral in character. During rainfall events, flow in the creeks and streams partially recharges the underlying alluvial deposits. Groundwater in these deposits constitutes baseflow to the surface water courses once flow in the creeks and streams diminish, and only when the elevation of the groundwater surface is greater than the base of the streambed. The ephemeral nature of these tributaries implies that the effective storage within alluvial deposits is limited and insufficient to supply baseflow over the entire dry season.'

The EIS recognised 'there are various river reaches in the study area that potentially receive baseflow from the outcropping aquifer systems of the GAB', but did not discuss this further in any detail.

## 6.4 APLNG EIS Supporting References

APLNG EIS (2010) discussion on groundwater-surface water connectivity was a summary of a literature review by WorleyParsons Ground Water Technical Report in Volume 5 Attachment 21 of the APLNG EIS (March 2010).

APLNG did not undertake additional field work to collect more data to verify the following reported investigations.

Brief descriptions regarding the quoted studies by APLNG are given below:

- CSIRO (2008). Water availability in the Condamine-Balonne. *A report to the Australian Government for the CSIRO Murray-Darling Basin Sustainable Yields Project*. CSIRO, Australia. 169pp.

Groundwater and surface water connectivity relationships in the Condamine-Balonne River Catchment were assessed as part of the CSIRO Murray Darling Basin Sustainability Yields Project (CSIRO 2008). In CSIRO (2008) Section 2.4.1 'Groundwater management units – the hydrogeology and connectivity' they consider the GAB aquifers only where the intake beds for the GAB outcrop, and where the groundwater has the potential to be connected to surface water systems. CSIRO (2008) note 'the Upper Condamine subcatchment hydrogeology is complex. The alluvium, the basalts and the GAB intake beds are hydraulically connected in the east of this subcatchment. The basalts here were deposited over the GAB intake beds by volcanic processes. Streams forming on the basalts began to incise and deposit alluvium within small valleys. This process of incision continued until the streams incised down to the GAB intake beds. Therefore, all three geological units may be in direct hydraulic contact with each other at different locations in the tributary valleys.'

CSIRO (2008) state the alluvium within the central valley of the Upper Condamine is underlain by low permeability layers (aquiclude) of the GAB and it is not in hydraulic contact with the GAB intake beds.'

The APLNG Talinga/Orana Gasfield straddles the lower boundary of the Upper Condamine subcatchment and the upper boundary of the Mid-Condamine subcatchment. CSIRO (2008) state there are Jurassic and Cretaceous sandstone aquifers that form the GAB intake beds, consolidated Tertiary sediment (which we know are the 'older' alluvial sediments not deposited by the current Condamine River), and minor modern alluvium flanking the major rivers. Where sediments of the GAB outcrop, they are recharged from rainfall and stream infiltration (including the main channel of the Condamine River).

In March 2006 CSIRO carried out an assessment of the main channel loss to or gain from groundwater. This was to represent a *drier than average* conditions so fluxes equated to maximum levels of 'losing' conditions and minimum levels for 'gaining' conditions for each reach.

That is:

- CSIRO undertook investigations in drier than average conditions
- River loss below the river bed was very high

- Groundwater table was at a depth quite below the river level so it was unlikely to provide recharge to the river along its reach.

Connectivity mapping estimated the potential flux of water to and from the river based on the proximity of underlying groundwater and the hydraulic gradients in the vicinity. No intrinsic barriers to vertical flow were assumed and 'maximum losing' conditions generally equated to a disconnected system. 'Maximum losing' meant the groundwater level was so far below the river level (due to drought and/or overpumping, for example near Dalby) that the river could not effectively recharge the CRAA because the river recharge water was evaporated, utilised by plants and transpired or held within the soil clay pores before the river could effectively recharge the deeply lying groundwater table. Therefore the river was effectively cut off or disconnected from the underlying CRAA.

CSIRO found 'the majority of the Condamine River, its North Branch and the Oakey Creek tributary are under 'maximum losing' conditions, with river losses of between 0.4ML/day/km to 1.8ML/day/km (that is, the river is largely disconnected from the underlying aquifer). This may result from large-scale groundwater extraction since the late 1960s which as contributed to a large depression in the potentiometric surface of the alluvial aquifer to the east of the North Branch (as previously discussed in Section 3.2 of this review report) and also south-east of Dalby (SKM, 2003 as reported in CSIRO, 2008). The river is connected and 'losing' at a medium rate up to Elbow Valley, upstream from the junction with Hodgson Creek. The main branch of the Condamine River is 'losing' at medium (0.37ML/day/km to 0.44ML/day/km) to high (1.3ML/day/km) rates from Tummaville to Chinchilla Weir. Surface water storage at the weir has changed conditions to 'gaining' immediately downstream of the weir at rates of between 0.05ML/day/km to 0.11ML/day/km.

CSIRO (2008) reported 'The Upper Condamine groundwater model assessed the Condamine River from Loudons Tailwater (stream gauge (422333B) to Yarramalong, which is located approximately 135km upstream. These reaches were found to be under losing conditions, consistent with CSIRO's March 2006 results of the connectivity mapping.'

'The tributaries of the Condamine-Balonne River system in and around the study area are ephemeral. During rainfall events, flow in the creeks and streams partially recharges the underlying alluvial deposits. Under the right conditions, groundwater in these deposits subsequently constitutes baseflow to the surface water courses once the flow in the creeks and streams diminish. The ephemeral nature of these tributaries implies that the effective storage in the alluvial deposits is limited, with insufficient storage to supply baseflow over the entire dry season.'

- AGE (2005). *Report on Great Artesian Basin Water Resource Plan - potential river baseflow from aquifers of the GAB*. Australasian Groundwater & Environmental Consultants Pty Ltd. Prepared for Department of Natural Resources and Mines. Project No. G1294.

