AGL Upstream Investments Pty Ltd

2013 Flow Testing of Craven 06 and Waukivory 03 Gas Wells

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PARSONS BRINCKERHOFF

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Author, Reviewer and Approver details

Prepared by:	Carolina Sardella	Date: 13/02/2014	Signature: 
Reviewed by:	Stuart Brown	Date: 13/02/2014	Signature: 
Approved by:	Rob Leslie	Date: 02/04/2015	Signature: 

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Parsons Brinckerhoff Australia Pty Limited

ABN 80 078 004 798

Level 27 Ernst & Young Centre
680 George Street, Sydney NSW 2000
GPO Box 5394
Sydney NSW 2001
Australia
Tel: +61 2 9272 5100
Fax: +61 2 9272 5101
Email: sydney@pb.com.au
www.pbworld.com

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Glossary

Acidity	Base neutralising capacity.
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.
Aquifer properties	The characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	An aquifer that is overlain by low permeability strata. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	An aquifer overlain by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the leaky confining layer – also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	Also known as a water table aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of an unconfined aquifer.
Artesian water	Groundwater that is under pressure when tapped by a bore and is able to rise above the level at which it is first encountered. It may or may not flow at ground level. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is a confined aquifer.
Biogenic methane	Biogenic methane is the principal product of anaerobic and bacterial decomposition of buried organic material. Biogenic methane can be formed by two processes; acetate fermentation where methanogens use acetate to produce CO_2 and methane, or CO_2 reduction (where methanogens use hydrogen gas to reduce CO_2.
Bore	A structure drilled below the surface to obtain water from an aquifer or series of aquifers.
Carbon-13 (^{13}C)	A natural, stable isotope of carbon and one of the environmental isotopes. It makes up about 1.109% of all naturally occurring carbon on Earth.
Carbon-14 (^{14}C)	Or radiocarbon is a radioactive isotope of carbon. Its nucleus contains six (6) protons and eight (8) neutrons. Its presence in organic materials is used in radiocarbon dating. It occurs naturally and has a relative abundance up to one part per trillion (0.0000000001%) of all naturally-occurring carbon on Earth. Carbon-14 is one of the most important nuclides in groundwater studies because its half-life of 5,730 years covers a critical time scale of ~500 to 50,000 years, which is ideal for dating regional and intermediate flow systems.
Cation	An ion with a positive charge – usually metal ions when disassociated and dissolved in water.

Chlorine-36 (^{36}Cl)	A naturally occurring radioisotope of chlorine. It has a half-life of 301,000±2,000 years and is suitable for age dating groundwaters up to 1 million years old.
Coal seam	A layer of coal within a sedimentary rock sequence.
Coal seam gas (CSG)	Coal seam gas is a form of natural gas (predominantly methane) that is extracted from coal seams.
Concentration	The amount or mass of a substance present in a given volume or mass of sample, usually expressed as microgram per litre (water sample) or micrograms per kilogram (sediment sample).
Confining layer	Low permeability strata that may be saturated but will not allow water to move through it under natural hydraulic gradients.
Deuterium (^{2}H)	Also called heavy hydrogen, a stable isotope of hydrogen with a natural abundance of one atom in 6,500 of hydrogen. The nucleus of deuterium, called a deuteron, contains one proton and one neutron, where a normal hydrogen nucleus has just one proton.
Discharge	The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.
Discharge area	An area in which there are upward or lateral components of flow in an aquifer.
Dissolved organic carbon (DOC)	The combined total of all organic carbon species dissolved in solution. Where dissolved is defined as below 0.45 micrometres.
Drawdown	A lowering of the water table in an unconfined aquifer or the pressure surface of a confined aquifer caused by pumping of groundwater from bores and wells.
Electrical Conductivity (EC)	A measure of a fluid's ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity.
Environmental isotopes	Also known as stable isotopes, they act as 'groundwater signatures' and can be used as natural groundwater tracers.
Fracture	Breakage in a rock or mineral along a direction or directions that are not cleavage or fissility directions.
Fractured rock aquifer	These occur in sedimentary, igneous and metamorphosed rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary rock aquifers.
Fracture stimulation	See hydraulic fracturing.
Global Meteoric Water	A line that defines the relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation from a number of global

Line (GMWL)	reference sites.
Groundwater	The water contained in interconnected pores or fractures located below the water table in the saturated zone.
Groundwater age classification	Groundwater ages are commonly referred to as: Modern <100 years Sub-modern 100-1,000 years Old >1,000 years
Groundwater flow	The movement of water through openings in sediment and rock within the zone of saturation.
Groundwater system	A system that is hydrogeologically more similar than different in regard to geological province, hydraulic characteristics and water quality, and may consist of one or more geological formations.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic fracturing	A fracture stimulation technique that increases a gas well's productivity by creating a pathway into the targeted coal seam by injecting sand and fluids through the perforated interval directly into the coal seam under high pressure.
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.
Hydrology	The study of the occurrence, distribution, and chemistry of all surface waters.
Ion	An ion is an atom or molecule where the total number of electrons is not equal to the total number of protons, giving it a net positive or negative electrical charge.
Isotope	One of multiple forms of an element that has a different number of neutrons than other atoms of that element. Some elements have isotopes that are unstable or radioactive, while others have 'stable isotopes'.
Lithology	The study of rocks and their depositional or formational environment on a large specimen or outcrop scale.
Local Meteoric Water Line (LMWL)	A line that defines the local relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation. In this report the LMWL used is for the Sydney region.
Major ions	Constituents commonly present in concentrations exceeding 10 milligram per litre. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulphate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.

Meteoric water	Water derived from precipitation (snow and rain).
Methane (CH_4)	An odourless, colourless, flammable gas, which is the major constituent of natural gas. It is used as a fuel and is an important source of hydrogen and a wide variety of organic compounds.
Methanogenesis	Formation of methane by microbes known as methanogens.
MicroSiemens per centimetre (µS/cm)	A measure of water salinity commonly referred to as EC (see also Electrical Conductivity). Most commonly measured in the field with calibrated field meters.
Monitoring bore	A non-pumping bore, is generally of small diameter that is used to measure the water level/pressure head of an aquifer and/or water quality. Bores generally have a short well screen against a single aquifer through which water can enter.
Nucleogenic isotopes (nuclides)	An isotope that is produced by a natural terrestrial nuclear reaction, rather than a reaction beginning with cosmic rays (the latter nuclides are cosmogenic).
Oxidising conditions	Conditions in which a species loses electrons and is present in oxidised form.
Oxygen-18 (^{18}O)	A natural, stable isotope of oxygen and one of the environmental isotopes. It makes up about 0.2 % of all naturally-occurring oxygen on Earth.
Percent modern carbon (pMC)	The activity of ^{14}C is expressed as percent modern carbon (pMC) where 100 pMC corresponds to 95 % of the ^{14}C concentration of NBS oxalic acid standard (close to the activity of wood grown in 1890).
Permeability	The property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. It is a measure of the relative ease of fluid flow under unequal pressure. The hydraulic conductivity is the permeability of a material for water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Permian	The last period of the Palaeozoic era that finished approximately 252 million years before present.
pH	potential of Hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).
Piezometer	See monitoring bore.
Precipitation	(1) in meteorology and hydrology, rain, snow and other forms of water falling from the sky (2) the formation of a suspension of an insoluble compound by mixing two solutions. Positive values of saturation index (SI) indicate supersaturation and the tendency of the water to precipitate that mineral.

Produced water	Natural groundwater generated from coal seam during flow testing and production dewatering.
Quaternary	The most recent geological period extending from approximately 2.6 million years ago to the present day.
Recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Radioisotope	Radioisotopes undergo radioactive decay allowing for determination of residence times in aquifers and groundwater systems.
Redox potential (ORP or Eh)	The redox potential is a measure (in volts) of the affinity of a substance for electrons – its electronegativity – compared with hydrogen (which is set at 0). Substances more strongly electronegative than (i.e. capable of oxidising) hydrogen have positive redox potentials. Substances less electronegative than (i.e. capable of reducing) hydrogen have negative redox potentials. Also known as oxidation-reduction potential and Eh.
Redox reaction	Redox reactions, or oxidation-reduction reactions, are a family of reactions that are concerned with the transfer of electrons between species, and are mediated by bacterial catalysis. Reduction and oxidation processes exert an important control on the distribution of species like O_2, Fe^{2+}, H_2S and CH_4 etc in groundwater.
Reducing conditions	Conditions in which a species gains electrons and is present in reduced form.
Residence time	The time that groundwater spends in storage before moving to a different part of the hydrological cycle (i.e. it could be argued it is a rate of replenishment).
Salinity	The concentration of dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS).
Salinity classification	***Fresh water quality –*** water with a salinity <800 µS/cm. ***Marginal water quality –*** water that is more saline than freshwater and generally waters between 800 and 1,600 µS/cm. ***Brackish quality –*** water that is more saline than freshwater and generally waters between 1,600 and 4,800 µS/cm. ***Slightly saline quality –*** water that is more saline than brackish water and generally waters with a salinity between 4,800 and 10,000 µS/cm. ***Moderately saline quality*** – water that is more saline than brackish water and generally waters between 10,000 and 20,000 µS/cm. ***Saline quality*** – water that is almost as saline as seawater and generally waters with a salinity greater than 20,000 µS/cm. ***Seawater quality*** – water that is generally around 55,000 µS/cm.
Saturated zone	The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric pressure. The water table is the top of

	the saturated zone in an unconfined aquifer.
Sandstone	Sandstone is a sedimentary rock composed mainly of sand-sized minerals or rock grains (predominantly quartz).
Secular equilibrium	A situation in which the quantity of a radioactive isotope remains constant because its production rate (e.g. due to decay of the parent isotope) is equal to its decay rate.
Sedimentary rock aquifer	These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater.
Specific yield	The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Specific yield generally relates to unconfined aquifers. Gravity drainage may take many months to occur.
Stable isotope	Stable isotopes are atoms of the same element that have different masses due to differences in the number of neutrons they contain. Stable isotopes are not subject to radioactive decay, meaning they do not breakdown over time.
Stratigraphy	The depositional order of sedimentary rocks in layers.
Surface water-groundwater interaction	This occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table adjacent to the streambed is greater than the water level in the stream; and (2) streams lose water to groundwater through streambeds when the elevation of the water table is lower than the water level in the stream.
Tertiary	Geologic time at the beginning of the Cainozoic era, 65 to 2.5 million years ago, after the Cretaceous and before the Quaternary.
Thermogenic methane	Thermogenic methane forms when organic matter present in a sedimentary geological formation is subjected to heat and pressure created by deep burial of sediments (coalification). The stress of this geological “maturation” process causes the methane molecule (CH_4) to break off from larger organic compounds.
Total Dissolved Solids (TDS)	A measure of the salinity of water, usually expressed in milligrams per litre (mg/L). See also EC.
Turbidity	Reduced clarity of surface water because of suspended particles, usually sediment.
Water bearing zone	Geological strata that are saturated with groundwater but not of sufficient permeability to be called an aquifer.
Water quality	Term used to describe the chemical, physical, and biological characteristics

	of water, usually in respect to its suitability for a particular purpose.
Water quality data	Chemical, biological, and physical measurements or observations of the characteristics of surface and ground waters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists.
Water table	The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.
Well	Pertaining to a gas exploration well or gas production well.
Wellbore	A wellbore is the physical hole that makes up the well and can be cased, open or be a combination of both completions. In this report it generally refers to uncased gas exploration boreholes prior to a gas well being completed.
Workover	The process of performing major maintenance or remedial treatments on an oil or gas well. In many cases, workover implies the removal and replacement of the production tubing string after the well has been killed and a workover rig has been placed on location. Through-tubing workover operations, using coiled tubing, snubbing or slickline equipment, are routinely conducted to complete treatments or well service activities that avoid a full workover where the tubing is removed. This operation saves considerable time and expense.

Abbreviations

List of units

°C	degrees Celsius
bbl	Standard oilfield barrel (*i.e.* 159 litres)
m	metres
mbgl	metres below ground level
m/day	metres per day
m^3/day	cubic metres per day
m/year	metres per year
µS/cm	microSiemens per centimetre
mg/L	milligrams per litre
mV	millivolt
‰	per mil
pCM	percent modern carbon
VPDB	Vienna PeeDee Belemnite
VSMOW	Vienna Standard Mean Ocean Water
yrs BP	Years before present

List of abbreviations

AGL	AGL Upstream Investments Pty Ltd
ANSTO	Australian Nuclear Science and Technology Organisation
BoM	Bureau of Meteorology
BTEX	Benzene, toluene, ethylbenzene and xylene
CSG	Coal seam gas
DTRIS	Department of Trade and Investment, Regional Infrastructure and Services
DIC	Dissolved organic carbon
DO	Dissolved oxygen
DRE	Division of Resources and Energy

EC	Electrical Conductivity
GFDA	Gas Field Development Area
GGP	Gloucester Gas project
GMWL	Global Meteoric Water Line
LMWL	Local Meteoric Water Line
LOR	Laboratory limit of reporting
ORP	Oxidation reduction potential
PAH	Polycyclic aromatic hydrocarbons
PEL	Petroleum Exploration Licence
PPL	Petroleum Production Lease
TD	Total depth
TDS	Total Dissolved Solids
TPH	Total petroleum hydrocarbons

Executive Summary

AGL Upstream Infrastructure Investments Pty Ltd is proposing to build the Gloucester Gas Project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas (CSG) from the Gloucester Basin. Part 3A Approval and EPBC Approval has been granted for the Stage 1 Gas Field Development Area (GFDA).

To assess gas flow potential and volume of water produced by coals within the Upper Permian Gloucester Coal Measures, and therefore determine whether the gas resource is economical, AGL Upstream Investments Pty Ltd (AGL) has undertaken a number of flow testing programs. For this study, flow testing was undertaken on the gas wells, Craven 6 (CR06) and Waukivory 3 (WK03) from April 2013 (CR06) and June 2013 (WK03) to November 2013. Samples were collected for chemistry and isotope analysis on three occasions, in June, August and October 2013.

The average water make at CR06 over the main flow testing phase was 8.8 m^3/day, with a peak produced water rate of 60.5 m^3/day and a minimum rate of 1.4 m^3/day. The average water make at WK03 over the main flow testing phase was 19.7 m^3/day, with a peak produced water rate of 42.4 m^3/day and a minimum rate of 8.2 m^3/day.

The produced water from CR06 and WK03 is characteristic of coal seams that produce methane. The water is brackish to saline, slightly alkaline, chemically classified as Na-HCO_3-Cl type water, and has low concentrations of sulphate, calcium and magnesium. The same trace elements were detected in both gas wells; however, concentrations are higher in CR06. Trace elements detected include molybdenum, manganese, chromium, zinc, fluoride and boron in low concentrations. Barium and strontium were detected in both gas wells, with CR06 having the higher concentrations. Moderate concentrations of barium and strontium are characteristic of coal seams. Ammonia is present in both wells at concentrations which are considered typical of coal seam waters.

