CONDAMINE RIVER GAS SEEP INVESTIGATION: TECHNICAL REPORT

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ORIGIN ENERGY
AND
QUEENSLAND CSG COMPLIANCE UNIT

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LIST OF TERMS, ABBREVIATIONS, AND SYMBOLS

Abbreviation	Meaning
%	Percent (parts per hundred)
‰	Per mil (parts per thousand)
<	Less than
>	Greater than
δC^{13}	Ratio of C^{12} and C^{13} isotopes
δD	Ratio of H^1 and H^2 isotopes
3D	Three-dimensional
AHD	Australian height datum (“mean sea level”)
Al	Aluminium
APLNG	Australia Pacific LNG
As	Arsenic
Ar	Argon
Arrow	Arrow Energy Limited
Atm	Atmosphere (unit of pressure, equivalent to 101.325 kPa, or 10.33 m of water head)
Ba	Barium
bbl	Barrel, common oil and gas industry measurement equal to 42 gallons
bgl	Below ground level
BOM	Australian Government, Bureau of Meteorology
bTOC	Below top of casing
Bo	Boron
bwpd	Barrels of water per day
C_1	Methane
C^{12}	C-12 natural and stable isotope of carbon
C^{13}	C-13 natural and stable isotope of carbon
C_2	Ethane
C_2H_4	Ethylene
C_3	Propane
C_3H_6	Propylene (cyclopropane)
C_6+	Hexane + heavier hydrocarbon compounds
CBL	Cement bond log
CBM	Coal bed methane
CH_4	Methane
Cm	Centimetre
Co	Cobalt
CO	Carbon monoxide
CO_2	Carbon dioxide

Abbreviation	Meaning
COGCC	Colorado Oil and Gas Conservation Commission
Cr	Chromium
CSG	Coal seam gas
CSGCU	Queensland CSG Compliance Unit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cu	Copper
DEEDI	Department of Employment, Economic Development, and Innovation (in March 2012 this department was split into multiple agencies)
DEHP	Queensland Government, Department of Environment and Heritage Protection
DERM	Queensland Government, Department of Environment and Resource Management
DIC	Dissolved inorganic carbon
DNRM	Queensland Government, Department of Natural Resources and Mines
DO	Dissolved oxygen
DST	Drill stem test
Dup	Duplicate sample
EC	Electrical conductivity
ECP	External casing packer
Fe	Iron
frack	Hydraulic fracture
FRC	FRC Environmental
GC	Gas chromatography
GDA	Geocentric datum of Australia
GISERA	Gas Industry Social and Environmental Research Alliance
GPS	Global positioning system
GSQ	Geological Survey of Queensland
H^1	H-1 (protium) natural and stable isotope of hydrogen
H^2	H-2 (deuterium) natural and stable isotope of hydrogen
H^2S	Hydrogen sulphide
HSE	Health, safety, and environment
iC_4	I-Butane
iC_5	I-Pentane
ICP-MS	Inductively coupled plasma mass spectrometry
ICP-OES	Inductively coupled plasma optical emission spectrometry
IR	Infra-red
km	Kilometre

Abbreviation	Meaning
kPa	Kilopascal
L	Litre
LNGEU	Queensland LNG Enforcement Unit
LNG	Liquefied natural gas
m	Metre
md	Millidarcy
mg/L	Milligrams per litre
MGA	Map grid of Australia
mGL	Metres below ground level
ML/d	Megalitres per day
mm	Millimetre
Mn	Manganese
mRT	Metres below the rotary table
N_2	Nitrogen
NATA	National Association of Testing Authorities, Australia
nC_4	N-Butane
nC_5	N-Pentane
ND	Not detected
O^{16}	O-16 natural and stable isotope of oxygen
O^{18}	O-18 natural and stable isotope of oxygen
O_2	Oxygen
ONF	O'Reilly Nunn Favier Surveyors
ORP	Oxidation reduction potential
P	Phosphorous
Pb	Lead
PDA	Personal digital assistant
pH	Hydrogen ion activity (measure of acidity and alkalinity)
PM	Permanent marker
ppm	Parts per million
QGC	Queensland Gas Company
REMP	Receiving Environment Monitoring Program
RN	Registration Number (for water bore)
SAP	Sampling and Analysis Plan
SMOW	Standard mean ocean water
SUIT	Southern Ute Indian Tribe
SWL	Static water level
TD	Total depth
TDS	Total dissolved solids