This report presented potential areas of groundwater and surface water interaction in the GAB WRP area, and contains mapping of the river reaches of river systems where there is a potential interaction with groundwater from aquifers of the GAB. This desk-top study, indicated the following river and creek systems may have the potential to contain reaches that receive baseflow from the following Great Artesian Basin intervals: The Kumbarilla Beds (Gubberamunda Sandstone equivalent) west of Dalby: Dogwood Creek, Condamine River, Wamboo Creek, Moonie River, Western Creek, Murri Murri Creek and MacIntyre Brook (summarised from APLNG/WorleyParsons Vol 5 Attachment 21, March 2010).

- Huxley (1982) *Condamine River Groundwater Investigation*.

Huxley (1982) Assessment of the groundwater input and output quantities of the alluvial aquifers and generation of a water balance within the Condamine River catchment.

WorleyParsons (March 2010) stated 'Huxley (1983) showed that during recharge events, a recharge mound builds up along the Condamine River. When river levels fall, following a rainfall event, discharge can take place back into the river. It was estimated by Huxley (1983) that downstream of Macalister where groundwater levels (at the time of his study) were near or above streambed level, approximately 1980ML/annum was discharged to the river from the shallow groundwater systems.'

- Lane (1979) *Progress Report on the Condamine Underground Investigation to December 1978* Volume 1.

Lane (1979) reported an investigation conducted to establish the feasibility of enhancing groundwater recharge through the clay soils along the Condamine River and the North Branch and in areas away from the North Branch on either side. As part of the investigation, a series of artificial recharge trials were conducted to facilitate actual measurements of absorption rates and assessment of likely recharge potential**.**

WorleyParsons noted CSIRO (2008) medium to high losing rates in the main branch of the Condamine River from Tummaville to Chinchilla Weir are supported by the infiltration trials conducted by Lane (1979). In his 1979 study, Lane considered that maximum river loss rates during low flow conditions in the Condamine River occurred between Ellangowan and the Pittsworth-Millmerran Road. As a result of his infiltration trials, Lane (1979) estimated the infiltration rates in this area to vary from 0.1ML/day/km to 0.3ML/day/km. Downstream of this point, Lane reported that the presence of interbedded clay strata reduced the infiltration rate.

## 6.5 Discussion

WorleyParsons (March 2010) stated 'the major river systems of the Condamine-Balonne River Catchment are variably connected with the underlying Cainozoic Units. Levels of groundwater–surface water interaction are largely controlled by climatic (rainfall) conditions, surface water storages and the magnitude of groundwater extraction from the alluvial system. The tributaries of the catchment system in and around the study area are ephemeral and may receive limited baseflow from the adjacent alluvial sediments for short durations following rainfall events.'

WorleyParsons (March 2010) stated that as 'described in Section 6.2.2, according to the initial 'project case' numerical model projections, the potential effects of the Project's CSG development on watertable intervals are indicated to be limited in extent. A number of these localised, shallow drawdown areas may have the potential to intersect major river systems of the Condamine-Balonne River Catchment. In particular, within and around Australia Pacific LNG's eastern and southern development areas, initial model projections indicate drawdown in the watertable aquifer (during and post-operation) in close proximity to the Condamine River, immediately downstream of the Condamine Weir.'

WorleyParsons (March 2010) state that: 'Such an effect to the watertable aquifer may have the potential to alter the groundwater – surface water interaction relationship of the Condamine River in this localised area.' WorleyParsons are effectively saying the groundwater – surface water interaction relationship of the Condamine River in the reaches immediately downgradient of the Chinchilla Weir is likely to be adversely affected due to the Talinga/Orana Gasfield CSG depressurisation activities. However they state: 'Operation of the weir itself is, however, likely to override any potential changes to the groundwater – surface water relationship in these localised areas.'

APLNG EIS (March 2010) groundwater-surface water connectivity discussions were based on desk top studies with no further fieldwork to obtain data to input into their numerical groundwater model. As such I think this is inadequate for an EIS for a CSG project which may have a considerable impact long term on groundwater-surface water connectivity.

# 7.0 Queensland Water Commission – Surat Underground Water Impact Report

## 7.1 Introduction

The Queensland Government states that:

'Petroleum and gas operators have the right to extract groundwater in the process of producing petroleum and gas because the water and the gas are intimately connected. The Surat Underground Water Impact Report (SUWIR) forms part of the regulatory framework for managing the impacts of this groundwater extraction (Underground Water Impact Report for the Surat Cumulative Management Area. Coal Seam Gas Water, Queensland Water Commission, 18 July 2012).'

CSG production is expanding in the Surat and southern Bowen Basins involving multiple companies such as Arrow, Queensland Gas Company, Santos and Australia Pacific LNG/Origin in adjacent tenements. As a consequence, the Surat Cumulative Management Area was established on 18 March 2011 (Queensland Water Commission, 18 July 2012). As required, the Queensland Water Commission has received approval for the Underground Water Impact Report by the Chief Executive of the Department of Environment and Heritage Protection (EHP).

The report has become a statutory instrument under the Water Act 2000. Obligations for individual petroleum tenure holders for activities arising from the Underground Water Impact Report have become legally enforceable. The EHP is responsible for ensuring petroleum tenure holders comply with their obligations.

The Underground Water Impact Report is to be strictly reviewed every three years. The next report which should have been published in July 2015 is now overdue. There has been no comment by the Queensland Government as to why this report has not been published.

## 7.2 Summary of findings in the Surat Underground Water Impact Report (18 July 2012).

The following is a summary of findings:

- CSG is produced from the Walloon Coal Measures which is part of the GAB in the Surat Basin.
- The GAB includes aquifers of economic importance; is critical for groundwater dependent ecosystems (GDEs); and has cultural significance.
- 21,000 water bores in the Surat CMA extracting ~215,000 megalitres per year (ML/year).
- 528 bores are expected to have a decline in water level of more than the trigger threshold due to CSG water extraction.
- 71 spring complexes (which in total contain 330 spring vents) in the Surat CMA. Springs are fed by aquifers.
- 43 watercourse springs in the Surat CMA.