Total petroleum hydrocarbons and BTEX compounds were detected at CR06 and WK03. Hydrocarbons have been found in early exploration programs in the Gloucester Basin indicating they are naturally occurring in the Gloucester Coal Measures.

Dissolved methane and ethane were detected in both gas well water samples, and dissolved propane was also present in WK03. The presence of higher chained carbon compounds is characteristic of thermogenically derived gas. Compound specific isotopes of dissolved methane (carbon-13 (δ^{13}C-CH_4) and deuterium (δ^{2}H-CH_4)) also indicate that methane detected in both gas wells is early mature thermogenic.

The stable isotopic composition (^{18}O and ^{2}H) is similar for WK03 and CR06, and indicates groundwater is of meteoric (rainfall) origin. The isotopic signatures suggest that the coal formations of the Gloucester Coal Measures have been flushed (original pore water replaced with meteoric recharge) at least once since deposition. The age of groundwater for both gas wells is beyond the limit of the radiocarbon dating method (>30,000 yrs) and from ^{36}Cl dating, it is more likely in the order of several hundred thousand years old.

Three water samples were collected from each of the gas wells throughout the flow testing period. No significant trends were observed in EC, pH, major ions or nutrients for either gas well for the testing period. Similarly, dissolved metal concentrations varied between sampling events, but there were no clear temporal trends. Minor changes in metals concentrations are expected during flow testing due to changes in pH and redox potential, and also because the gas wells are perforated against multiple coal seams of likely varying water quality and there is a variable volumetric contribution from each seam.

1. Introduction

1.1 Gloucester Gas Project

AGL Upstream Infrastructure Investments Pty Ltd is proposing to build the Gloucester Gas Project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas (CSG) from the Gloucester Basin. Concept Plan and Project Approval (Part 3A Approval) for the Stage 1 Gas Field Development Area (GFDA) was granted on 22 February 2011 under Part 3A of the *Environmental Planning and Assessment Act (1979) (EP&A Act)*. In addition the project received approval under the *Environment Protection and Biodiversity Conservation Act (1999) (EPBC Act)* (EPBC Approval) on 11 February 2013.

AGL Upstream Investments Pty Ltd (AGL) holds Petroleum Exploration Licence (PEL) 285, under the *Petroleum (Onshore) Act 1991*, covering the whole of the Gloucester Basin, approximately 100 km north of Newcastle, NSW. The Stage 1 GFDA in relation to the PEL boundary is shown in Figure 1.1.

The GGP will involve the dewatering of deep groundwater and the extraction of gas from multiple coal seams within the Gloucester Coal Measures. Target coal seam depths will vary from site to site but are expected to range between 200 and 1,000 metres below ground level (mbgl). The current GGP includes the construction, operation and decommissioning of not more than 110 coal seam gas wells and associated infrastructure, including gas and water gathering lines, within the Stage 1 GFDA.

1.2 Flow testing program

Craven 6 (CR06) and Waukivory 3 (WK03) are gas production wells that were drilled to test the gas flow potential and volume of water produced by coals within the Upper Permian Gloucester Coal Measures (Figure 1.2) (AGL 2009, AGL 2010). Flow testing of gas wells generally operates for several months to collect the necessary data to determine whether the gas resource is economical. Flow testing programs started in April 2013 at CR06 and in June 2013 at WK03 and ended in November 2013 at both wells. Testing is expected to recommence in 2014 at CR06.

1.3 Objectives

The objectives of this water quality monitoring program are to:

- characterise the water quality of the deep groundwater at CR06 and WK03
- identify any changes in water chemistry over the period of individual flow tests.

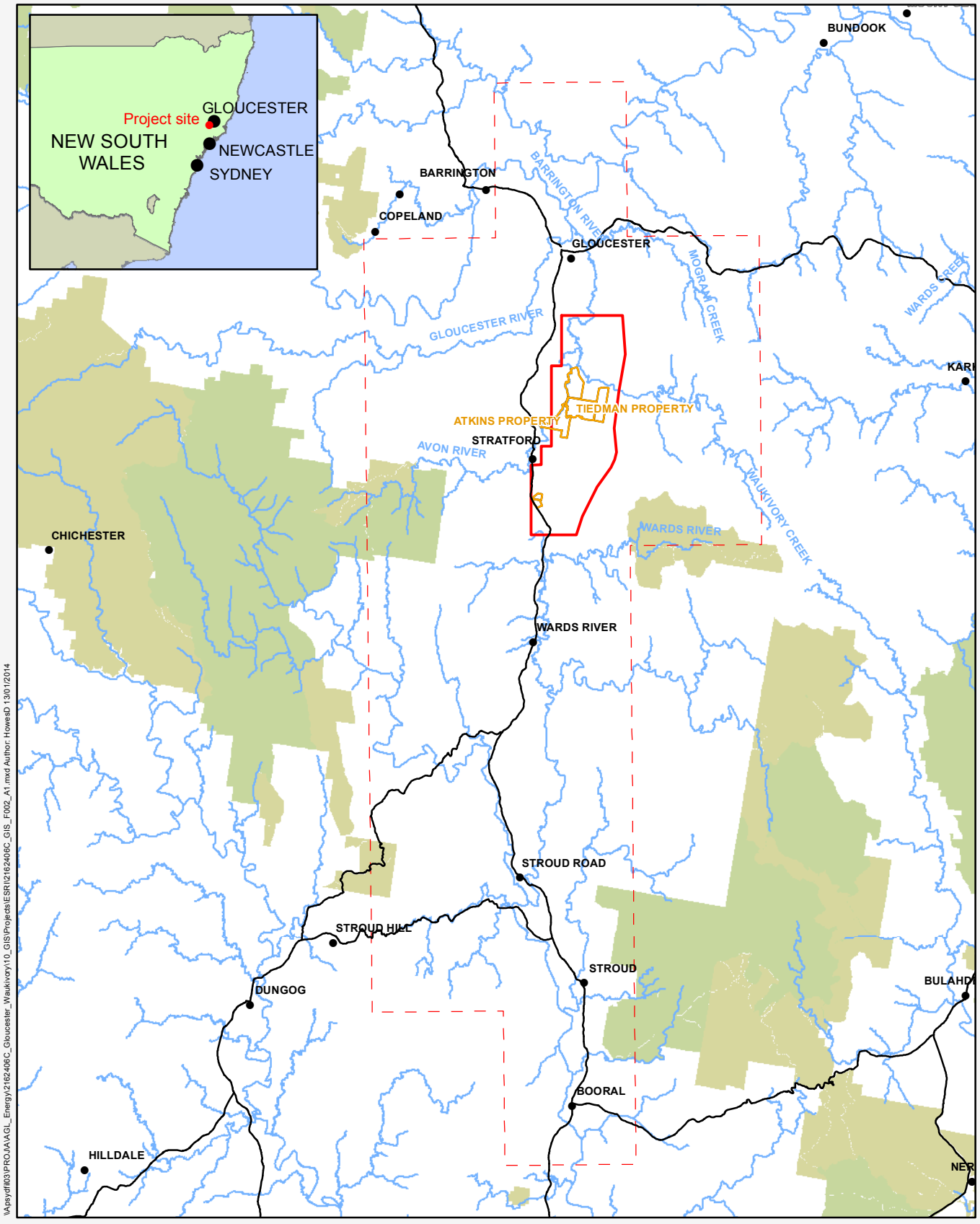
1.4 Report structure

This report provides a review of the water quality data and observed trends during the flow testing programs at CR06 and WK03 for the period April to November 2013.

The structure of the report is as follows:

- Chapter 2: describes the gas well approvals and completions of CR06 and WK03
- Chapter 3: provides an overview of the 2013 flow testing program

- Chapter 4: provides an overview of the methodology used for the water quality sampling and discusses the water quality results during flow testing
- Chapter 5: presents the discussion on water quality characteristics, isotopic composition, groundwater age and changes in water chemistry over the flow testing period
- Chapter 6: presents the conclusions of the current investigations
- Chapter 7: outlines limitations relating to analysis and reporting of data
- Chapter 8: comprises the references used in this report.



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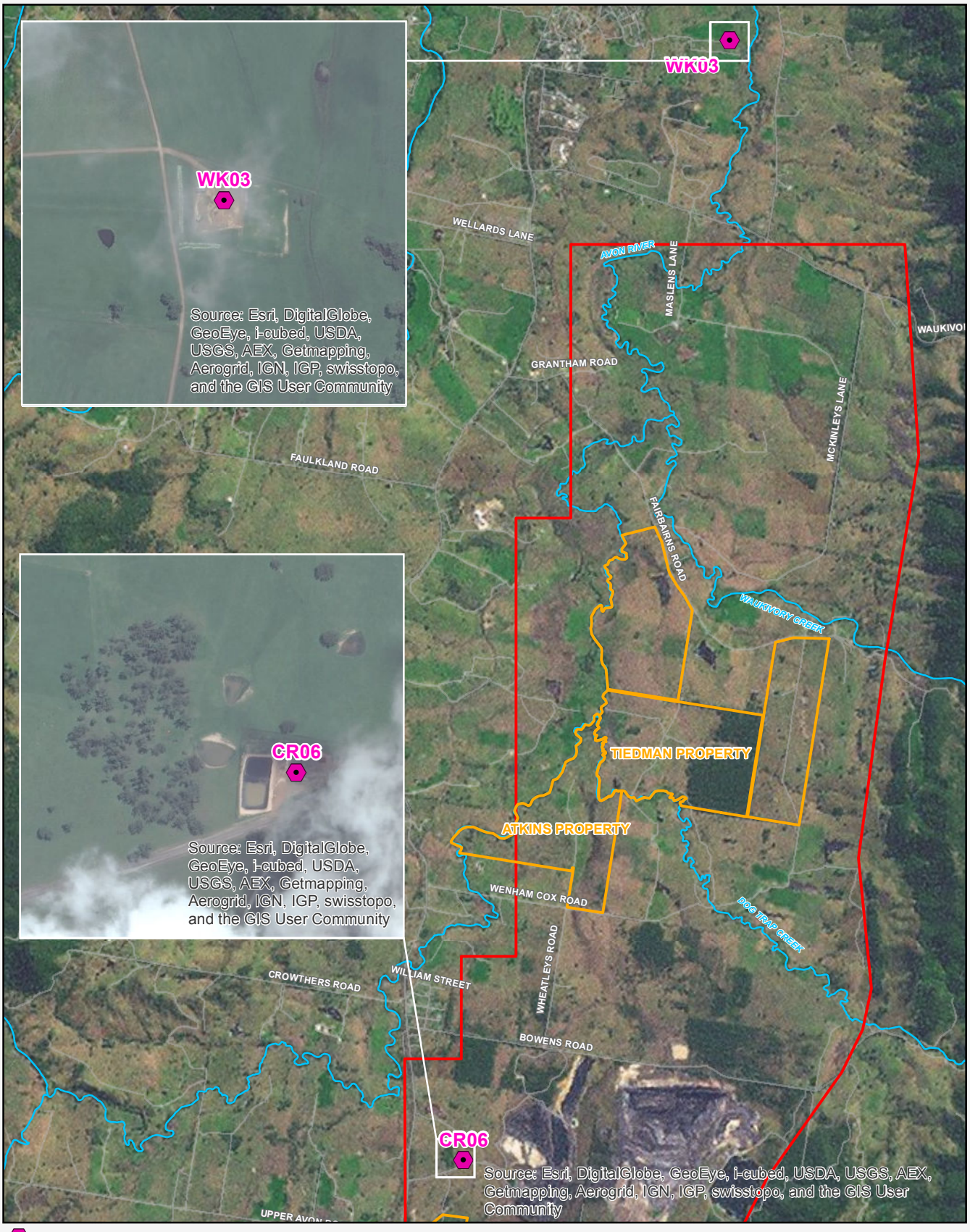
Stage 1 GFDA boundary
PEL 285 boundary
AGL owned properties
Towns
Rivers and streams
NSW State Forest
National Park, Nature Reserve or State Conservation Area

N
0 10
Kilometres

Figure 1.1
Regional Location



- Pilot Gas Wells
- AGL owned properties
- Stage 1 GFDA boundary
- Rivers and streams
- Roads

N

0 2

Kilometres

Figure 1.2
Location of AGL's CR06 and WK03 pilot gas wells

2. Gas well approvals and completions

This chapter describes the gas well completions including the intercepted geological formations, summary gas well construction details, perforation intervals and pilot testing setup. Well completion reports for CR06 and WK03 are provided in Appendix A.

2.1 Approvals

These two flow testing programs were completed under the approved REFs issued by the Department of Trade and Investment, Regional Infrastructure and Services (DTRIS) and the Division of Resources and Energy (DRE) and irrigation and industrial bore licences issued by the NSW Office of Water (NOW). There is no environment protection licence issued by the Environment Protection Authority (EPA) for the PEL area at this time. Details are provided in Table 2.1.

Table 2.1 Summary approvals for the Flow Testing Programs

Site	REF Approval		NOW Bore Licence		
	Date issued	Expiry Date	Number	Date issued	Expiry Date
Craven 6 (CR06)	3 October 2008	3 October 2015	20BL173465	10 May 2013	9 May 2018
Waukivory 3 (WK03)	9 December 2008	9 December 2013	20BL173466	10 May 2013	9 May 2018

There are no special groundwater monitoring conditions attached to the REF approvals. The bore licences allow for a maximum of 5 megalitres (ML) of water to be pumped per year. There are no special groundwater monitoring conditions attaching to the bore licences but pumped volumes are included in the annual compliance reports to NOW. The water monitoring data outlined in this report has been collected voluntarily by AGL to provide additional information on produced water quality across the basin.

2.2 CR06

CR06 is located approximately 16 km south of Gloucester, NSW (Figure 1.2). CR06 was drilled between 12 and 16 January 2009 to a total depth of 983 mbgl. Seven formations within the Gloucester Coal Measures were encountered during drilling (AGL 2009). The specific coal seams and thicknesses are summarised in Table 2.2.

CR06 was perforated at 28 depths in the Leloma, Jilleon and Wenhams formations and selected intervals were fracture stimulated (Table 2.2). The remainder of the gas well was fully cased and pressure cemented to exclude water (and gas) from other horizons.