Abbreviation	Meaning
UCG	Underground coal gasification
US EPA	United States Environmental Protection Agency
USA	United States of America
UTM	Universal Transverse Mercator geographic coordinate system
V	Vanadium
VPDB	Vienna Pee Dee belemnite
WCM	Walloon Coal Measures
WQO	Water quality objectives
XYZ	Location in three dimensions
Zn	Zinc

EXECUTIVE SUMMARY

This Report presents the results of the first and second phases of the Condamine River Gas Seep Investigation. This is an investigation into four gas seeps at sites on the Condamine River located southwest of Chinchilla in Queensland, Australia. Gas seepage was first reported to the Queensland CSG Compliance Unit (CSGCU) (formerly LNG Enforcement Unit) by a landholder on 17 May 2012. It is a voluntary, integrated, and multi-disciplinary project commissioned by Origin Energy (Origin), in collaboration with the Queensland CSGCU.

Queensland Gas Company (QGC) also participated in the Condamine River Gas Seep Investigation by providing information about their coal seam gas (CSG) operations and baseline water bore sampling.

For the purposes of the investigation, there are four named seeps, from east to west (upstream to downstream), “Pump Hole”, “Fenceline”, “Camping Ground”, and “Rock Hole”. The following were investigated:

- The extent and source(s) of the gas emanating from the four gas seeps.
- The potential impacts to the environment, including groundwater and surface water quality, water supply bores, vegetation, and aquatic ecology.
- The potential pathway(s) and the mechanism(s) that enables gas migration.
- The potential contribution to the seeps from CSG activities, other industries in the area, water and coal exploration bores, and natural phenomena.

The first two phases comprised a wide range of desk and field investigatory activities, all of which contribute to an improved understanding of the nature and extent of the seeps. The work was not intended to, and should not be expected to provide immediate conclusions in the absence of sound scientific data. The results are presented in the context of an initial conceptual site model that includes the geology and hydrology of the study area. Based on the results, this report describes how the initial conceptual model has been expanded to include a range of potential sources, pathways, and mechanisms, and how the revised conceptual model has been used to develop recommendations for future investigatory and monitoring activities that will be conducted in a third phase of work.

The general geologic framework of the area is fairly well understood, but with the very low overall formation dip (approximately 1 degree), minor variations 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 initial site conceptual model includes the Springbok Sandstone overlying the Walloon Coal Measures (WCM), both gently-dipping to the south-west, and both overlain by low-permeability alluvium. The Springbok Sandstone is partially confined and partially unconfined, with a water table roughly 25 metres (m) 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. The Condamine River is deeply and steeply incised (~8 m) below its flood plain. A consolidated conglomerate outcrops along large areas of the River channel, and has been cut through by river erosion. The Springbok Sandstone is exposed in some areas of the channel. The initial model included the presence of many man-made potential conduits: CSG wells, water bores, and coal exploration bores.

The first two phases have confirmed the presence and persistence, and have mapped the general extents, of each of the gas seeps. One of the four seeps (Rock Hole) had been known before 2012, but the other three were reported as first observed in early 2012. Later information revealed that one of the latter three seeps (Camping Ground) had been observed in November 2011. There is also an unconfirmed report by one local landholder that bubbles have historically been present at the Camping Ground seep, but not as vigorous as the current bubbling. Although there is a range of dates of when the seeps were first observed, in this report the key date will be taken as 17 May 2012 – the date when the seeps were first reported to the CSGCU by a landholder. The seeps are located on properties which have not yet experienced CSG development (only exploration drilling).

Origin’s 70-kilometre (km) inspection of the Condamine River and a 21-km inspection of Charleys Creek did not identify any other gas seeps, including along a reach of the Condamine River that bisects Origin’s Talinga Field with producing CSG wells on both sides of the river. Determining whether the seeps were a short-term or persistent phenomenon was critical to developing and refining the conceptual model and for identifying the need and making recommendations for future investigation and monitoring. Seep gas samples are composed of 84% to 92% methane, with 7% to 13% nitrogen, and 0.12% to 0.53% carbon dioxide (CO_2). The stable-isotope character of the gas samples falls within the scatter area of Surat Basin CSG methane samples, as did gas samples from nearby water bores completed in the Springbok Sandstone and the WCM that have been bubbling methane for decades, some since they were drilled.