A numerical groundwater model was constructed and verified by independent experts and meets the national standard 'Barnett et al, 2012, *Australian groundwater modelling guidelines*, Waterlines report, National Water Commission, Canberra.'

Predicted impacts include:

- 95,000 ML/year groundwater over the life of the industry.
- Groundwater levels will be impacted.
- Trigger threshold level is 5m for consolidated aquifers (e.g. Springbok Sandstone, Hutton Sandstone, Gubberamunda Sandstone).
- Trigger threshold level is 2m for unconsolidated aquifers (e.g. the Condamine River Alluvial Aquifer).

- Immediately Affected Areas: 85 registered bores in the WCM aquifer will have a water level decline greater than the trigger threshold within the next three years.
- Long-term Affected Areas: 528 registered bores are predicted to decline more than the trigger threshold level anytime in the future.
    - 400 bores are in the Walloon Coal Measures
    - 104 bores are in the Springbok Sandstone
    - 23 bores are in the Hutton Sandstone
    - 1 bore in the Gubberamunda Sandstone
- Predicted impact on the Condamine River Alluvial Aquifer (CRAA) is 1.2m along the western edge of the alluvium and 0.5m for most of the area. This impact is less than the trigger threshold of 2m and therefore the Queensland Government says there will be no long-term affected areas in the CRAA.

The government states there is an ongoing integrated regional water monitoring network in place. This is operated by government and petroleum tenure holders. To complete the regional monitoring network there will be:

- As of 18 July 2012 there was 102 monitoring points. (This is what the groundwater model was based on to make drawdown predictions. There is clearly a lack of data to base model predictions).
- 396 additional water level monitoring points will be constructed by petroleum tenure holders.
- Total network will then have 498 monitoring points at 142 sites.
- Water quality will be monitored at 120 sites.
- Legislation requires petroleum tenure holders to undertake a baseline assessment of private water bores before production commences.
- Petroleum tenure holders also have to carry out baseline assessments for any additional bores in which a water level impact of more than one metre is expected within the next three years.

Spring impact management strategy includes:

- Springs are fed by aquifers.
- If water levels decline in the source aquifers then springs will be reduced affecting GDEs.
- There are 5 springs in areas of predicted water level declines in source aquifers of more than 0.2m at the location of the spring.
- At these spring sites petroleum tenure holders are required to evaluate potential mitigation measures and submit reports to Office for Groundwater Impact Assessment (OGIA).
- Petroleum tenure holders are also required to monitor conditions of the springs and submit monitoring results to OGIA on a regular basis.

Petroleum tenure holders are obliged under law to 'make good' impairment of private bore supplies that result from petroleum and gas activities. The SUWIR sets rules for which petroleum tenure holder should undertake this work in areas where more than one tenure holder could be contributing to the impact. The EHP has legislative authority to ensure this obligation is carried out. 'Making good' could include:

- Making alterations to the bore.
- Establishing a replacement water supply.
- Or some other measure.

OGIA has stated that further research is required to improve knowledge about groundwater flow systems. Two critical areas were noted by the Queensland Water Commission (18 July, 2012):

- Interconnectivity between aquifers. New data will be fed into a new generation of groundwater flow modelling, which will support subsequent revisions of the SUWIR.
- Continued research into springs.

Summarising government and petroleum tenure holders' responsibilities:

- Government (OGIA) provide:
    - Oversight in the implementation of their report.
    - Prepare an annual report on implementation
    - Progress on the Water Monitoring Strategy and Spring Impact Management Strategy/
    - Obtain regular updates from the petroleum tenure holders about their development plans.
    - Assess if changes in development will cause changes to impact predictions.
    - OGIA will continue to liaise with the Gasfields Commission; EHP; and DNRM.

- Petroleum tenure holders provide:
    - Implementing the 'make good' obligations
    - Undertake baseline assessments
    - Implement the Water Monitoring Strategy and Spring Impact Mitigation Strategy.

## 7.3 Discussion

The implementation of the SUWIR is critical for the protection of groundwater dependent ecosystem (GDEs) and for those people who rely on groundwater as a water source and for cultural reasons. The success of the SUWIR depends on realistic conceptual modelling of the groundwater system, baseline and monitoring data (physical and chemical properties); realistic numerical groundwater modelling; effective mitigation measures by the petroleum tenure holders and oversight by the Queensland Government.

The SUWIR (2012) states:

*'Queensland's regulatory framework provides that a new UWIR is to be prepared at least every three years. In developing a new underground water impact report, key matters for consideration will be:*

*1. Is the regional groundwater flow model still appropriate for its purpose?*

*The Commission may update the existing model by incorporating new monitoring data into the model calibration, or alternatively build a new model if that would appropriately incorporate new knowledge and new technologies.*

*2. Is the regional water monitoring program still appropriate?*

*The Commission will assess if new understanding of the system indicates that the monitoring strategy should be extended or altered.*

*3. Is the spring impact management strategy still appropriate?*

*The current strategy has identified springs at risk, established monitoring requirements at those springs and required responsible tenure holders to evaluate options for impact mitigation at some sites. At the time of reviewing the underground water impact report, it is expected that new methodologies for monitoring will have been developed, and the need for mitigation strategies and appropriate pathways to implementation will have become clearer.*

*4. Are responsible tenure holder arrangements still appropriate?*

*Any changes in understanding about predicted impacts, changes to planned petroleum and gas development, and changes in tenure ownership may require revision of the assignment of responsible tenure holder obligations.'*

Currently the public is waiting for the release of the next SUWIR which is overdue as of July 2015. The critical data that has been gathered over the previous three years will highlight whether the implementation of the SUWIR recommendations has occurred. The next SUWIR will update whether the predicted effects on bore water levels and springs was conservative or not.