Table 2.2 CR06 summary geology and construction details

Group	Formation	Seam	Top depth (mbgl)	Base depth (mbgl)	Thickness
Gloucester Coal Measures	Crowthers Rd conglomerate		–	–	
	Leloma formation	Bindaboo Coal	149.35	228.09	78.74
		Deards Coal	248.67	358.85	110.18
	Jilleon formation	Cloverdale Coal	389.74	406.40	16.66
		Roseville Coal	446.96	473.30	26.34
		Tereel Coal/Fairbairns Lane	533.22	698.83	165.61
	Wards River conglomerate		689.86	723.98	25.12
	Wenhams formation	Bowens Rd Coal	723.98	737.9	13.92
	Speldon formation		–	–	
	Dogtrap Creek formation	Glenview Coal	773.61	799.03	25.42
	Waukivory Creek formation	Avon Coal	852.04	855.70	3.66
		Triple Coal	898.12	917.98	19.86
		Rombo Coal	940.16	950.48	10.32
		Glen Road Coal	954.90	965.63	10.73
		Total depth	983.00		

Perforations (mbgl)			
245.5	396.0	497.0	660.5
298.0	404.0	498.0	725.0
296.0	408.5	620.5	726.5
311.5	454.0	627.5	727.5
318.5	461.0	633.0	731.0
320.0	466.0	654.0	736.0
393.5	474.0	658.5	736.5

Casing

Surface casing (8 $^{5}/_{8}$" diameter) – ground to 105.0 mbgl (cemented in place)

Production casing (5 $^{1}/_{2}$" diameter) – ground to 981.0 mbgl (cemented in place)

Internal tubing (2 $^{7}/_{8}$" diameter) (for testing) – ground to 717.95 mbgl (suspended)

2.3 WK03

WK03 is located approximately 2 km south-east of Gloucester. WK03 was drilled between 6 and 9 January 2009 to a total depth of 818 mbgl. Seven formations within the Gloucester Coal Measures were encountered during drilling (AGL 2010). The specific coal seams and thicknesses are summarised in Table 2.3.

WK03 was perforated at 17 depths in the Wenhams, Dogtrap Creek and Waukivory Creek formations and selected intervals were fracture stimulated (Table 2.3).

Table 2.3 WK03 summary geology and construction details

Group	Subgroup	Formation	Coal seam	Top depth (mbgl)	Bottom depth (mgl)	Thickness (m)
Gloucester Coal Measures	Craven	Leloma				
		Jilleon	Cloverdale			
			Roseville	150.31	165.00	14.69
			Fairbairns Lane	180.68	251.31	70.63
		Wards River Conglomerate				
		Wenhams	Bowens Rd	269.80	295.87	26.07
	Speldon formation					
	Avon			304.00	818.00	514.00
		Dogtrap Creek	Glenview	309.72	327.93	18.21
		Waukivory Creek	Avon	434.36	440.72	6.36
			Triple	456.70	481.55	24.85
			Valley View	508.16		
		Total depth		818.00		

Perforations (mbgl)			
273.0	298.0	437.5	617.0-621.6
276.0	298.5	440.0	650.4-651.3
277.0	313.0	441.0	
280.0	328.0	597.0	
296.5	437.0	598.0	

Casing

Surface casing (8 $^{5}/_{8}$" diameter) – ground to 105.0 mbgl (cemented in place)

Production casing (5 $^{1/}_{2}$" diameter) – ground to 981.0 mbgl (cemented in place)

Internal tubing (2 $^{7/}_{8}$" diameter) (for testing) – ground to 717.95 mbgl (suspended)

2.4 Cementing

All casings (except the internal tubing) are cemented in place to ensure the zonal isolation and casing integrity exceeds the life of the well. The production casing is pressure cemented in place against the different geological strata and the integrity checked using cement bond geophysical logs. This evaluation too provides confirmation of the integrity of the pressure cementing after the well has been cemented and before the well is fracture stimulated and completed.

The major objective of cementing is to maintain the geological integrity and to isolate all gas and water formations, and to ensure there is no connectivity of shallow aquifers with deeper coal seams. To achieve this objective, a hydraulic seal must be obtained between the casing and the cement, and between the cement and the formations for the life of the well. This requirement makes pressure cementing a very important operation performed to complete the construction of each well.

2.4.1 CR06 and WK03 setup

The wellhead configuration of WK03 and CR06 for the pilot testing program is described below.

An internal 73 mm (2⅞ inch) diameter tubing string liner was installed from 0 to 717.95 mbgl in CR06 and a 60 mm (2⅜ inch) diameter tubing string liner was installed from 0 to 674.47 mbgl in WK03. A hydraulic pump was installed at the bottom of the casing in each gas well.

The pump intake was located at the base of the tubing string. During pumping groundwater from coal seam water bearing zones was drawn down towards to the pump intake. Gas generated by depressurisation of the coal seams was drawn out of the coal seams and into the annulus between the tubing and the production casing.

The wellhead configuration was fully enclosed and pressure sealed for both gas wells. At the surface the pumped water was directed to a gas/water separator where any remaining entrained gas was removed from the pumped water. The pumped water was stored in tanks on site and periodically removed to the produced water dams located on the Tiedman property (Figure 1.2) for storage and irrigation reuse.

For both gas wells, a portal was fitted to the wellhead to allow gas to be vented from the annulus and directed through a gas line to the gas separating chamber. The gas lines were fitted with an adjustable choke that allowed the flow of gas to be regulated.

3. Flow testing program

The 2013 flow testing of CR06 and WK03 program was conducted by AGL Operations staff between April and November 2013. Details of the timing, duration and water production profile for the flow testing programs are presented in this chapter.

3.1 CR06

The flow testing at CR06 was undertaken in three phases due to two workover events required on the gas well (May and September 2013).

The initial dewatering of CR06 started on 8 April 2013. The first gas flow was encountered on 30 April 2013. CR06 produced on average 30 m^3/d of water until 5 May 2013, when a workover was required due to pump failure. The flow testing program restarted on 28 May 2013 and ran until 1 September 2013. There was another workover program in early September. Flow testing recommenced on 19 September 2013 and continued to 2 November 2013. The average water make throughout this flow testing phase was 8.8 m^3/day (0.1 L/s) with more water produced in the first month after the restart of the flow test.

The maximum produced water rate was 60.5 m^3/day (0.70 L/s) and the minimum produced water rate was 1.4 m^3/day (0.02 L/s). Generally the produced water rate reduced from the start of the test. The volume of produced water pumped to 2 November 2013 was 1.66 ML.

Details of the timing of the flow testing are presented in Figure 3.1 together with water levels and the water production profile.

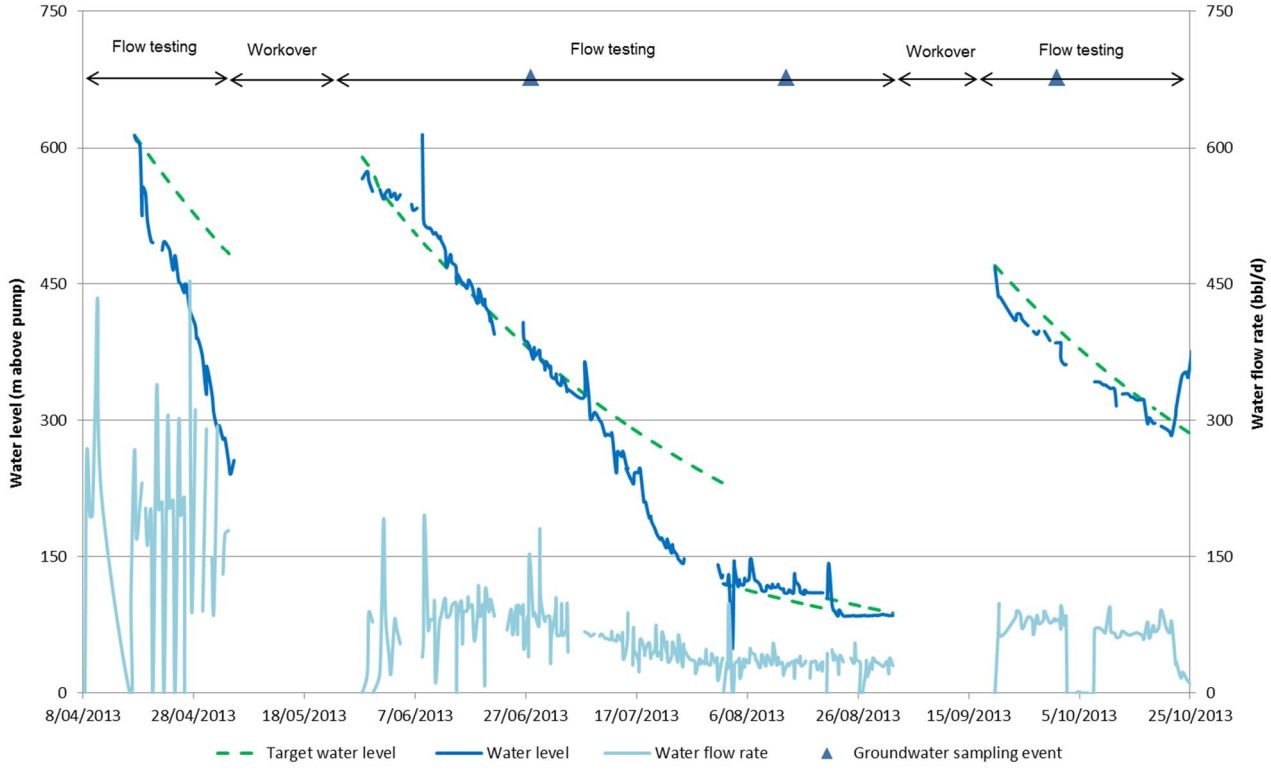


Figure 3.1 Details of flow testing at CR06

3.2 WK03

The initial dewatering of WK03 started on 4 June 2013. WK03 produced an average of 16 m^3/day (0.19 L/s) of water until 28 August 2013, when the test was stopped for a workover. The flow testing program restarted on 3 September 2013 and ran until 25 November 2013. The average water make throughout the second part of the flow testing was 19.7 m^3/day (0.23 L/s).

The maximum produced water rate was 42.4 m^3/day (0.49 L/s) and the minimum produced water rate was 8.2 m^3/day (0.09 L/s). Generally the produced water rate reduced from the start of the test. The volume of produced water pumped to 25 November 2013 was 2.47 ML.

Details of the timing of the flow testing are presented in Figure 3.2 together with water levels and the water production profile. The gas well was plugged and abandoned in early December 2013.

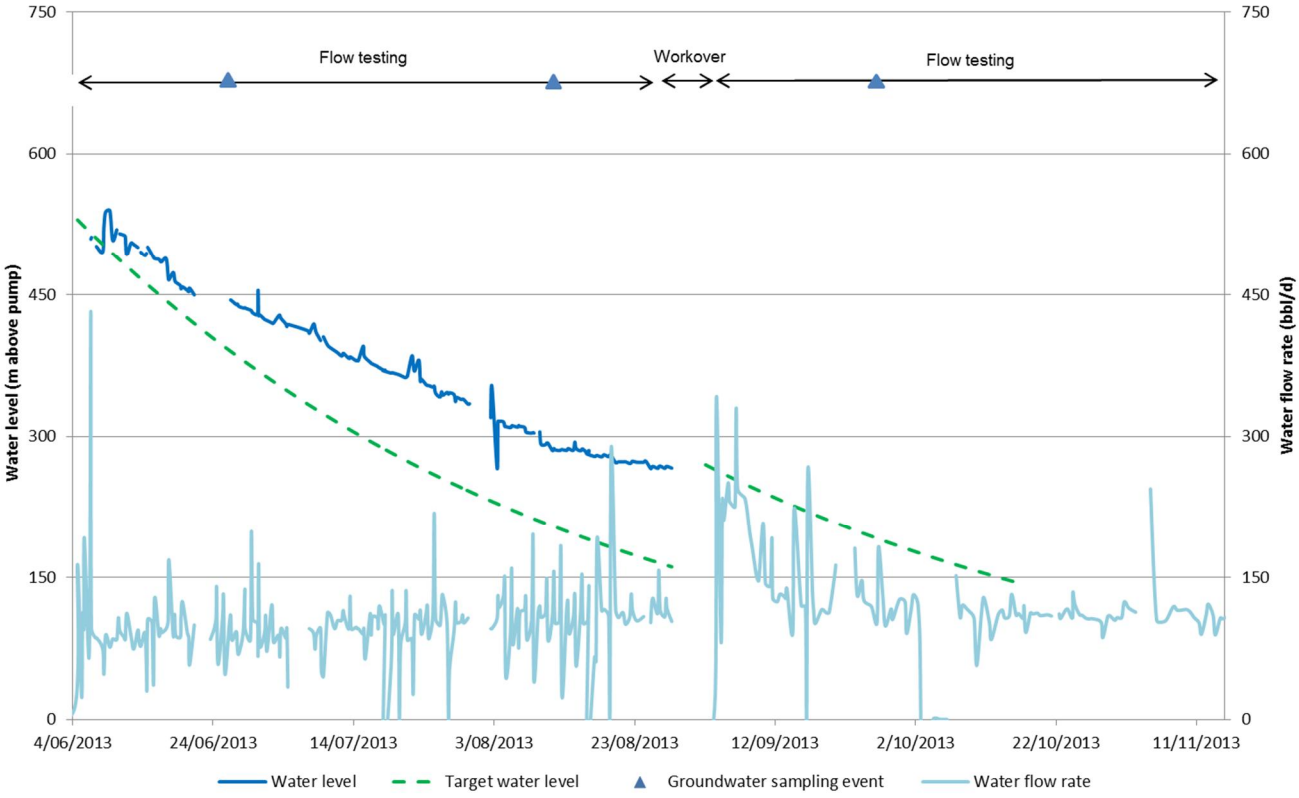


Figure 3.2 Details of flow testing WK03

4. Water quality sampling

The methodology and the results for the water quality sampling program are provided in this chapter. All chemistry and isotope results are presented in Appendix B.

4.1 Methodology

The schedule of sampling events was as follows:

- first sampling event (comprehensive suite plus isotopes) on 28 June 2013
- second sampling event (basic suite) on 13 August 2013
- third sampling event (basic suite) on 1 October 2013.

The gas wells were sampled from the separator valve. Field parameters, as listed in Table 4.1, were measured using a calibrated YSI meter at the time of sampling.

Water quality samples were collected in the sample bottles provided by the laboratory, with the appropriate preservation when required.

Table 4.1 details the analytical suites. Samples undergoing dissolved metal analysis were filtered through 0.45 µm filters in the field prior to collection.

The samples were sent to the following laboratories under appropriate chain-of-custody protocols (documentation and laboratory results are provided in Appendices C to H):

- Australian Laboratory Service (ALS) Environmental Pty Ltd, Smithfield, Sydney – chemistry analysis. NATA certified laboratory (Appendix C).
- GNS Stable Isotope Laboratory, Lower Hutt, New Zealand – oxygen-18 and deuterium analysis (Appendix D).
- Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand – carbon-14 analysis (Appendix E).
- UC Davis Stable Isotope Facility, Davis, California, USA – carbon-13 ($^{13}C_{DIC}$) and methane isotope analysis ($^{13}C\text{-}CH_4$ and $^{2}H\text{-}CH_4$) (Appendix F).
- Australian National University (ANU) Department of Nuclear Physics, Canberra - chlorine-36 (Appendix G).