Data and observations presented in this report rely in part upon information obtained from existing water and coal exploration bores and CSG wells. Landowner interviews, government records, and published reports indicate that 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. Reports of methane in numerous bores date back to the early 1900s, predating CSG production.

Many water bores in the study area were visited and investigated, some of which are - or at one time were - gas-producing. In some cases water was vigorously gas-lifted from the bores at the time they were drilled, which pre-dates CSG development. However, records of bore construction are limited and it is not always certain from which formation bores have produced water and gas, or whether fluids and gas from different formations may be mixed. In addition, there are known to be coal exploration bores in the area that are not always recorded, and generally these bores were not plugged. These bores are likely to remain open or partially open, potentially allowing fluids from different formations to mix and to migrate. As a result, there are a number of potential man-made conduits for gas migration, not all of which are mapped or documented.

Origin performed downhole video inspection of eight gassy water bores, but due to obstructions in the bores, it was not possible to clearly identify the formation from which the gas was entering the bore.

Focused field investigations looked at different aspects of water and ecological quality in the Condamine River. Continuous monitoring of water levels, and regular sampling events for basic water quality parameters such as temperature, salinity, pH, and dissolved oxygen (DO) over several months, showed that conditions vary throughout the year. In the dry season, the river becomes a series of disconnected pools, conditions that cause salinity to increase and DO to decrease.

An aquatic ecology assessment was performed during the dry season, in early October 2012. The assessment was a significant expansion of an existing monitoring plan that has been approved for Origin's Talinga Water Treatment Facility's Receiving Environment Monitoring Program (REMP). This work is documented in a separate report. At eight locations, representing the seeps and upstream, midstream, and downstream locations, standard parameters were assessed for aquatic habitat, water quality, sediment, aquatic plants, zooplankton, macroinvertebrates, and vertebrates. The overall conclusion of this study was that the gas seeps are potentially having a minor impact on some water quality parameters, but there are no evident adverse effects on local flora and fauna. DO was lower at two of the three main seeps, but it did not appear to have had any immediate effects on aquatic plants, macroinvertebrates, or fish. This suggests that there has been minimal impact to the aquatic ecology in the Condamine River. Further monitoring was recommended.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) was engaged to develop methods to quantify the gas flux from the river. This required the development of new sample collection and measurement equipment and a method for deploying this equipment on the Condamine River. This work is considered "proof-of-concept" and continues to be refined and improved. Once the design has been finalized and the equipment successfully deployed and tested, the CSIRO will develop a monitoring protocol. The CSIRO has developed and deployed similar equipment and protocols for measuring and sampling methane flux and concentrations from several reservoirs in Australia, including the Little

Nerang and Hinze Dam. In addition, the CSIRO has been engaged under the Gas Industry Social and Environmental Research Alliance (GISERA) to conduct a separate preliminary research programme to characterise regional fluxes of methane in the Surat Basin, including natural seepage[1].

The extent of the seeps in the Condamine River was mapped with sub-metre accuracy. At the time of the mapping the lengths of the river segments that contained the four visible gas seeps were:

Seep	Approximate length of river segment (metres)
Pump Hole	59
Fenceline	196
Camping Ground	278
Rock Hole	100

At all four seeps bubbles were observed in certain parts of the river segments, but not over the entire length.

Soil gas testing was performed on the river banks and land adjacent to each seep, as well as at areas of stressed or dead vegetation identified by landowners. A total of 107 soil gas probes were installed. At all but one of the seeps, methane concentrations dropped below the detection limit within 10 to 20 m from the river. Next to the Camping Ground seep, methane was detected at one site 30 m from the river.

A bathymetric survey of the river was performed. This did not show a correlation between gas seeps and deeper or shallower sections of the river bed. This survey will act as a benchmark for future surveys, to help identify whether flood events redistribute river bed sediment or erode the base of the bed, and if so whether that has any effect on gas seep location or discharge rate.