Importantly, the next SUWIR will contain more information regarding aquifer connectivity. Two short comings of the 2012 SUWIR have been:

- The lack of recognition of structural influences such as fractures and faulting on the effectiveness of the aquitards in protecting GAB aquifers. Recent studies by UNSW/Holloway College University of London have highlighted there is a need for more research in this area.

- The likelihood of increased hydraulic conductivity of aquifer and aquitards due to fractures and faulting. It does not matter how thick an aquitard is or how low its permeability is if there are fractures through the formation. An aquitard can be thin and effective if it is intact; and if there are many layers of these thin aquitards then they will be more effective than a thick aquitard affected by structural deformity (Dr Wendy Timms, UNSW, pers. comm.).

- The lack of discussion on groundwater – surface water connectivity. The 'bubbling' of methane gas in the Condamine River along specific reaches has led to CSIRO providing technology to Origin to determine the nature and source (s) of the methane gas and migratory path. Studies I have previously discussed suggest faulting may be responsible and need to be addressed in the next SUWIR.

SUWIR (2012) reports the areas currently targeted for research and these are briefly summarised as follows:

- interconnectivity between the Condamine Alluvium (CA) and Walloon Coal Measures (WCM);
- influence of geological structures on groundwater flow in the Surat CMA;
- hydrogeology of the Walloon Coal Measures;
- re-conceptualisation of the groundwater systems in the Surat and Bowen Basins in Surat CMA;
- second generation regional flow modelling for the Surat CMA;
- improving knowledge about springs.

## 8.0 Discussion and Conclusion

Iverach et al. (2015) investigation indicated that thermogenic methane from the Walloon Coal Measures is appearing in private groundwater bores completed in the overlying Condamine River Alluvial Aquifer in the middle area of the Upper Condamine Plains (south of Dalby and east of Cecil Plains). No conclusions were drawn regarding the methane gas migration pathway as the paper was primarily looking at using methane isotopes/dissolved organic carbon/tritium as a tool to determine methane gas sources. However, methane migration is suspected to occur via a natural fault ((Charlotte Iverach pers. comm. 6 February 2016 and Professor Bryce Kelly pers comm. 15 February 2016).

Grace Denis[2] mapped the locations of the major fault structures in the Surat Basin. Her studies have indicated three of the four boreholes completed in the CRAA affected by thermogenic methane from the underlying WCM lie along a natural faultline (Prof, Bryce Kelly pers comm., 15 February 2016). Professor Bryce Kelly informed me that further work needs to be carried out to confirm methane gas is migrating along the sub-vertical faultline.

On Sunday February 14, 2016, ABC's Mark Willacy reported the documentary 'The Condamine River's mysterious bubbling intensifying'. Professor Damian Barrett[3]said they have been monitoring the Condamine River gas seeps and confirmed to the ABC that the bubbling had intensified. Professor Barrett provided the following comments:

"There have been changes in the flux of methane through the river over the past 12 months."

"We know that methane is coming to the surface along a fault line, a very small fault line that occurs and intersects with the river."

"We know that the methane that is bubbling in that river is varying in time and the reason for that - while it is unknown - could be perfectly natural."

The Bureau of Meteorology GDE Atlas (2012) indicates from desk top studies that GDEs are reliant on a surface expression of groundwater along the Condamine River within the APLNG Talinga/Orana Gasfield. This GDE zone occurs from the Chinchilla Weir, and extends past the confluence with Charley's Creek and further downstream into the mid-Condamine River Catchment.

Many studies undertaken in the Upper- and Mid-Condamine River Catchment indicate there is inter-aquifer leakage between the Walloon Coal Measures, the overlying Springbok Sandstone and the Condamine River Alluvial Aquifer. The current bubbling water in the Condamine River has indicated an origin from the Walloon Coal Measures or the Springbok Sandstone, which has migrated under pressure into the Condamine River. Therefore there is strong field evidence proving there is a connection between the Condamine River and its Alluvial Aquifer downgradient of the Chinchilla Weir under favourable hydraulic conditions. There is also a connection between the river and the outcropping Kumbarilla Beds (including the Gubberamunda Sandstone) where the Condamine River cuts through.

To complicate matters further Coal Gasification activities carried out by Linc Energy between 2007 and 2013 included fracturing of the Walloon Coal Measures and this may have also created preferential pathways for the migration of methane gas into the overlying Springbok Sandstone aquifers. There are also an unknown number of old coal exploration boreholes open at the ground surface which allows methane gas to be emitted. In addition the poorly constructed boreholes act as conduits to migratory methane gas flow.

[2] Research Thesis, School of Earth Sciences, Holloway College, University of London.
[3] CSIRO's lead researcher into unconventional gas and who is also the director of the Gas Industry Social and Environmental Research Alliance, a partnership between the CSIRO and the CSG industry.

The migration pathway for the thermogenic methane gas from the Walloon Coal Measures and/or the Springbok Sandstone to the surface water is uncertain. There may be a number of conditions responsible for this, for example, faulting, fracture migration in the overlying confining aquitard units of the Kumbarilla Beds, poorly constructed water and old coal wells, the right groundwater-surface water hydraulic conditions, the water level in the Chinchilla Weir and climatic conditions. Maybe they all have a role to play in the migration of methane gas from the Walloon Coal Measures and/or Springbok Sandstone.

The Queensland Government report released in December 2012 found the cause of the bubbles was "unlikely to be determined in the short-term, and that a long-term approach to find more science-based answers to the phenomenon was needed". A spokesman for Queensland's Department of Natural Resources and Mines confirmed that there was "currently insufficient information to identify the cause of the gas seeps" and that further investigation was warranted. "Geological complexity and the requirement to gather and analyse surface and subsurface data make this a long-term investigation," the spokesman said.