Table 4.1 Analytical suites

Category	Suites		Parameters	
Field parameters	Basic	Comprehensive	Electrical conductivity Total Dissolved Solids (TDS) Temperature	pH Redox potential Dissolved oxygen
Check on field parameters			Electrical conductivity	TDS (measured)
Major ions			Calcium Magnesium Sodium Potassium	Chloride Carbonate Bicarbonate Sulphate
Dissolved metals and minor / trace elements			Aluminium Antimony* Arsenic Barium Beryllium Boron Bromine Cadmium Chromium Cobalt Copper	Iron Lead Manganese Mercury Molybdenum Nickel Selenium Strontium Uranium Vanadium Zinc
Other analytes			Fluoride Total organic carbon	Reactive silica/silicon Cyanide*
Total Suspended Solids			TSS	
Nutrients			Nitrate Nitrite Ammonia*	Reactive phosphorus Total phosphorous*
Dissolved gases			Methane	
Hydrocarbons			Phenol compounds Polycyclic aromatic hydrocarbons (PAH)	Total petroleum hydrocarbons (TPH) Benzene, toluene, ethyl- benzene and xylenes (BTEX)
Isotopes			oxygen-18 (^{18}O) deuterium (^{2}H) Carbon-13 dissolved inorganic carbon ($^{13}C_{DIC}$)	Carbon-13 methane ($^{13}C\text{-}CH_4$) and deuterium methane ($^{2}H\text{-}CH_4$) radiocarbon (^{14}C) chlorine-36 (^{36}Cl)

* Not analysed as part of the 2013 basic suite.

4.2 Assessment criteria

All results have been compared to the ANZECC (2000) guidelines for freshwater ecosystems (south-east Australia – lowland rivers) because the rivers are the ultimate receiving waters for deep groundwater discharge. However, these guidelines are often naturally exceeded in catchments with rocks deposited in marine environments, hence they are only guidelines and not strict criteria that should be used to evaluate individual groundwater quality results. This is the case for the Avon River catchment which contains shallow marine and estuarine sedimentary rocks and is a known saline catchment. Guidelines for shallow and deep groundwater have not been determined at this time.

4.3 Water quality results

Water quality results for the three sampling events during the 2013 flow testing program are presented in Table 4.2 for CR06 and Table 4.3 for WK03.

Changes in water quality during the flow testing program have been assessed by calculating the relative percentage differences (RPDs) between groundwater chemistry results of the three monitoring events. The RPDs are presented in Appendix B.

A piper diagram is a graphical representation of the chemistry of a water sample and can be used to graphically show the relative concentrations of major ions (Ca^{2+}, Mg^{2+}, Na^{2+}, K^{+}, Cl^{-}, HCO^{3-} and SO_4^{2}). Major ion chemistry for the gas well samples is shown on the piper diagram in Figure 4.1.

Table 4.2 Water quality results for the 2013 water sampling program at CR06

Parameters	Units	LOR	ANZECC 2000 guidelines[a]	June 2013	August 2013	October 2013
General parameters						
pH (field)	pH units	0.01	6.5 - 8.0[b]	7.52	**9.63**[c]	7.53
pH (lab)				7.64	7.84	**8.14**
Conductivity (field)	µS/cm	1	125 – 2200[b]	**6,549**	**6,746**	**5,439**
Conductivity (lab)				**6,920**	**7,200**	**5,550**
Temperature	°C	0.01	-	18.08	13.9	22.6
Dissolved oxygen	% sat	0.01	80 - 110%[b]	**42.8**	**80.2**	**42.6**
TDS (calc.) (field / lab)	mg/L	1	–	na / na	4,385 / 4,680	3,530 / na
TDS (measured)				3,870	4,510	3,120
Suspended Solids	mg/L	1	–	197	276	170
Redox	mV	–	–	-62	-153	-173
Water type[d]				$Na\text{-}Cl\text{-}HCO_3$	$Na\text{-}HCO_3\text{-}Cl$	$Na\text{-}HCO_3\text{-}Cl$
Major cations / anions						
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	–	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	–	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	–	1,880	2,020	1,360

Parameters	Units	LOR	ANZECC 2000 guidelines[a]	June 2013	August 2013	October 2013
Total alkalinity as $CaCO_3$	mg/L	1	–	1,880	2,020	1,360
Calcium	mg/L	1	–	12	9	14
Magnesium	mg/L	1	–	3	4	3
Sodium	mg/L	1	–	1,550	1,710	1,270
Potassium	mg/L	1	–	11	12	6
Chloride	mg/L	1	–	958	1,270	1,020
Sulphate	mg/L	1	–	14	<1	<1
Reactive silica / silicon as SiO_2	mg/L	0.1	–	15.2 / na	na / 13.7	na / 14.0
Total cyanide	mg/L	0.004	0.007	<0.004	na	na
Fluoride	mg/L	0.1	–	1.4	1.4	1.5
Dissolved metals						
Aluminium	mg/L	0.01	0.055	0.05	0.01	**0.06**
Antimony	mg/L	0.001	–	<0.001	na	na
Arsenic	mg/L	0.001	0.013 (As V)	<0.001	0.001	0.004
Barium	mg/L	0.001	–	3.65	4.30	2.46
Beryllium	mg/L	0.001	ID	<0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	0.0002	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	**0.007**	**0.004**	**0.007**
Cobalt	mg/L	0.001	ID	<0.001	<0.001	0.002
Copper	mg/L	0.001	0.0014	**0.002**	0.001	**0.002**
Lead	mg/L	0.001	0.0034	<0.001	<0.001	<0.001
Manganese	mg/L	0.001	1.9	0.233	0.475	0.190
Mercury	mg/L	0.0001	0.0006	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	ID	0.003	0.005	0.006
Nickel	mg/L	0.001	0.011	0.003	0.001	0.006
Selenium	mg/L	0.01	0.011 (total)	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	–	3.36	3.06	2.15
Uranium	mg/L	0.001	ID	<0.001	<0.001	<0.001
Vanadium	mg/L	0.01	ID	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.008	**0.045**	0.006	**0.041**
Boron	mg/L	0.05	0.37	0.33	0.27	0.20
Iron	mg/L	0.05	ID	4.26	37.8	6.83
Bromine	mg/L	0.1	ID	2.4	2.8	2.0

Parameters	Units	LOR	ANZECC 2000 guidelines[a]	June 2013	August 2013	October 2013
Nutrients						
Ammonia as N	mg/L	0.01	0.02[b]	**1.9**	na	na
Nitrite as N	mg/L	0.01	–	<0.01	<0.01	<0.01
Nitrate as N	mg/L	0.01	0.7	<0.01	<0.01	0.02
Total Phosphorus	mg/L	0.01	0.05[b]	**1.26**	na	na
Reactive phosphorus	mg/L	0.01	0.02[b]	<0.01	<0.01	<0.01
Total Organic Carbon	mg/L	1	–	9	na	na
Gases						
Methane	µg/L	10	–	13,000	na	na
Ethene	µg/L	10	–	<10	na	na
Ethane	µg/L	10	–	14	na	na
Propene	µg/L	10	–	<10	na	na
Propane	µg/L	10	–	<10	na	na
Butene	µg/L	10	–	<10	na	na
Butane	µg/L	10	–	<10	na	na
Phenolic compounds	µg/L		–	<LOR's	na	na
Polycyclic aromatic compounds	µg/L		–	<LOR's	na	na
BTEX compounds						
Benzene	µg/L	1	950	3	na	na
Toluene	µg/L	2	ID	8	na	na
Ethylbenzene	µg/L	2	ID	<2	na	na
Meta- & para-Xylene	µg/L	2	ID	5	na	na
Ortho-Xylenes	µg/L	2	350	<2	na	na
Total petroleum hydrocarbons						
C_6-C_9	µg/L	20	–	30	na	na
C_{10}-C_{14}	µg/L	50	–	270	na	na
C_{15}-C_{28}	µg/L	100	–	500	na	na
C_{29}-C_{36}	µg/L	50	–	130	na	na

a) ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).
b) ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.
c) Suspected problem with pH probe.
d) Calculated using AQUACHEM.
e) BOLD indicates a value outside of the ANZECC (2000) guideline range.
f) ID indicates insufficient data for trigger value to be established.
g) na indicates "not analysed".

Table 4.3 Water quality results for the 2013 water sampling program at WK03

Parameters	Units	LOR	ANZECC 2000 guidelines[a]	June 2013	August 2013	October 2013
General parameters						
pH (field)	pH units	0.01	6.5 - 8.0[b]	7.55	**5.73**[c]	7.57
pH (lab)				7.55	7.60	**8.15**
Conductivity (field)	µS/cm	1	125 – 2200[b]	**4,391**	**4,487**	**4,464**
Conductivity (lab)				**4,650**	**4,450**	**4,520**
Temperature	°C	0.01	–	22.06	23.54	24.58
Dissolved oxygen	% sat	0.01	80 - 110%[b]	100.6	**33.1**	**57.8**
TDS (calc.) (field / lab)	mg/L	1	–	na / na	2,918 / 2,890	2.912 / na
TDS (measured)				2,640	2,660	2,610
Suspended Solids	mg/L	1	–	67	84	11
Redox	mV	-	–	-171	-154	-96
Water type[d]				$Na\text{-}HCO_3\text{-}Cl$	$Na\text{-}HCO_3\text{-}Cl$	$Na\text{-}HCO_3\text{-}Cl$
Major cations / anions						
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	–	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	mg/L	1	–	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	–	1,810	2,100	1,770
Total alkalinity as $CaCO_3$	mg/L	1	–	1,810	2,100	1,770
Calcium	mg/L	1	–	6	7	6
Magnesium	mg/L	1	–	1	2	2
Sodium	mg/L	1	–	1,090	1,230	1,110
Potassium	mg/L	1	–	12	8	5
Chloride	mg/L	1	–	394	437	432
Sulphate	mg/L	1	–	4	<1	<1
Reactive silica / silicon as SiO_2	mg/L	0.1	–	19.1 / na	na / 19.9	na / 18.1
Total cyanide	mg/L	0.004	0.007	<0.004	na	na
Fluoride	mg/L	0.1	–	0.3	0.3	0.2
Dissolved metals						
Aluminium	mg/L	0.01	0.055	0.02	**0.06**	0.02
Antimony	mg/L	0.001	–	<0.001	na	na
Arsenic	mg/L	0.001	0.013 (As V)	<0.001	<0.001	<0.001
Barium	mg/L	0.001	–	1.11	2.02	1.48
Beryllium	mg/L	0.001	ID	<0.001	<0.001	<0.001

Parameters	Units	LOR	ANZECC 2000 guidelines[a]	June 2013	August 2013	October 2013
Cadmium	mg/L	0.0001	0.0002	<0.0001	<0.0001	<0.0001
Chromium	mg/L	0.001	0.001	<0.001	**0.006**	0.001
Cobalt	mg/L	0.001	ID	<0.001	0.001	<0.001
Copper	mg/L	0.001	0.0014	<0.001	0.001	0.001
Lead	mg/L	0.001	0.0034	<0.001	<0.001	<0.001
Manganese	mg/L	0.001	1.9	0.155	0.320	0.086
Mercury	mg/L	0.0001	0.0006	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001	ID	0.003	0.003	0.001
Nickel	mg/L	0.001	0.011	0.002	0.004	<0.001
Selenium	mg/L	0.01	0.011 (total)	<0.01	<0.01	<0.01
Strontium	mg/L	0.001	–	0.986	1.01	0.960
Uranium	mg/L	0.001	ID	<0.001	<0.001	<0.001
Vanadium	mg/L	0.01	ID	<0.01	<0.01	<0.01
Zinc	mg/L	0.005	0.008	**0.024**	**0.030**	**0.016**
Boron	mg/L	0.05	0.37	0.23	0.19	0.15
Iron	mg/L	0.05	ID	2.20	27.20	1.76
Bromine	mg/L	0.1	ID	0.9	1.0	0.9
Nutrients						
Ammonia as N	mg/L	0.01	0.02[b]	**1.46**	na	na
Nitrite as N	mg/L	0.01	–	<0.01	<0.01	<0.01
Nitrate as N	mg/L	0.01	0.7	<0.01	<0.01	0.03
Total Phosphorus	mg/L	0.01	0.05[b]	**0.51**	na	na
Reactive phosphorus	mg/L	0.01	0.02[b]	<0.01	0.02	<0.01
Total Organic Carbon	mg/L	1	–	22	na	na
Gases						
Methane	µg/L	10	–	6,940	na	na
Ethene	µg/L	10	–	<10	na	na
Ethane	µg/L	10	–	384	na	na
Propene	µg/L	10	–	<10	na	na
Propane	µg/L	10	–	70	na	na
Butene	µg/L	10	–	<10	na	na
Butane	µg/L	10	–	<10	na	na
Phenolic compounds	µg/L		–	<LOR's	na	na

Parameters	Units	LOR	ANZECC 2000 guidelines[a]	June 2013	August 2013	October 2013
Polycyclic aromatic compounds						
Fluoranthene	µg/L		–	1.9	na	na
Pyrene	µg/L		–	8.6	na	na
Benz(a)anthracene	µg/L		–	7.2	na	na
Chrysene	µg/L		–	17.5	na	na
Benzo(b)fluoranthene	µg/L		–	5.0	na	na
Benzo(k)fluoranthene	µg/L		–	2.0	na	na
Benzo(a)pyrene	µg/L		–	8.2	na	na
Dibenz(a.h)anthracene	µg/L		–	2.3	na	na
Benzo(g.h.i)perylene	µg/L		–	4.7	na	na
BTEX compounds						
Benzene	µg/L	1	950	7	na	na
Toluene	µg/L	2	ID	4	na	na
Ethylbenzene	µg/L	2	ID	<2	na	na
Meta- & para-Xylene	µg/L	2	ID	4	na	na
Ortho-Xylenes	µg/L	2	350	<2	na	na
Total petroleum hydrocarbons						
C_6-C_9	µg/L	20	–	30	na	na
C_{10}-C_{14}	µg/L	50	–	100	na	na
C_{15}-C_{28}	µg/L	100	–	14,400	na	na
C_{29}-C_{36}	µg/L	50	–	11,400	na	na

a) ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).
b) ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.
c) Suspected problem with pH probe.
d) Calculated using AQUACHEM.
e) BOLD indicates a value outside of the ANZECC (2000) guideline range.
f) ID indicates insufficient data for trigger value to be established.
g) na indicates “not analysed”.