Data provided by QGC regarding the CSG wells and production in their Argyle Field were evaluated and the results have been included in Section 9. Typically, gas monitoring during drilling in the Argyle field has shown low detections in the Springbok Sandstone, with the main gas shows being from the WCM. However, QGC provided documentation of the presence of large flows of gas from two CSG wells when they intersected the Springbok Sandstone. This indicates that both Springbok Sandstone and WCM coals are potential sources for the gas observed at the seeps.

[1] http://www.gisera.org.au/research/ghg/ghg-proj-1-methane-seeps.pdf.

The CSGCU has undertaken its own independent and comprehensive investigations and testing along the Condamine River. A two phased approach has been used: one focused on ensuring public safety, assessing environmental harm, and determining the extent and locations of the gas seeps and the other a long-term investigation that involves a process in which technical experts will verify the information received from Origin and its consultants.

The revised site conceptual model includes a number of hypotheses regarding sources, pathways, and mechanisms of the methane at the gas seeps, as follows:

Sources: Based on the stable isotope character of the methane at the seeps, the primary source of the gas seeps is coals in the Springbok Sandstone and/or WCM, and not shallow sourced "swamp" gas.

Pathways: Free gas will rise vertically through water due to buoyancy. There are several possible gas migration pathways. Geological pathways include updip migration via the more permeable beds of the WCM and Springbok Sandstone, and naturally-occurring fractures or faults. If the source is the Springbok, little migration would be required, as the Springbok subcrops directly beneath alluvium, and in some cases outcrops in the bed of the river. Man-made pathways include water bores and coal exploration bores that were not properly cased and sealed and hence may connect deeper and shallower formations. Water bores in the area are documented as being completed predominantly in the Springbok Sandstone, the WCM, or an unknown combination (i.e. Springbok and/or Walloon). There are many examples (both historic and current) of water bores producing gas, and documented coal exploration bore blowouts in the area.

Forty-five water bores were identified, of which 25 were located and inspected. Methane was detected in 17 of the 25 (68%), which are considered to have high potential to act as conduits for gas migration into overlying aquifers and the atmosphere.

CSG wells could also act as vertical conduits if they were not properly sealed in overlying formations. Data from the nearest CSG pilot wells in the Orana field was reviewed and soil gas measurements were made in their immediate vicinity. Lack of detection of methane at and around the wells indicates that gas is not migrating via these wells to the ground surface. These pilot wells have not produced water or gas.

Man-made mechanisms: There are several types of mechanism that can cause gas to migrate. The primary release of sorbed gas from coals is caused by depressurization. Man-made depressurization can be caused by historic and ongoing water bore pumping, by coal exploration bores that were converted to water bores or that are allowed to flow gas, by connection of two formations by water or coal exploration bores, and by CSG production pumping.

Natural mechanisms: The typical seasonal alternation of dry/drought and wet/flood conditions, sometimes extreme, provides a set of natural mechanisms that could also affect gas migration. These include displacement of trapped gas due to falling or rising water tables, dissolution of gas due to increased water pressure (and release when pressures reduce), release of dissolved and free gas at springs, trapping of gas by capillary forces (released at higher pressures that reduce gas bubble size), and erosion of a potential low permeability alluvium "cap" due to stream bed erosion or shifting sediment.

Following the principle of multiple working hypotheses, where there is insufficient data to eliminate any of these hypotheses, they have been retained, and it is recommended that more data is collected to test them further. Where there is sufficient data to eliminate hypotheses, they have been rejected.

This report focuses on results from Phase 1 and Phase 2 activities, and does not present final conclusions regarding one specific set of source(s), pathway(s), or mechanism(s) responsible for the observation and timing of the gas seeps. Expectations regarding conclusions at this stage in the study should be tempered, because the sources, pathways, and mechanisms are geologic phenomena that are typically based on inference from subsurface (bore and well) data.

The primary data gap identified in this report is subsurface data. Although prior to the observation of the gas seeps in 2012 Origin has implemented a baseline water bore monitoring program and has installed a network of groundwater monitoring bores elsewhere in their tenements where CSG production is occurring. However, in the seep investigation area Origin is currently acquiring data and implementing a monitoring network in advance of proposed future CSG development. The monitoring network is not yet fully operational, hence the data needed to evaluate relationships between seasonal droughts and rainfall, river levels, groundwater recharge, fluid production and reservoir pressure changes from CSG wells, variations in potentiometric levels, and gas release, are not yet available. Monitoring bore installation is a key recommendation for the next phase.