Although APLNG recognised in their 2010 EIS ‘there were various river reaches in the study area that potentially receive baseflow from the outcropping aquifer systems on the Great Artesian Basin (GAB)’ these were not adequately discussed with actual field data characterising the groundwater-surface water hydraulic relationship. APLNG EIS (2020) did not undertake investigation of inter-aquifer leakage using hydraulic data from their own monitoring bores.

Likewise, Queensland Gas Company concluded only the Springbok Sandstone Aquifer (or ‘the first aquifer above the Walloon Coal Measures’) would be impacted, and the Condamine River Alluvial Aquifer and the Condamine River itself would not be negatively affected. However, this is based on a numerical groundwater model that had not been calibrated for steady state or transient conditions. Therefore the model is not considered here to be suitable to make such predictions.

QGC noted the area having a significant fractured environment of the sedimentary sequence which has resulted in an overall higher hydraulic conductivity (as has been observed in drill stem testing undertaken by QGC), porosity and storativity in all the lithological units (both aquifer and aquitard units) which comprise the sequence. As a result, it is possible that hydraulic connection of previously vertically isolated aquifers and aquitards has occurred, giving rise to the potential for of intra-formational groundwater flow under suitable hydraulic gradient conditions.

Both APLNG and QGC failed to carry out a cumulative impact assessment for the coal seam gas fields. Groundwater dependent ecosystem due diligence has not been adequately addressed in both Environmental Impact Statements.

The evidence gathered by scientists to date regarding inter-aquifer leakage and groundwater-surface water connectivity suggests that neither the APLNG Talinga/Orana Gasfield nor the QGC Argyle Gasfield should be extended. No underground coal gasification plants should be permitted in the Condamine River Catchment. Relevant, meaningful data needs to be gathered, processed and an updated numerical groundwater model completed, before the assessment of environmental effects is made.

The Surat Underground Water Impact Report (2012) is a good start in the cumulative management of the groundwater resource to protect GDEs and groundwater users. The SUWIR highlights the need to undertake further research in the following areas:

- interconnectivity between the Condamine Alluvium (CA) and Walloon Coal Measures (WCM);
- influence of geological structures on groundwater flow in the Surat CMA;
- hydrogeology of the Walloon Coal Measures;

- re-conceptualisation of the groundwater systems in the Surat and Bowen Basins in Surat CMA;
- second generation regional flow modelling for the Surat CMA; and
- improving knowledge about springs.

The next Surat Underground Water Impact Report is due and the data gathered over the previous three years will allow the groundwater model to be calibrated, updated and groundwater drawdown predictions to be checked.

Until the next SUWIR is released it would be negligent to allow any expansion of CSG activities in the Upper and Mid-Condamine River Catchment.

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# 10.0 Abbreviations

| | |
|---|---|
| APLNG | Australia Pacific Liquefied Natural Gas |
| CRAA | Condamine River Allluvial Aquifer |
| CSG | coal seam gas |
| CMA | cumulative management area |
| DNRM | Department of Natural Resources and Mines |
| EIS | environmental impact statement |
| EHP | Department of Environment and Heritage Protection |
| GAB | Great Artesian Basin |
| ha | hectares |
| m | metres |
| ML/year | mega litres per year |
| Mm | millimetres |
| mg/L | milligrams per litre |
| OGIA | Office for Groundwater Impact Assessment |
| Origin | Origin Energy Ltd |
| QGC | Queensland Gas Company Pty Ltd |
| UCG | underground coal gasification |
| UWIR | underground water impact report |
| WCM | Walloon Coal Measures |
| WRP | water resource plan |

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**10 July 2013**

**Referral Business Entry Point, EIA Policy Section (EPBC Act)**

Approvals and Wildlife Division

Department of the Environment, Water, Heritage and the Arts

GPO Box 787 Canberra ACT 2601

**Email:** epbc.referrals@environment.gov.au

**Fax:** +61 2 6274 1789

Dear Sir/Madam,

Reference Number: EPBC 2013/6918

Title: Santos NSW (Eastern) P/L/Exploration (mineral, oil & gas – non-marine)/PEL 238 & PAL 2, Narrabri Area, Gunnedah Basin/NSW/Energy NSW Coal Seam Gas (CSG) Exploration & Appraisal Program

I am an Independent Contract Hydrogeologist operating as a sole trader under the name Groundwater Solutions International, NZ. I worked for the formerly named Department of Water Resources, NSW, from 1992 until 1995 as a Project Hydrogeologist and was located in Gunnedah/Sydney. As a result of my work I obtained a good understanding of the hydrogeological processes that occur within, and between, the southern Surat Basin and Gunnedah Basin geological units, having undertaken an intense property-by-property three year study of all bores. Data collected and reviewed included bore and well hydrographic and water quality records; geological records from both the bores, wells and mining exploratory bores; hydrological data from creeks and rivers; and climatic data. I also participated in the mass installation of observation piezometers in the alluvial soils and shallow aquifers of the Liverpool Plains. I ran educational workshops for property owners and government employees working in the area. On occasions since then I have reviewed groundwater impacts of mining operations at the request of community groups. I remain an active interested party with respect to any hydrogeological investigations, and other relevant scientific studies, undertaken in the Namoi Valley Catchment.

**I consider that this action will have a significant impact on Matters of National Environmental Significance (Water Resources).**

## 1. Introduction

This review has been prepared in response to a document written by CH2M HILL (7 June 2013). This document, 'Referral of Proposed Action: Water Resources Assessment, Energy NSW Coal Seam Gas Exploration and Appraisal Program', was commissioned by Santos NSW (Eastern) Pty Ltd and serves as a supporting document for the Santos' Referral of Proposed Action which covers an area defined by Petroleum Exploration Licence (PEL) 238 and Petroleum Assessment Lease (PAL) 2 located in the Pilliga State Forest, Narrabri region.