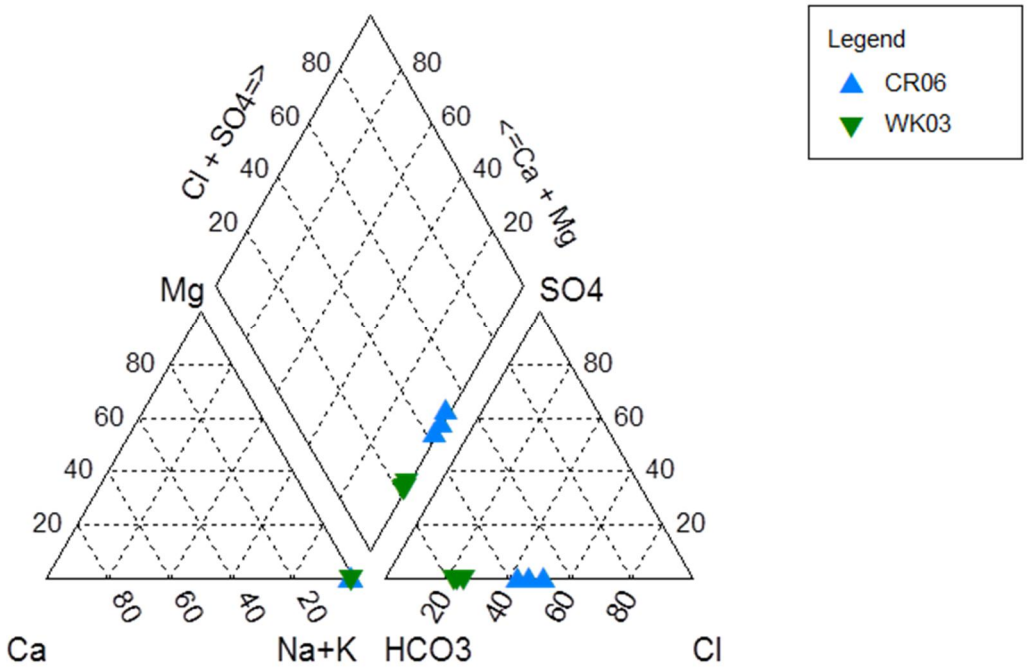


Figure 4.1 Piper plot displaying major ion chemistry for the 2013 pilot testing program

4.3.1 Field parameters

The produced water from CR06 was slightly saline (5,439 µS/cm to 6,746 µS/cm) and brackish from WK03 (4,391 µS/cm to 4,464 µS/cm). Electrical conductivity (EC) values exceeded the ANZECC (2000) guideline values (125-2,200 µS/cm). Electrical conductivity was stable throughout the flow test at WK03, but decreased between the first and last sampling events at CR06.

The field pH conditions showed no significant change and were slightly alkaline throughout the flow testing program. (Note: the pH probe for the water quality meter used in August 2013 sampling event was faulty and these values have not been used for interpretation).

Reducing conditions were encountered throughout the monitoring program at both wells.

4.3.2 Major ion chemistry

The water types for CR06 and WK03 were both Na-HCO_3-Cl. Small variations in the concentrations of major ions occurred during the flow test period; however, the relative proportions of these ions (and therefore water type) did not change (Figure 4.1).

4.3.3 Dissolved metals

The major findings of dissolved metal analysis for the two gas wells are as follows:

- Aluminium, chromium, and zinc concentrations were above ANZECC (2000) guideline criteria at both gas wells on a least one occasion.
- Copper concentrations exceeded the ANZECC (2000) guideline value (0.0014 mg/L) at CR06 on one occasion.
- Arsenic, cadmium, manganese, nickel, selenium and boron were detected but below ANZECC (2000) guideline values at CR06 and WK03.

- Barium, molybdenum, strontium, iron and bromine concentrations were detected at CR06 and WK03 above the laboratory limit of reporting (LOR).
- Antimony, beryllium, lead, mercury, selenium, uranium and vanadium concentrations were below the laboratory limit of reporting (LOR) at both CR06 and WK03.

The occurrence of these metals in produced water is not unexpected; these metals are naturally present in low concentrations in coal seams and are mobile at the in-situ pH and redox conditions. There are a few exceedences of the ANZECC (2000) guideline criteria but none that are unusual for these deep coal seams.

There were fluctuations in aluminium, chromium, copper, manganese, molybdenum, nickel, zinc and iron during the flow testing program at both CR06 and WK03, but there were no distinct trends. Changes in metals concentrations are expected during flow testing due to changes in pH and redox, and also because the gas wells are perforated against multiple coal seams of likely varying water quality.

4.3.4 Nutrients

Ammonia as N concentrations were above the ANZEC (2000) guideline value (0.02 mg/L) at both CR06 and WK03. Nitrite and nitrate concentrations were generally below the LOR.

Total phosphorus concentrations were above the ANZECC (2000) guideline value (0.05 mg/L) at both gas wells in the first sampling round. Reactive phosphorous was only detected at WK03 in August 2013 and the concentration was below the ANZECC (2000) guideline value (0.02 mg/L).

4.3.5 Hydrocarbons

Phenolic compounds, polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH) and BTEX compounds were analysed for the first sampling event in June 2013. Phenolic compounds and polycyclic aromatic hydrocarbons concentrations were below the LOR at CR06 with phenolic compounds and some PAHs below the LOR at WK03. TPH and BTEX were detected at CR06 and WK03.

Hydrocarbons in these types of formations can be naturally occurring (Volk *et al*. 2011) and have been detected in sedimentary rocks in the Gloucester Basin during early exploration programs (Thornton1982; Hunt *et al.* 1983).

4.3.6 Dissolved gases

Dissolved C_1-C_4 gases (methane, ethene, ethane, propene, propane, butene and butane) were analysed for the first sampling event. Dissolved methane (13,000 µg/L) and ethane (14 µg/L) were detected at CR06. Dissolved methane (6,940 µg/L), ethane (384 µg/L) and propane (70 µg/L) were detected at WK03. The presence of higher chained carbon compounds is characteristic of thermogenically derived gas and gas samples collected in early geological investigations in the basin in 1993 and 1997 contained ethane (Weber and Smith 2001). Trace amounts of propane were also detected in a few samples during the 1993 program (Weber and Smith 2001).

4.3.7 Isotopes

4.3.7.1 Stable isotopes of water

Stable isotope ($\delta^{18}O$ and $\delta^{2}H$) values are compared to the Global Meteoric Water Line (GMWL) ($\delta^{2}H = 8.13\ \delta^{18}O + 10.8$) (Rozanski *et al.* 1993) in Figure 4.2. The GMWL (as seen on Figure 4.2) provides an important key to the interpretation of oxygen-18 and deuterium data. It is a line that defines the relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation from a number of global reference sites. Water with an isotopic composition that lies on the meteoric water line is assumed to have originated from the atmosphere and to be unaffected by other isotope fractionating processes. The isotopic values for the groundwater samples are also compared to the Local Meteoric Water Line (LMWL) ($\delta^{2}H = 8.3$

$\delta^{18}O$ + 16.3) (Crosbie *et al*. 2012). This line defines the relationship between ^{18}O and ^{2}H for rainfall in the Sydney region.

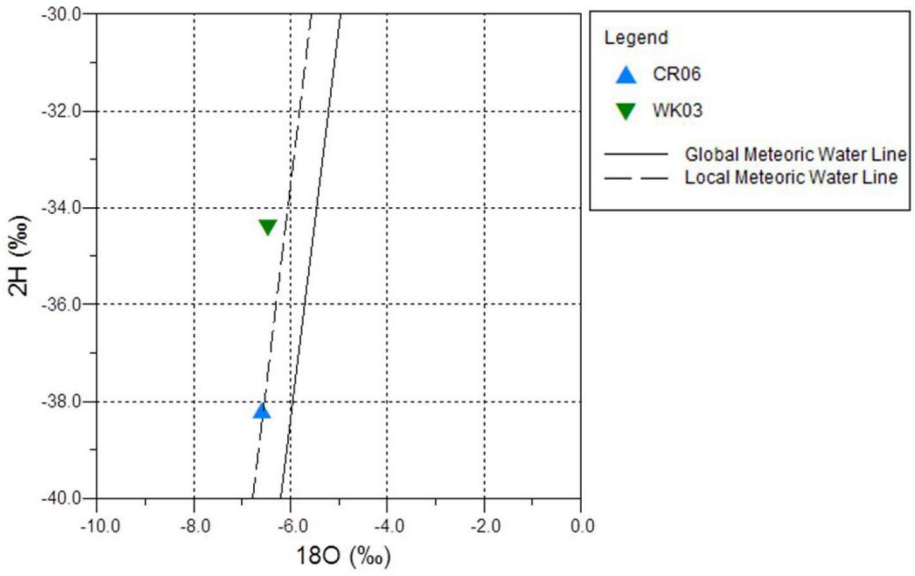


Figure 4.2 Deuterium and oxygen-18 for CR06 and WK03

Stable isotopes were analysed on samples collected in the first sampling event and results are presented in Table 4.4. Samples from both gas wells plot along the LMWL indicating groundwater is of meteoric (rainfall) origin (Figure 4.2).

Table 4.4 Stable isotope results for CR06 and WK03

Gas well	Oxygen-18 (‰)	Deuterium (‰)
CR06	-6.58	-38.2
WK03	-6.46	-34.4

4.3.7.2 Radiogenic isotopes

Radiocarbon results are presented in Table 4.5. Carbon-13 of dissolved inorganic carbon (δ^{13}C-DIC) is also presented in Table 4.5.

The isotopically heavy δ^{13}C-DIC values indicate residual biogenic CO_2 remaining after biogenic conversion of some of the CO_2 to CH_4. During biogenic methane production via CO_2 reduction, the CO_2 reducing bacteria utilise the lighter isotopes leaving the heavy isotopes in the residual CO_2. δ^{13}C values of CO_2 of up to +21‰ was detected in coal seams during AGL drilling exploration programs, and up to +23.7‰ during earlier exploration programs in 2000 (Weber and Smith 2001).

Carbon-14 activities (a^{14}C) were 1.4±0.05 pMC for CR06 and 1.25±0.06 pMC for WK03. The ^{14}C activities correspond to apparent (uncorrected) ages of respectively 34,222±284 yrs BP and 35,162±403 yrs BP. Radiocarbon ages have been corrected to account for potential dilution by processes such as carbonate dissolution, sulphate reduction and methanogenesis (as defined in Clark and Fritz (1997)). However, it is important to note that the results for the two gas wells are at the limit of the radiocarbon dating and the results are only an estimate of age at best.

Corrected ages indicate water from the two gas wells is >30,000 yrs BP.

Table 4.5 δ^{13}C-DIC and radiocarbon results for CR06 and WK03

Gas well	δ^{13}C (‰)	a^{14}C (pMC)	^{14}C age[a] (yrs BP)	^{14}C age[b] (yrs BP)
CR06	25.77	1.4 ± 0.05	34,222 ± 284	>30,000
WK03	8.27	1.25 ± 0.06	35,162 ± 403	>30,000

a) Uncorrected radiocarbon age.
b) Corrected radiocarbon age.

4.3.7.3 Carbon and hydrogen isotopes of methane (δ^{13}C-CH_4 and δ^{2}H-CH_4)

Compound specific isotopes of dissolved methane (carbon-13 (δ^{13}C-CH_4) and deuterium (δ^{2}H-CH_4)) were analysed for samples collected from both gas wells in the first monitoring event. Dissolved methane concentrations and isotope results are presented in Table 4.6 and are compared to data collected by AGL from coal seams during exploration in the Gloucester Gas Project area (Figure 4.3 and Figure 4.4).

Table 4.6 Dissolved methane concentrations and isotope results for CR06 and WK03

Gas well	CH_4 (µg/L)	$\delta^{2}H_{CH4}$ (‰)	$\delta^{13}C_{CH4}$ (‰)
CR06	13,000	-135.9^	-38.29^
WK03	6,940	-268.7	-41.57

a) ^ Below LOQ.

AGL has carried out compound specific isotope analysis on numerous gas samples collected from coal seams during their exploration phase in the Gloucester Gas Project. Gas samples were collected from numerous depths from the Gloucester Coal Measures. Isotopic values vary from -81.40‰ to -27.15‰ for δ^{13}C-CH_4 and -251.0‰ to -195.0‰ for δ^{2}H-CH_4, indicating methane is a mix of both thermogenic and biogenic methane (Figure 4.3), with the majority of samples thermogenic (Figure 4.4). Biogenic methane was detected in parts of the basin where thermogenic methane has been replaced by 'secondary' biogenic methane formed in association with meteoric water flow into permeable coals.

The isotope data for dissolved methane in the CR06 and WK03 are consistent with gas well data, and indicate methane is early mature thermogenic methane.

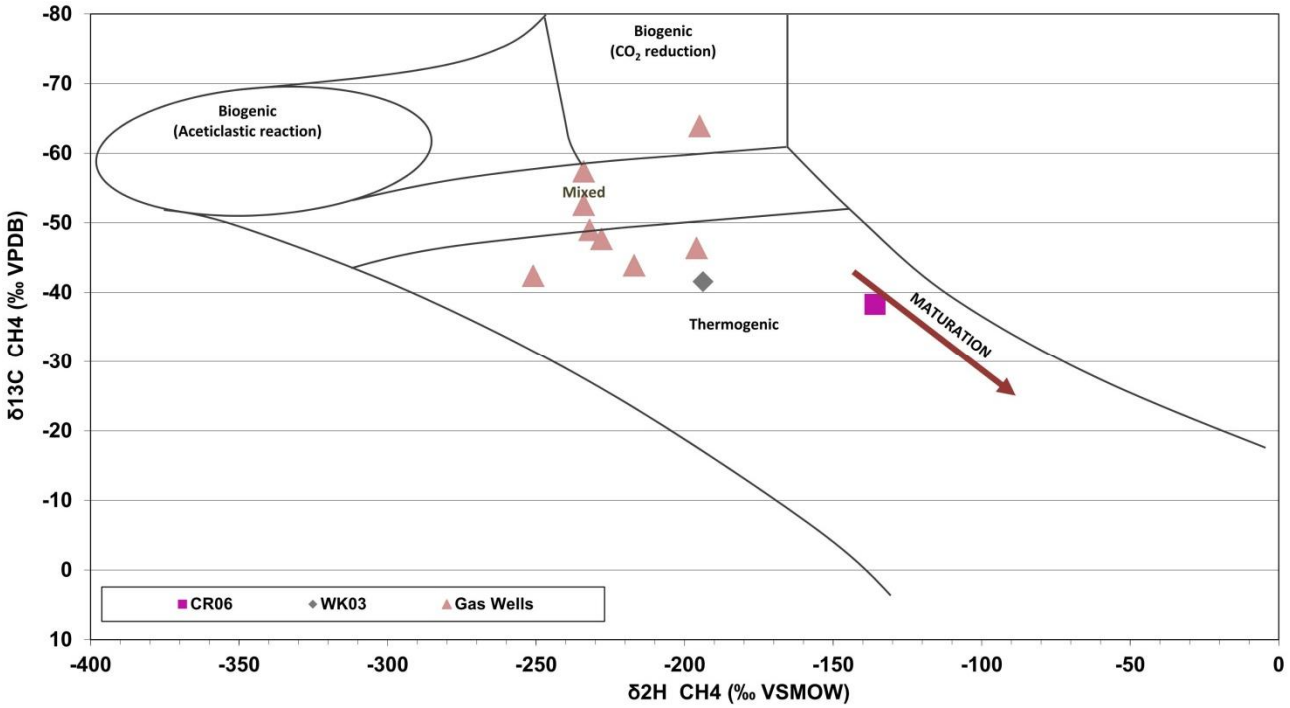


Figure 4.3 Plot of carbon-13 (δ^{13}C-CH_4) and deuterium (δ^{2}H-CH_4) in methane gas from gas wells, CR06 and WK03