## 2. Background

The federal government announced in March 2013 that it proposes to amend the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) (EPBC Act) to include Water Resources as a Matter of National Environmental Significance (MNES), in relation to large coal mining and coal seam gas (CSG) developments. In anticipation of this amendment, Santos commissioned CH2M HILL to provide an assessment of the potential risks of the proposed pilot activities and associated works, on the water resources within the potential influencing distance of the proposed action.

Of great concern are the potential impacts of CSG exploration on the groundwater quality and quantity within the Great Artesian Basin (GAB) Pilliga Sandstone aquifer beds and the Quaternary (recent) unconsolidated alluvial aquifers beds. The GAB aquifer beds within PEL 238 and PAL 2 provide water for stock and domestic purposes. Of equal concern is that the CSG Program is located above the Pilliga Sandstone recharge beds to the GAB, which are unique to the region. Any activity which intercepts and potentially removes water from the recharge areas, or potentially allows cross contamination of GAB waters with the poor water quality from the coal seams should be scrutinised in light of these potential risks. Any degradation of the GAB beds may have significant consequences to this unique and highly valuable water supply.

## 3. Discussion

The purpose of this review is to highlight those parts of the CH2M HILL Water Resources Assessment that require further consideration.

The three most important conclusions stated in the report and my comments are as follows:

1. *Based on the modelling of cumulative pilot operational impacts to groundwater within the Bohena Creek Alluvium and Pilliga Sandstone groundwater sources, impacts are* ***not significant****, defined as long-term drawdown of less than 0.5m.*

If models are going to be used to make critically important decisions on whether a sensitive water resource receptor will be affected, then it is important to get appropriate data at the outset. There is no hydraulic data on the hydrostratigraphic units presented in this report.

Step drawdown and aquifer recharge tests, long term pump tests, and chemical analyses could have been carried out on bores located within the Pilliga Sandstone aquifer. Critical information could have been collected using observation bores located in the overlying alluvial aquifer system and the Keelindi Beds. This would help determine whether there is a leaky component to the Keelindi Beds. This would determine whether the Pilliga Sandstone is a confined, semi-confined or leaky confined aquifer.

The same could be done for the underlying Purlawaugh Formation to see if there is any leakage up from the lower quality Garrawilla Volcanic fracture rock aquifer system through the Purlawaugh Beds and into the Pilliga Sandstone aquifer.

The pump tests would help clarify the conceptual hydrogeology of the aquifer, aquitard and aquiclude units.

In addition, it is not shown how the hydrostratigraphic, aquitard and aquiclude units have been characterized in the Numerical Model. For example, have model runs been made for leaky Keelindi and Purlawaugh Aquicludes? Is the Pilliga Sandstone modelled as a confined aquifer, or have runs also been made for a leaky confined or semi-confined aquifer.

If this was done then we could see how sensitive this model is to its inputs. As it stands I have no confidence in the numerical model outcomes and long term drawdown predictions for the Pilliga Sandstone and Bohena Alluvial aquifers of less than 0.5m.

2. *Risks of leakage of Produced Water to the water resource as a result of poor bore construction, improper site practices and operational procedures will be considered to be* ***low to insignificant*** *as they will be mitigated by adopting best practice site environmental processes and monitoring; appropriate site management procedures and appropriate design, construction, maintenance and monitoring.*

Even before drilling has reached the target seams and pulling out produced water I have concerns for well design in the initial stages of drilling. I have reservations about drilling an open hole, with water-based mud, right through to the Purlawaugh Beds before placing steel casing, back sealing with cement and then drilling through to the lower target formations.  There would be considerable difference in water quality between the Bohena Alluvial aquifer and the Pilliga Sandstone aquifer. I am concerned that if the Keelindi Beds do serve as a protective semi-confining layer then driving through without sealing off the alluvial aquifer first could induce unwanted leakage between the Bohena alluvial and Pilliga sandstone aquifers. The high water quality of the Pilliga Sandstone aquifer may be degraded due to a decrease in groundwater residence time (effectively allowing bacteria to enter into the bacteria-free Pilliga Sandstone aquifer).

Figure 4-4 Schematic conceptualisation of hydrostratigraphy of the Bohena Trough suggests the Pilliga Sandstone aquifer's potentiometric surface is well below the alluvial aquifer water table. This would set up the likelihood of groundwater leakage down from the alluvial aquifer to the Pilliga sandstone aquifer if the drilling fluid fails and/or the Keelindi Beds are leaky.

Table 5-3: Water Resources Impacts and Mitigation Measures outlines Santos' management/mitigation approach for stopping passage of water between transmissive units. I am not confident that the well design is appropriate for the section including the Bohena Alluvial and Pilliga Sandstone semi-confined aquifers, and the Keelindi Beds.

3. *'A detailed baseline and on-going monitoring program is to be implemented to provide baseline water level and quality data to validate results of modeling and provide early warning of any potential impact to water resources within and surrounding the Program area.'*

It may be more useful for this monitoring and model ground truthing to be undertaken **before** the start of the Program in the upper Gunnedah Basin and Surat Basin aquifer, aquitard and aquiclude units. Pump testing and groundwater analysis before and after this pump testing would take some of the uncertainty out of the hydraulic parameters assigned to these model layers (including introducing model layers representing the aquitards and aquicludes).

I do not think there is sufficient real data input into the numerical model. I do not think the conclusion stating 'impact to the Bohena Creek Alluvium and Pilliga Sandstone groundwater sources are considered **not significant**', is appropriate at this referral stage. Bore monitoring should be carried out and the numerical model run again before approving this Referral of Proposed Action.

## 4. Discussion on Specific Concerns

### 1) Table 4-4: Summary of Groundwater Receptors.

Table 4-4 is based on Table 2-3: Significance of Impact. The construction of Table 2-3: relies heavily on the defining of Sensitivity of Water Resource Receptor (Table 2-1) and the Magnitude of Potential Impact (Table 2-2).