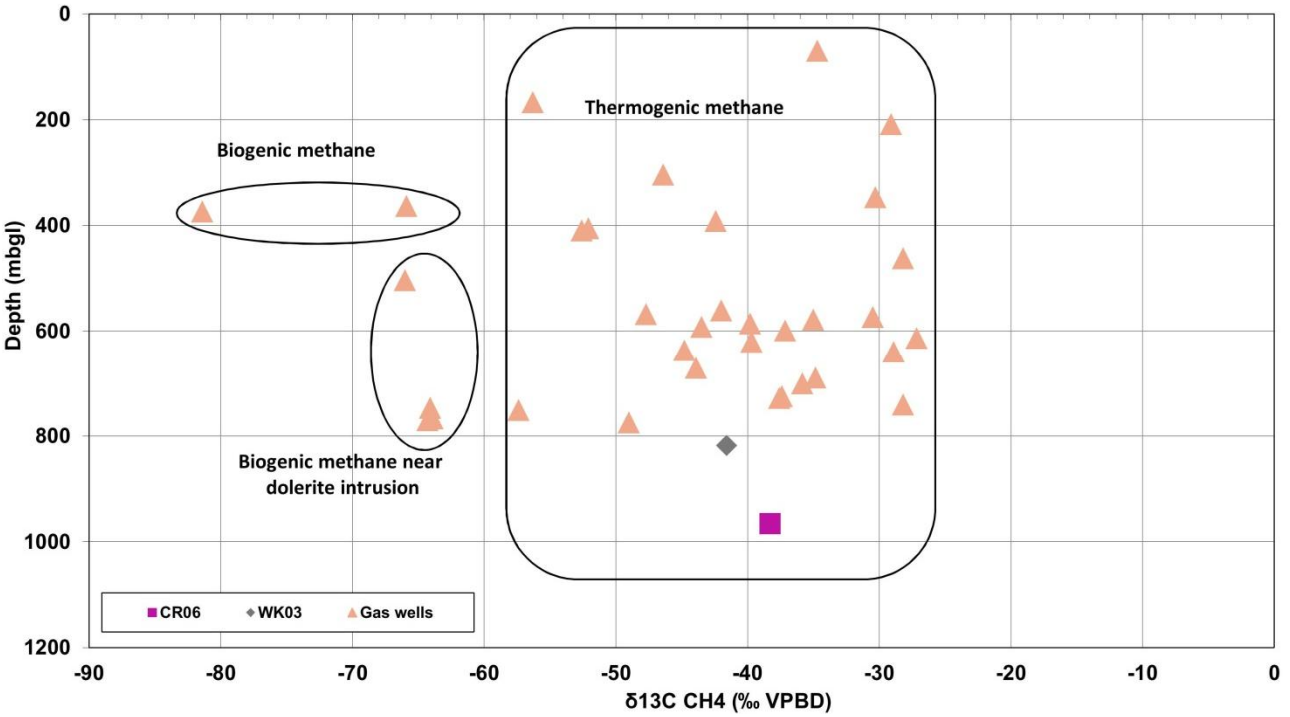


Figure 4.4 Plot of depth versus carbon-13 (δ^{13}C-CH_4) in methane gas collected from gas wells, CR06 and WK03

4.3.7.4 Chlorine-36

Chlorine-36 has a half-life of 301,000 ± 2,000 years and is capable of dating groundwater with an age range of 46,000 to 1,000,000 years old. Chlorine-36 was selected as an age dating method as radiocarbon activities indicated groundwater age for targeted sections of the Gloucester Coal Measures was beyond the limit of radiocarbon dating. Chlorine-36 results are presented in Table 4.7.

The $^{36}Cl/Cl$ ratios of both gas wells still carry a meteoric recharge signature. That is, the $^{36}Cl/Cl$ ratio is above the in situ background value (secular equilibrium) estimated for methane bearing coal seams (~$4x10^{-15}$) (Snyder and Fabryka-Martin 2007). An estimate of groundwater age was calculated using a literature $^{36}Cl/Cl$ ratio for south-eastern Australia (~60 $x10^{-15}$) (Davie *et al*. 1989) for the initial $^{36}Cl/Cl$ ratio.

Groundwater ages were calculated using the equation defined in Bentley *et al.* (1986) (Eqn 1). This equation assumes that chloride and ^{36}Cl are solely derived from atmospheric sources with no internal sources or sinks except for ^{36}Cl decay and nucleogenic ^{36}Cl production.

$$t = \frac{1}{\lambda_{36}} \ln \frac{R - R_{se}}{R_0 - R_{se}} \qquad \textit{Eqn 1}$$

Where λ_{36} is the decay constant for ^{36}Cl, R is the $^{36}Cl/Cl$ measured in groundwater, R_0 is the $^{36}Cl/Cl$ initial value, and R_{se} is the $^{36}Cl/Cl$ at secular equilibrium.

Based on calculated values, the age estimates for CR06 and WK03 are 468±34 $x10^3$ yrs and 332±27 $x10^3$ yrs BP, respectively.

With the decrease in the $^{36}Cl/Cl$ ratio the initial ratio can either be due to decay, or dilution by other sources of ^{36}Cl (e.g. mixing with low ^{36}Cl waters; leaching of salts and dissolution of evaporates). Due to the lack of data for these sources, age estimate calculations did not include these, and assumed chloride and ^{36}Cl are solely derived from atmospheric sources with no internal sources or sinks except for ^{36}Cl decay and nucleogenic ^{36}Cl production. Therefore, these age estimates are likely to be an upper estimate.

Table 4.7 Chlorine-36 results

Gas well	$^{36}Cl/Cl$ $x10^{-15}$	^{36}Cl $x10^8$ atoms/L	Age estimate (10^3 yrs)
CR06	23.1 ± 1.5	3.76 ± 0.24	468 ± 34
WK03	30.1 ± 1.6	2.01 ± 0.11	332 ± 27

5. Discussion

This chapter provides a discussion on the chemical characteristics, isotopic composition, and age of produced water from CR06 and WK03. Water chemistry trends during the flow testing program are also discussed.

5.1 Chemical characteristics

The produced water from CR06 and WK03 is characteristic of coal seams that produce methane. These waters are typically brackish to saline, chemically classified as Na-HCO_3-Cl type waters, and have low concentrations or are devoid of sulphate, calcium and magnesium (Van Voast 2003). They may also contain variable concentrations of barium, strontium, fluoride, and trace metals. They may also contain high concentrations of ammonia (Brinck *et al*. 2008).

The geochemical processes that result in this distinct geochemical signature have been studied and published by a number of researchers including Van Voast (2003), Brinck *et al*. (2008), Rice *et al*. (2008) and Healy *et al.* (2011). The principal geochemical processes include microbial sulphate reduction, bicarbonate enrichment through carbonate dissolution recharge zones, sulphate reduction and methane fermentation processes and calcium and magnesium depletion through inorganic precipitation of calcite and dolomite and possibly cation exchange.

The produced water from the two gas wells have similar chemical composition. The water from both gas wells is chemically classified as Na-HCO_3-Cl, slightly alkaline, reducing and brackish to slightly saline. WK03 water has a lower salinity than CR06 water.

The same trace elements are present in both gas wells; however, concentrations of these are higher in CR06. Trace elements present include molybdenum, manganese, chromium, zinc, fluoride and boron in low concentrations. These are more mobile in natural alkaline waters because common adsorption media, mineral oxides and hydroxides, take on a negative charge in alkaline conditions which decreases the adsorption of anionic species and therefore increases the presence of cationic species such as the trace elements as mentioned above (Brinck *et al*. 2008).

Barium and strontium are present in both gas wells, with CR06 having the higher concentrations. Moderate concentrations of barium and strontium are characteristic of coal seams. These cations remain in solution in coal seam water bearing zones because sulphate reduction has removed sulphate ions that would cause barium to precipitate as the very insoluble species barite ($BaSO_4$) and strontium as celestite ($SrSO_4$).

Ammonia concentrations are similar for the two gas wells, and are above the ANZECC (2000) guideline criteria. Elevated concentrations of ammonia are typical for produced water since coals seams contain nitrogen bearing compounds (pyridines and amines) (Berton Fisher and Santamaria 2002). Coal generally contains 0.5% to 3% (dry weight) nitrogen, most of which is organic. In coal deposits, coalification (coal formation), coal weathering, and anaerobic degradation of coal can result in the mineralisation of organic nitrogen to ammonium. Therefore, coal can contain relatively high amounts of exchangeable ammonium.

Total petroleum hydrocarbons and BTEX compounds were detected at both CR06 and WK03. Hydrocarbons in Permian coals can be naturally occurring (Volk *et al.* 2011) and they were detected in sedimentary rocks in the Gloucester Basin during early exploration programs (Thornton 1982; Hunt *et al.* 1983).

Dissolved methane and ethane were present in both gas well samples, and propane was also present in WK03. The presence of higher chained carbon compounds is characteristic of thermogenically derived gas and gas samples collected in early geological investigations in the basin in 1993 and 1997 contained ethane

(Weber and Smith 2001).T race amounts of propane were also detected in a few samples during the 1993 program (Weber and Smith 2001).

5.2 Isotopic composition and age

The stable isotopic composition (^{18}O and ^{2}H) is similar for WK03 and CR06, and plots to the left of the Global Meteoric Water Line and on the Local Meteoric Water Line, indicating groundwater is of meteoric (rainfall) origin. The isotopic signatures suggest that the coal formations of the Gloucester Coal Measures have been flushed (original pore water replaced with meteoric recharge) at least once since deposition.

The age of groundwater for both gas wells is beyond the limit of the radiocarbon dating method (>30,000 yrs) and using ^{36}Cl dating, it is more likely in the order of several hundred thousand years old.

Compound specific isotopes of dissolved methane (carbon-13 ($\delta^{13}C\text{-}CH_4$) and deuterium ($\delta^{2}H\text{-}CH_4$)) indicate that methane detected in both gas wells is early mature thermogenic in origin. This finding is consistent with those of AGL investigations and earlier investigations by Pacific Power in 1997 and 2000 (Weber and Smith 2001). Weber and Smith (2001) stated that the coals in the Gloucester Basin are medium-volatile bituminous, with a vitrinite reflectance of 0.9% to 1.3%, which is known to be favourable for thermogenic methane generation. They also concluded from the vitrinite reflectance data that folding took place prior to coalification and thermogenic methane generation took place after folding.

5.3 Water chemistry trends

There were no significant trends in EC, pH, major ions or nutrients in water samples collected from either gas well for the six month flow testing period. There were changes in some metal concentrations; however, there were no clear temporal trends, and the majority of metal concentrations were below ANZECC (2000) criteria for freshwater ecosystems (south-east Australia – lowland rivers). Minor changes in metals concentrations are expected during flow testing due to changes in pH and redox, and also because the gas wells are perforated against multiple coal seams of varying water quality and there is a variable volumetric contribution from each seam.

It would appear that all groundwater pumped/sampled is derived from the target coal seams and no other formations with different water quality above or below the exposed coal seams are providing any major contribution.

6. Conclusions

AGL has undertaken a number of flow testing programs to assess gas flow potential and volume of water produced by coals within the Upper Permian Gloucester Coal Measures. Flow testing was undertaken on the gas wells, Craven 6 (CR06) and Waukivory 3 (WK03) from April 2013 (CR06) and June 2013 (WK03) to November 2013. Groundwater samples were collected for chemistry and isotope analysis throughout the testing period on three occasions, in June, August and October 2013.

The main conclusions of the study are:

- The average water make at CR06 throughout the main flow testing phase was 8.8 m^3/day (0.1 L/s). The maximum produced water rate was 60.5 m^3/day (0.70 L/s) and the minimum produced water rate was 1.4 m^3/day (0.02 L/s). Generally the produced water rate reduced from the start of the test.
- The average water make at WK03 throughout the main flow testing was 19.7 m^3/day (0.23 L/s). The maximum produced water rate was 42.4 m^3/day (0.49 L/s) and the minimum produced water rate was 8.2 m^3/day (0.09 L/s). Generally the produced water rate reduced from the start of the test.
- The produced water from CR06 and WK03 is characteristic of coal seams that produce methane. The water is brackish to slightly saline, chemically classified as Na-HCO_3-Cl type water, and has low concentrations of sulphate, calcium and magnesium
- Water from both gas wells is chemically classified as slightly alkaline, reducing and brackish to slightly saline. CR06 has a higher salinity than WK03.
- The same trace elements are detected in both gas wells; however, concentrations of these are higher in CR06. Trace elements present include molybdenum, manganese, chromium, zinc, fluoride and boron and are present in low concentrations.
- Barium and strontium are detected in both gas wells, with CR06 having the higher concentrations. Moderate concentrations of barium and strontium are characteristic of coal seams.
- Ammonia concentrations are similar for the two gas wells, and are above the ANZECC (2000) guideline criteria. However, elevated concentrations of ammonia are typical for coal seam waters.
- Total petroleum hydrocarbons and BTEX compounds were detected at CR06 and WK03. Hydrocarbons have been found in early exploration programs in the Gloucester Basin indicating they are naturally occurring in the Gloucester Coal Measures.
- Dissolved methane and ethane were present in both gas well samples, and propane was also present in WK03. The presence of higher chained carbon compounds is characteristic of thermogenically derived gas. Compound specific isotopes of dissolved methane (carbon-13 ($\delta^{13}C$-CH_4) and deuterium ($\delta^{2}H$-CH_4)) also indicate that methane detected in both gas wells is early mature thermogenic.
- The stable isotopic composition (^{18}O and ^{2}H) is similar for WK03 and CR06, and indicates groundwater is of meteoric (rainfall) origin. The isotopic signatures suggest that the coal formations of the Gloucester Coal Measures have been flushed at least once since deposition.
- The age of groundwater for both gas wells is beyond the limit of the radiocarbon dating method (>30,000 yrs) and using ^{36}Cl dating, it is more likely in the order of several hundred thousand years old.
- There were no significant trends in EC, pH, major ions or nutrients for either gas well for the flow testing period. There were changes in some metal concentrations; however, there were no clear trends, and the majority of metal concentrations were below ANZECC (2000) criteria. Minor changes in metals concentrations are expected during flow testing due to changes in pH and redox, and also because the gas wells are perforated against multiple coal seams of likely varying water quality and there is a variable volumetric contribution from each seam.