According to Table 4-4 the Pilliga Sandstone is considered to be of Medium sensitivity. I disagree. The Pilliga Sandstone is part of the very limited GAB Recharge Beds. The recharge beds only exist in northern NSW and the eastern GAB area of Queensland. According to Table 2-1 they are considered to be of medium sensitivity as they are locally unique but have few regional equivalents. Just because they exist in Queensland does not mean they should be classified as medium. All the recharge beds should be classified as highly sensitive given the important job they have in keeping the GAB replenished and of good quality.

Pump tests on the bores located in the Pilliga sandstone aquifer in the project area will show how responsive the potentiometric surface is due to changes in water levels. I am not convinced the numerical model represents the true drawdown of the Pilliga sandstone aquifer at a radius of 2km of less than 0.5m over 500 years. What will it be in 3, 5, 10, 50 and 100 years? As this is what will directly affect the property owners and their livelihoods in the near future; and ecosystems which will struggle to recover if at all.

I am not convinced that drawdown effects occur for only a 2km radius and that, at worst, it will be less than 0.5m. I do not have confidence that the model is valid due to the ambiguous conceptual model (see comments on Figure 4-4 below) and lack of ground truthed parameter inputs.

### 2) Figure 4-4: Schematic Conceptualisation of Hydrostratigraphy of the Bohena Trough.

What part of the Program area is this really representing? This figure is inconsistent with topographic information shown on Figure 4-2 and Figure 4-3 Surface Geology. Without seeing any geological logs for the pilot bores, the surface geological map suggests the bores should have encountered Keelindi Beds before the Pilliga Sandstone. The Pilliga Sandstone recharge beds outcrop at the surface further to the east of the Program area and they dip to the northwest. The report stated the Pilliga sandstone was considered to be confined at the Program area, but some of the pilot bores suggest that this can't be the case in Figure 4-4. They suggest the pilot bores are located directly in the Pilliga Sandstone recharge beds. The cross section indicates the Keelindi Beds outcrop all the way up to the top of the Bohena Creek Catchment. It does not show the Pilliga sandstone exposed in the upper tributaries of the Bohena Creek catchment as Figure 4-3 does. Which is correct the Schematic Cross section or Figure 4-3 Surface Geology. This is important as it affects the Conceptual Model on which the Numerical Model is based.

Hence I do not have confidence the numerical model is correctly set up leading to questionable model outcomes.

### 3) Section 5: Potential Impacts and Management/Mitigation Measures

I have concerns with the validity of the model set up. Section 5 is vague and there are no tables summarizing the parameters assigned to the hydrostratigraphic units and the boundary conditions used. It is hard to know if the model is sound. Given how important the numerical model setup is to the model outcome and conclusions drawn on significant impactsMy concerns are discussed section by section as outlined in the Water Resources Assessment as follows:

*5.2.1 Model Development*

*Model Code and Layering*

1. The Keelindi Beds have not been modeled at all or not as a separate unit.
2. I don't agree that the Garawilla Volcanics and the Purlawaugh Beds should be modeled as the same layer. The Garawilla Volcanics is a fractured rock aquifer and the thinly bedded silts and clays of the Purlawaugh Beds probably act as an aquitard. Both have very different hydraulic characteristics and different roles to play in the numerical model.
3. The Triassic Digby, Napperby and Deriah Formations should be modeled separately. I would think they would all behave differently if the depressurized Permian target beds compacted over time. Some of these Formations may preferentially fracture along existing weakened planes and should be modeled for this scenario to see how they affect groundwater drawdown in the overlying Jurassic Garrawilla Volcanics, Purlawaugh Formation and Pilliga Sandstone beds.

I have no confidence the numerical model scenarios have been set up realistically.

*Configuration of Pilot Program*

I do not consider the results of the cumulative groundwater impact assessment should be considered to be conservative just because they included the five pilot sites within the proposed action. I do not think the setup of the numerical model has been done meaningfully. I do not think the conceptual model is clear and a model sensitivity analysis has not been reported to show how the drawdowns would change for various aquifer interaction scenarios.

*Historical Abstraction*

My concerns here are the vagueness of the comments. The historical abstraction values are used to form part of the steady-state model which in turn is used as the baseline for the predictive model. The predictive model outcomes contribute to the determination of aquifer drawdown in all the hydrostratigraphic units.

Which three pilot sites were used between March 2009 and February 2012? What formation were the bores screened over? What was the magnitude of these historical abstractions and was it for a continuous period (where the aquifers would be stressed so that good information could be obtained on aquifer characteristics)? Or were the abstractions for short time periods? The comments are vague as to whether the impacts on heads in the respective target seams were actually measured at the time of abstraction? What is the 'respective target'?

*Initial Conditions and Transient Simulation Protocols*

Initial heads (IH) for any of the hydrostratigraphic units are not available for the Program area.

A precursor 'steady-state model' was set up using limited data from the 'shallow Namoi Alluvial aquifers' and 'sparse head data for deeper layers obtained during exploratory drilling'.

Which 'deeper layers' are they referring to? Was this exploratory drilling the ten exploration bores they refer to further on? The groundwater regime and aquifer interactions in the Namoi alluvial aquifer will differ greatly from the Bohena Alluvial aquifer. Despite this, were the measurements from the Namoi alluvial aquifer carried out during the same time as the deep exploratory drilling? That is, were the measurements taken during the same climatic cycle?

The IH have then been used as 'seed heads' for the 'historical model'. As have historical abstractions from the pilot bores between March 2009 and February 2012. The historical model yields 'historical heads' (HH) which are supposed to represent the groundwater condition at the time of the start of the 'predictive model'.

The HH and the planned pilot site water extractions are used in the predictive model to yield 'pilot heads' (PH) representing the groundwater conditions at the end of the extraction phase of the last ten pilot sites.