7. Statement of limitations

7.1 Scope of services

This report has been prepared in accordance with the scope of services set out in the contract, or as otherwise agreed, between the client and Parsons Brinckerhoff (scope of services). In some circumstances the scope of services may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.

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Appendix A

Well completion reports

AGL Energy Limited

Well Completion Report

Craven 6
(CR06)

Gloucester Production Testing Evaluation Program

Gloucester Basin
NSW

November 2009

Table of Contents

1. EXECUTIVE SUMMARY

Craven 6 is a gas production evaluation well that was drilled to test the gas flow potential of coals within the Upper Permian Gloucester Coal Measures. Craven 6 is located approximately 4km south of the Stratford Pilot where the same coals have undergone successful production testing from multiple wells.

Craven 6 was spudded on the 12th January, 2009 and reached a total depth of 983 meters on the 16th January, 2009. The well was drilled using McDermott's Rig 16, Drillmech G-55 with 8 5/8" surface casing cemented at 105 metres. The well was drilled using a combination of PDC and UD bits (11" and 7 7/8"). The well was drilled using water and mud-up with a gel slurry as the drilling fluid.

Geophysical logging of the hole was carried out by Groundsearch Australia upon total depth being reached.

The 5 ½" production casing was set to a depth of 981 metres. Craven 6 was one of three wells in the Gloucester Production Program to utilise BJ Services' Opti-Frac SJ method to perforate multiple zones. The intervals were fracture treated by BJ Services from the 10th May, 2009 to the 16th May, 2009 and 2 7/8" tubing was seated in the casing at 717.95 m.

A well head with telemetry was fitted allowing AGL to clean out the well until production flow rates were reached and applicable site remediation was carried out.

2. WELL SUMMARY

TABLE1 - Well Summary Sheet

WELL SUMMARY SHEET

WELL	Craven 6 (CR06)		**GEOLOGY**	Earth Data	
WELL TYPE	Production				
OPERATOR	Lucas Energy		**GEOPHYSICS**	Groundsearch Australia	
PARTICIPANTS	Lucas Energy	70.00%			
	Molopo	30.00%	**TARGET ZONES**	Gloucester Coal Measures	
BASIN	Gloucester Basin				
BLOCK/LICENCE	PEL 285				
STATE	New South Wales				
LOCATION	-32° 7' 57.777"	*Lattitude*	**REMARKS**		
	151° 56' 39.552"	*Longitude*			
MGA 94 (Zone 56)	400426.83	*X (m)*			
	6444365.65	*Y (m)*			
ELEVATION	158.67m (KB)				
TD Date/Depth (m MD)	16th January, 2009	983.00	**CASING PROGRAM**		
RIG	DRS056 Rig#16		CASING SIZE	SHOE DEPTH (m MD)	TYPE
SPUD DATE	12th January, 2009		8 5/8"	105.00	Surface
Rig Release Date	19th january, 2009		5 1/2"	981.00	Production

DRILLING PROGRAM

BIT TYPE	SIZE	DEPTH (m MD)	PROGNOSED FORMATION	ACTUAL (m MD)
PDC	11"	105.00		
UD513	7 7/8"	983.00		

GEOPHYSICAL LOGGING PROGRAM

RUN NO	RUN NAME	LOG TYPE	INTERVAL (m MD)
N/A	9239 B1	Gamma, Caliper, Density, Resistivity	0 - 983.82
N/A	9512 A	Gamma, Conductivity, Resistivity, Temperature	97.44 - 983.43
N/A	9057 A	T Depth, Deviation, Azimuth, Resisivity, Neutron	0 - 983.22
N/A	9057 A	Gamma, Temp, Resistivity, Neutron	0 - 982.24

WELL TESTING PROGRAM

TEST NO	TEST TYPE	CONFIGURATION On Penetration / Straddle	INTERVAL (m MD)		
			From	To	Thickness (m)
N/A	-	-	-	-	-

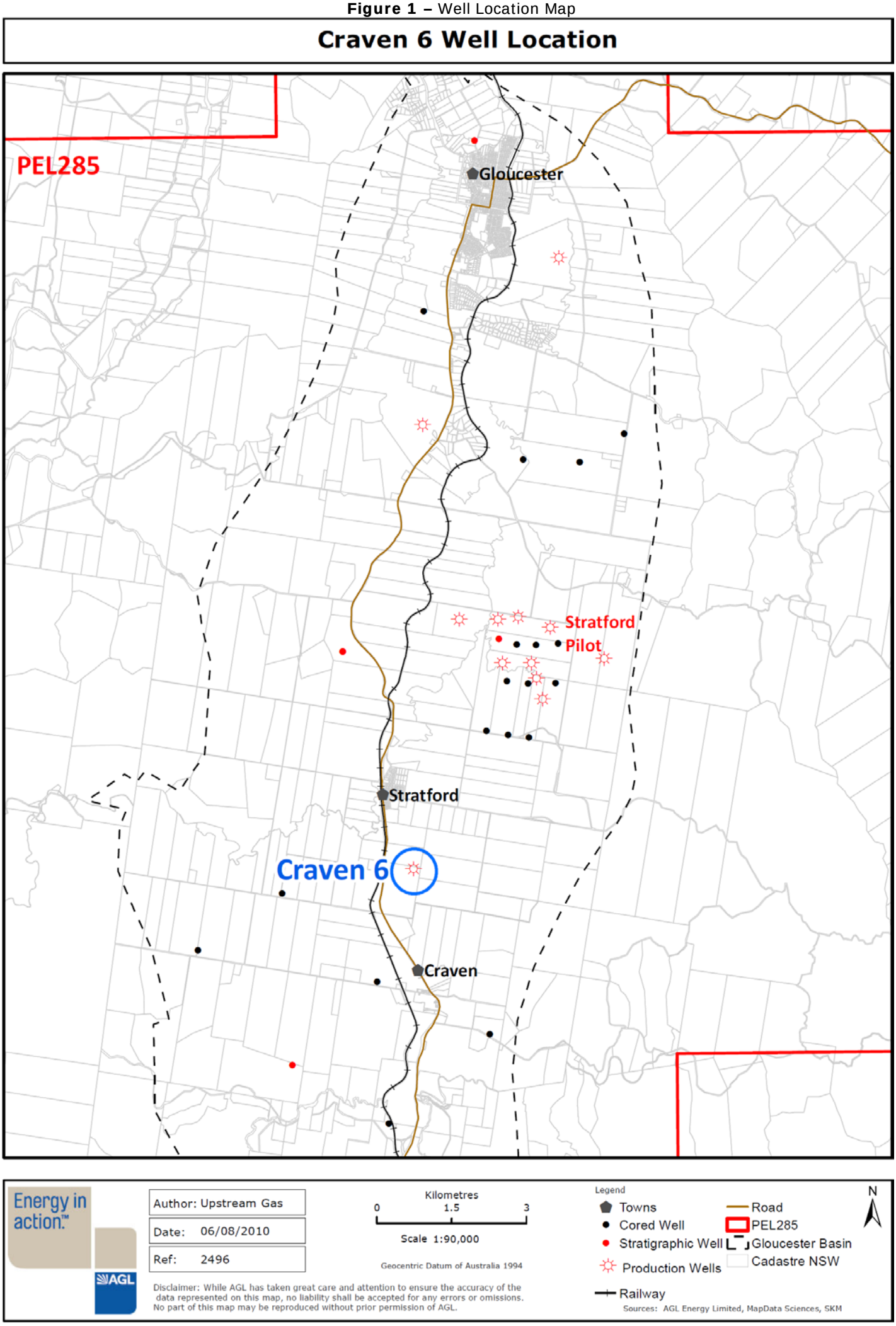
GEOLOGICAL SUMMARY

AGE	GROUP / SUBGROUP	FORMATION / MEMBER	Top Depth (m) MD	Base Depth (m) MD	Thickness (m)	HIGH / LOW
Upper Permian	Gloucester Coal Measures					-
	Craven SubGroup					-
	Crowthers Rd Conglomerate					
	Leloma Formation	Bindaboo Coal	149.35	228.09	78.74	
		Deards Coal	248.67	358.85	110.18	
	Jilleon Formation	Cloverdale Coal	389.74	406.4	16.66	
		Roseville Coal	446.96	473.3	26.34	
		Tereel Coal/Fairbairns Lane	533.22	698.83	165.61	-
	Wards River Conglomerate		698.86	723.98	25.12	-
	Wenhams Formation	Bowens Rd Coal	723.98	737.9	13.92	-
	Speldon Formation					
	Avon SubGroup					
	Dogtrap Creek Formation	Glenview Coal	773.61	799.03	25.42	
	Waukivory Creek Formation	Avon Coal	852.04	855.70	3.66	
		Triple Coal	898.12	917.98	19.86	
		Rombo Coal	940.16	950.48	10.32	
		Glen Road Coal	954.9	965.63	10.73	
		Total Depth	**983.00**			

TABLE 1 cont'd: Well Summary Sheet

WELL STATUS		Suspended			
CASING TREATMENT					
ZONE	**TYPE**	**Depth (m MD)**	**ZONE**	**TYPE**	**Depth (m MD)**
Z11/12	Sand Jet Perforation	245.5	Z7	Sand Jet Perforation	497
Z11/12	Sand Jet Perforation	298	Z7	Sand Jet Perforation	498
Z11/12	Sand Jet Perforation	296	Z6	Sand Jet Perforation	620.5
Z10	Sand Jet Perforation	311.5	Z6	Sand Jet Perforation	627.5
Z10	Sand Jet Perforation	318.5	Z6	Sand Jet Perforation	633
Z10	Sand Jet Perforation	320	Z5	Sand Jet Perforation	654
Z9	Sand Jet Perforation	393.5	Z5	Sand Jet Perforation	658.5
Z9	Sand Jet Perforation	396	Z5	Sand Jet Perforation	660.5
Z9	Sand Jet Perforation	404	Z4	Sand Jet Perforation	725
Z9	Sand Jet Perforation	408.5	Z4	Sand Jet Perforation	726.5
Z8	Sand Jet Perforation	454	Z4	Sand Jet Perforation	727.5
Z8	Sand Jet Perforation	461	Z4	Sand Jet Perforation	731
Z8	Sand Jet Perforation	466	Z4	Sand Jet Perforation	736
Z8	Sand Jet Perforation	474	Z4	Sand Jet Perforation	736.5

Figure 1 – Well Location Map



3. GLOUCESTER BASIN GEOLOGY

3.1 Overview

The Gloucester Basin is a north south trending synclinal trough containing shaped trough containing Permian volcanics and sediments. Basement comprises Carboniferous sedimentary rocks and volcanic units. The basin sequence is capped by Late Permian fluvial-deltaic sediments of the Dewrang Group and Gloucester Coal Measures. The top of the Permian section has been exposed to erosion.

The Gloucester Basin is divided up into three major stratigraphic units: the Alum Mountain Volcanics, the Dewrang Group and the Gloucester Coal Measures. The Dewrang Group and the Gloucester Coal Measures contain 15 laterally extensive coal units and represent the main coal seam gas targets.

Throughout the evolution of the Gloucester Basin, sandstones, mudstones, conglomerates and coals were deposited in fault-controlled troughs. The preserved basin stratigraphy is up to 4000m thick. Widespread Early Permian volcanic activity may be related to thermal upwelling beneath the base of the continental lithosphere in a retroarc basin setting. Due to the Late Permian fall in relative sea level, shallow water and fluvial conditions prevailed. The complex interplay of tectonics extensional faulting, high rates of sediment supply produced significant lateral stratigraphic variability throughout the Gloucester Basin.

3.2 Structure

The Gloucester Basin exhibits a complex structural history. Early normal and syn-depositional faults occur and in many cases have been reactivated by the later Hunter-Bowen orogenic events. The Gloucester Basin displays steep dips of up to 80° on its flanks, dipping towards the north-south trending basin axis and relatively flattening towards the centre of the basin. The basin is dissected by several major thrust structures.

3.3 Stratigraphy

The Gloucester Basin is divided up into three major stratigraphic units: the Alum Mountain Volcanics, the Dewrang Group and the Gloucester Coal Measures. These are described below. The stratigraphic nomenclature used for the Gloucester Basin in this report is based

on Lennox, M., 1991, which is contained in Roberts, J., and Chapman, J., 1991, and is tabulated in Figure 4. Stratigraphy penetrated at Craven 6 is summarised in table 1 and a full lithology log can be found in Appendix 3.

3.3.1 Alum Mountain Volcanics

The Alum Mountain volcanics lie unconformably over the carboniferous Johnsons Creek Conglomerate. The Volcanics commence with a basal coal measure sequence of pebble conglomerate which is overlain by the 12m Basal Coal seam. This seam is overlain by basalt flows, rhyolites, and acid tuffs. Towards the top of the sequence conglomerates are more prevalent and the Clareval seam, along with several thinner coals are present.

3.3.2 Dewrang Group

The **Durallie Road Formation** contains two distinct facies. The lower part of the formation is predominantly a well sorted fine grained sandstone, while further up this becomes coarser grained. Overlying this is a conglomerate which is particularly prevalent on the eastern side of the basin. The formation is both alluvial and marine influenced and likely represents a near shore environment where braided alluvium such as conglomerate has flowed directly into the sea.

The **Weismantel Formation** was deposited in a back-barrier lagoonal environment during a regressive phase. The formation's major feature is the thick Weismantel seam which lies at its base. The seam is an average of 10m thick along the flanks of the basin increasing to 25m in the south. The seam continues north along the eastern flank if the basin. The Weismantel seam is overlain by bioturbated siltstone and sandstone.

The **Mammy Johnsons Formation** consists of fine to medium grained sandstones with laminated siltstone at its top and base. These sandstones are bioturbated in parts and are considered to have been deposited in a shallow marine environment. The Intra Mammy Johnsons Coal is up to 5m thick and was most likely formed in a back barrier swamp or lagoon.

3.3.3 Gloucester Coal Measures

3.3.3.1 Avon Subgroup

The **Waukivory Creek Formation** represents a change in depositional environment from marginal marine setting of the underlying Dewrang Group to a terrestrial coastal plain. Deposited in a coastal plain environment and represents a shift away from marine influenced sediments. Units generally fine grained but with occasional 10m thick medium grained beds which are most likely from a meandering river system. The formation contains several substantial coal seams in the Parkers Road, Rombo, Triple and Avon coal seams. These coal seams are best developed on the eastern side of the basin.

The **Dogtrap Creek Formation** is indentified by its coarsening upward sequences, bioturbated mudstones and crevasse splays. The Dogtrap Creek formation represents the start of a transgressive phase of deposition. The depositional environment was most likely lower delta plain. The Glenview coal is well developed near the top of the sequence.