There have been three steady-state models used, each relying heavily on the head conditions of the previous model, to produce the drawdown conditions in the Bohena Alluvial unconfined and Pilliga Sandstone semi-confined to confined aquifers. The dispute the validity of the initial heads and do not think in my professional opionion they represent the initial head conditions in the relevant aquifers. I also feel with each subsequent model being built the cumulative effect of these uncertain heads only increase my concern that they are not using a valid enough model to make statements that Bohena Alluvial unconfined and Pilliga Sandstone semi-confined to confined aquifers will not be significantly impacted.

A fourth model, the 'recovery model' was developed to simulate the recovery of groundwater heads over a 500 year period. They note they had to use three transient models to maintain model stability. I would like to know what part of the model was unstable, that is, which part of the model was sensitive to inputs and boundary condition changes? I believe the model was not robust enough and not valid for this water resource assessment. Ground truthing and some real head conditions needed to be input into the model earlier on before producing the predictive model.

*5.2.2 Model Outcomes*

Based on the numerical model inputs I do not have confidence the cumulative impact assessment indicates the depressurization of the target coal seam, as a result of pilot activities, would result in a negligible decline in water levels (less than 0.5m) within the Bohena Alluvium and the Pilliga Sandstone groundwater sources (the document actually says the Namoi Alluvium which I suspect is incorrect and should read Bohena Alluvium). They state that this would take at least 500 years to occur which I have no confidence in as there is no real data to suggest this.

**Table 5-3: Water Resources Impacts and Mitigation Measures.**

*Page 39* 'Evidence to date indicates non-artesian conditions within the vicinity of the pilot activities; this will be confirmed through further geological and hydrogeological investigations.'

Where is the evidence for this and in what formation? If they are referring to the Pilliga Sandstone they have modelled the hydrostratigraphic unit as being confined with artesian conditions. I do not have confidence in what is being modelled in this report and that the model outcomes suggest the Pilliga Sandstone aquifer will have less than 0.5m drawdown over the long term period (>500 years).

*Page 40* In Table 5-3 it is stated that the cumulative groundwater impact assessment undertaken for PEL238 suggests that coal seam depressurization will result in negligible decline in water levels within the Bohena Creek Alluvium and Pilliga Sandstone groundwater sources. I do not have confidence in the parameters set for the aquifer, aquitard and aquiclude model units and that the aquifer relationships are not modelled realistically. The do not think the numerical model is valid for this water resources assessment.

*Page 41* In Table 5-3 with reference to the decline in groundwater quality as a result of coal seam depressurization it is stated that ‘groundwater flow induced by CSG activities will be from generally ‘good quality’ aquifers and hence to ‘low quality’ coal seam aquifers and hence the risk to groundwater dependent ecosystems is low’. This suggests they are taking good quality groundwater away from groundwater dependent ecosystems.

### 4) Leewood Produced Water Storage Facility

I have concerns about the impact the Leewood Produced Water Storage pond will have on shallow groundwater flow. Bores completed in the shallow Bohena Alluvial aquifer located down gradient of the storage facility may experience a decrease in yield due to altered flow patterns by the impedinig nature of the storage pond. There is no information on the dimensions of the pond to check this and it has not been mentioned as a potential impact on a receptor in Table 5-3 or in Appendix A.

## 5. Summary

1. The Conceptual diagram of the Hydrogeology of the area is at odds with their geological and topographic maps.

2. Their conceptual ideas of how some of the hydrostratigraphic beds interact with each other, including the aquitards and aquicludes, are a cause for concern. Especially given this information forms the basis of the numerical model. Therefore, I have no confidence in the model outcomes.

3. I do not agree with the designation of the Pilliga Sandstone aquifer as a Medium sensitivity receptor as 'they are locally unique but have few regional equivalents'. This statement is ambiguous. The Pilliga Sandstone aquifer Recharge Beds are very limited regionally too and should be given a High sensitivity status anyway.

4. Drawdown of the Pilliga Sandstone leaky confined to confined aquifer potentiometric surface is significant when pumping commences. When the poteniometric surface is lower than the Bohena Alluvial unconfined aquifer water table then leakage from the alluvial aquifer down to the Pilliga via the Keelindi Beds would have an effect on the water quality of the Pilliga sandstone aquifer and the lowering of water levels in the Bohena alluvial aquifers. This means domestic bores could start to produce lower quality water and sensitive ecosystems would be adversely affected due to lack of water in the alluvial aquifer.

5. The absence of any ground truthing of the numerical models hydraulic parameters and the process by with the numerical model was developed does not give me any confidence in the model outputs which forms the basis of their arguments that the Bohena Alluvium and the Pilliga Sandstone aquifers will experience drawdowns of less than 0.5m (which they say only manifests over 500 years or more).

Yours faithfully

Andrea Broughton

Independent Hydrogeologist

*This submission has been prepared solely for the purpose of commenting on the supporting document 'Referral of Proposed Action: Water Resources Assessment' (CH2M Hill Australia Pty Ltd, 7 June 2013) which forms part of Referral of Proposed Action, Santos NSW (Eastern) Pty Ltd, Energy NSW Coal Seam Gas Exploration and Appraisal Program Gunnedah Basin. Neither this report nor its contents may be referred to or quoted in any statement, study, report, application, prospectus, loan, other agreement or document, without the express approval of Andrea Broughton, Groundwater Solutions International.*

### *Disclaimer*

The information contained in this desktop review is based on the contents of the Referral of Proposed Action: Water Resource Assessment (CH2M Hill Australia Pty Ltd, 7 June 2013), and my own professional experience. I accept no responsibility for the results of actions taken as a result of information contained herein and any damage or loss, howsoever caused, suffered by any individual or corporation.

The findings and opinions in this report are based on a desk top review undertaken by myself, Andrea Broughton, independent consultant (Contract Hydrogeologist, BSc (Hons), MAppSci Hydrogeology and Groundwater Management) of Groundwater Solutions International.