The **Speldon Formation** represents the culmination of the marine transgression seam in the Dogtrap Creek formation. The formation contains well bedded medium to fine grained sandstone with minor siltstone and becomes darker and siltier towards its top. The formation is heavily bioturbated and the north eastern part of the basin contains marine fossils.

3.3.3.2 Craven Subgroup

The **Wenham Formation** contains the Bowens Road Lower seam at its base and the Bowens Road seam at the top. The Bowens Road Lower is generally thin (~2m) while the Bowens Road is up to 14m in the Stratford area. Between the seams is fine grained sandstone which is interspersed with plant debris. The main Bowens Road seam is characterized as being bright at the base and considerably duller and banded towards the top. This is believed to have been caused by a lowering of the water table which led to subaerial oxidation. The formation represents a hiatus after regression.

The **Wards River Conglomerate** is a major feature of the Gloucester Basin. While it is considered to lie stratigraphically above the Wenham formation and below the Jilleon Formation, this is only the case in its type section in the eastern part of the basin. The conglomerate was deposited as several large alluvial fans whose sediment source was the carboniferous sequence which outcrops to the west of the Gloucester Basin. On the western

side of the basin the conglomerate forms the lateral equivalent of all the formations above the Bowens Road seam. In this area at its thickest it consists of matrix supported conglomerate and becomes thinner and finer grained (but generally still conglomeratic) moving east through a braided river system into an interfan or overbank deposit.

The **Jilleon Formation** onlaps and is eventually replaced by the Wards River Conglomerate in the west of the basin. This formation contains the Roseville seam and Cloverdale seam (at its top), as well as the less consistent Tereel (or Fairbairns Lane) coals. The Jilleon Formation consists of coarsening upward sandstones with occasional upward fining siltstone. It was deposited in an alluvial plain environment, and was subsiding rapidly which has lead to a lot of thin coal seams forming. The Roseville and Cloverdale seams can be traced across a wide area on the eastern flank. Both seams are several metres thick, and the Cloverdale contains a distinct tuff band which proves useful when correlating wells.

The **Leloma Formation** outcrops only in the middle of the basin. It contains the Deards, Bindaboo, and Linden seams as well as several thin unnamed coals. These are overlain by a 300m thick homogeneous fine to medium grained sandstone layer deposited in an upper alluvial plain environment. Correlation of coal seams is particularly difficult as they vary in thickness and split across relatively short distances. The coals of the Leloma formation are best developed in the Clear Hill sub basin area on the western flank of the basin. There are several tuff bands throughout the sequence, the largest being the Jo Doth Tuff. The JD Tuff is 15 to 30m thick and is consistent across the formation until it is replaced by the Wards River Conglomerate in the east.

The **Crowthers Road Conglomerate** marks the top of the Gloucester basin Stratigraphy and as such is the present day erosion surface. It consists of pebble conglomerate and medium to coarse grained sandstone derived from the carboniferous formations to the west and north of the basin. As such it is generally confined to the western and northern part of the basin and imbricated clasts show flow was in an easterly direction. Deposition was due to several large alluvial fans.

Figure 2: Stratigraphic Unit

Stratigraphy of the Gloucester Basin

			Formation		Seam	Depositional Environment
UPPER PERMIAN	GLOUCESTER COAL MEASURES	CRAVEN SUBGROUP	Crowthers Rd Conglomerate	oO Oo	Conglomerate, minor sandstone	Distal Alluvial Fan
			Leloma Formation		Sandstone, minor siltstone and coal	Alluvial Plain
					Linden Coals	
					Marker/JD Coals	
				^ ^ ^ ^	Jo Doth Tuff	
					Bindaboo Coals	
					Deards Coal	
					Sandstone, minor siltstone and coal	
			Jilleon Formation		Cloverdale Coal	Hiatus Coal
					Conglomerate, sandstone and siltstone	Alluvial Plain
					Roseville Coal	
					Tereel Coals/Fairbairns Lane	
			Wards River Conglomerate	oO Oo oO Oo oO	Conglomerate and sandstone	Distal Alluvial Fan
			Wenhams Formation		Bowens Rd Coal	Hiatus Coal
					Siltstone	Marsh
					Bowens Rd Lower Coal	Back Barrier Coal
			Speldon Formation		Marine influenced sandstone	Marginal Marine, prodelta, beach
		AVON SUB GROUP	Dogtrap Creek Formation		Glenview Coal	Back Barrier Coal
					Sandstone, siltstone	Lower Delta Plain
			Waukivory Creek Formation		Avon Coals	Hiatus Coal
					Triple, Rombo, Glen Rd	Upper Delta Plain
					Sandstone and siltstone	Upper Delta Plain
					Parkers Rd and Valley View Coals	Hiatus Coal
					Siltstone and mudstone	Transitional
	DEWRANG GROUP		Mammy Johnsons Formation		Sandstone and siltstone	Marginal Marine, Barrier, Wave Dominated Delta
					Intra Mammy Johnsons Coal	Back Barrier Coal
					Bioturbated sandstone	Marginal Marine, Barrier, Wave Dominated Delta
			Weismantels Formation		Siltstone and mudstone	Back Barrier Lagoon
					Weismantels Coal	Back Barrier Coal
			Duralie Road Formation		Marine Sandstone, conglomerate	Marginal Marine, Fan Delta
LWR PERM			Alum Mountain Volcanics		Clareval Coal	Hiatus Coal
				oO Oo	Conglomerate and coal	Distal Alluvial Fan
				^ ^ ^ ^	Rhyolite, basalt, welded tuff	Bimodal Terrestrial Volcanics
					Basal Coal	

4. DRILIING, STIMULATION & COMPLETION

4.1 Contractor Details

Craven 6

Drilling Contractor:

McDermott Drilling Pty Ltd
P.O Box 6027
Minto, NSW 2566
Contact: Kerry Brydon
Ph: 02 8796 0900
Fax: 02 8795 0633
Mobile: 0416 242 881
E-mail: kerry@mcdermottdrilling.com.au
Website: www.mcdermottdrilling.com.au

Casing/Cementing:

Surface Casing – McDermott Drilling
Production Casing – AGL Energy Operations Pty Ltd
Contact: Mark Bonisch
Tel: 02 6558 1166
Fax: 02 6558 1066
Mobile: 0427 404 129
Email: MBonisch@agl.com.au

Logging:

Groundsearch Australia
16 Johnston St
Rutherford, 2320
Contact: John Lea
Ph: (02) 4932 3582
Fax: (02) 4932 3529
Mobile: 0427 494 234
Email: geology@groundsearch.com.au

Perforating/Fracturing Contractor:

BJ Services Company Pty Ltd
Suite 537, Level 5 Towong Tower
9 Sherwood Rd
Towong QLD 4066
Contact: Paul Unwin
Tel: +61 4481 31030
Fax: 07 3310 8753
Email: punwin@bjservices.com.sg

Wireline Services:

Vause Wireline Aust Pty Ltd
179 Raglan St
PO Box 130
ROMA QLD 4455
Contact: Paul Nunn
Ph: +61 7 46222 511
Fax: +61 7 46222 611
Email: paul.nunn@vause.com.au

4.2 Drilling

Well Completion Report – CR06 Drilling Summary

CR06 was spudded on 12th January, 2009

Pre-Spud Prognosis

Craven 6 was planned as a vertical well. With the drilling plan being:

- RU Rig to drill 279mm (11") PDC OH to 110 m for 8 5/8"surface casing. Run surface casing and cement surface casing back to surface. WOC 8hrs minimum, WOC time can be reduced if $CaCl_2$ is used in the mix water.
- RU for Production drilling. Nipple up BOP and pressure test to 350psi for 10 mins and 750 psi for 10mins, formation integrity test to be performed once virgin formation is drilled outside the 8 5/8" casing shoe.
  RIH with 7 7/8" PDC bit and drill with WBM to TD of 850m, it is predicted to intersected the Bindaboo Coal seam at 90m through to Triple Coal seam at 705 m.

Drilling Summary

CR06 was spudded on the 12th January 2009 using Lucas McDermott Rig No. 16 Drillmec G55.
An 11" open hole was drilled to a depth of 105m using a REED PDC bit with a bentonite gel and PAC based fluid system. The surface hole was then cased off with 8 5/8" 24ppf J-55 casing to a shoe depth of 105m. 23.9BBl 15.6ppg Class A cement slurry was pumped and displaced with drill fluid. Wait on cement was 6 hours.
An 7 7/8" open hole was drilled to a total depth of 983m using an 7 7/8" UD513 PDC bit with a bentonite gel and PAC based fluid system on the 15th January 2009. A LOT test was performed outside the surface casing shoe and forward drilling progressed to TD, at 860m MD it was noted that 18.8BBLs of fluid were lost to formation. Upon reaching TD the well was circulated and conditioned with a wiper trip prior to open hole logging being conducted. Well was then cased with 5 1/2 " 15.5ppf K-55 casing to a shoe depth of 981m on the 19th January 2010. 127BBL 15.6ppg Class A cement slurry containing 4% bentonite, 4% Cal Seal and 9%CFL-3 was pumped and displaced with fluid.
Rig was released on the 19th January 2010

McDermott Drilling cemented the surface casing string. Refer to Appendix 1 (Daily Drilling Reports) for surface and production casing cement report.
GroundSearch Australia performed Density, Gamma, Neutron, Temperature, Sonic, Verticality and Caliper OH logs.

A summary bit table is presented below

Table 2: Bit Summary Table

Bit No.	1	2
Size (in)	11	7 7/8
Manufacturer	Reed	Ulterra
Type	4 blade PDC	5 blade PDC
Serial No.	101755	UD513
Jets	4x12	5 x 10
TFA (in2)	0.442	0.383
RPM	130	130
WOB (lbs)	5000	5000
Depth Drilled (m)	105	878
ROP (n/hr)	27.2	38.6

4.3 Lithology – Logging

Please refer to Geological Report (Appendix 3)

4.4 Fracture Stimulation

Please refer to Frac Report (Appendix 6)

4.5 Well Completion

Craven 06 was one of three wells in the Gloucester Production Program that utilises BJ Services' Opti-frac SJ method. BJ Services' Optic-frac method was used to conduct the fracture stimulation by slotting the casing and fraccing by utilising coiled tubing and a sand jet tool.

BJ Services conducted the perforation and fracture operations on several zones in the Gloucester Coal Measures perforated (Refer to Table 1 Craven 06 Well Summary). The completion operations conducted on CR06 began on 27th July, 2009. The completion prognosis was as follows;

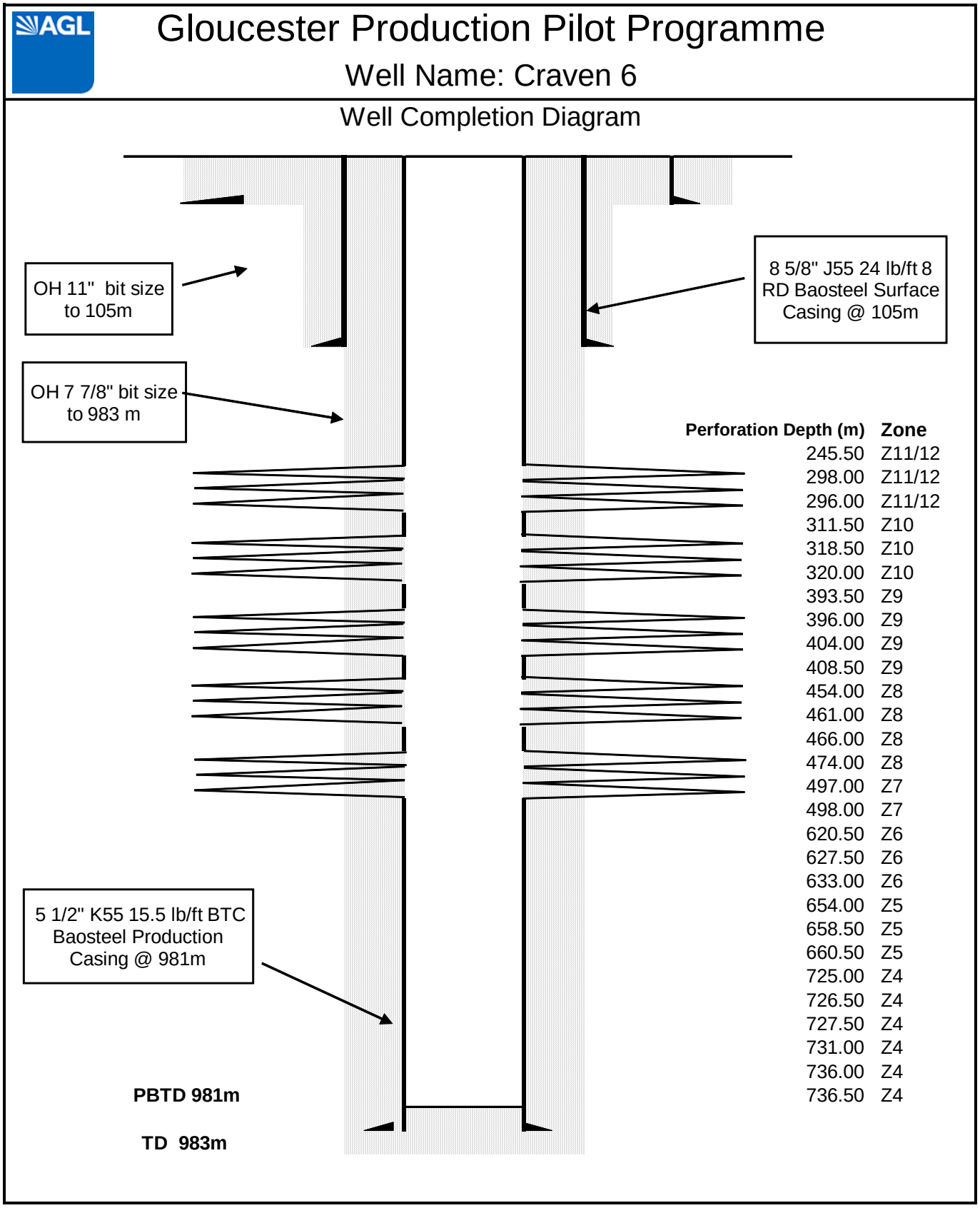
- RIH and clean out wellbore.
- RIH 2 3/8" 4.7 lb/ft and 2 7/8" production tubing set at 717.95m

In total 89 joints of 2 7/8" 4.7lb/ft and 12 joints of 2 3/8" production tubing were used, including a pump seat nipple. The production tubing was landed at 717.95m. Well completion operations were completed on the 19th September, 2009.

Well was circulated with water. Fill was first tagged at approx 711.83m, well was then washed and then tagged TD at 983m.

The operation was supervised by Anthony Sutton, Driller Brendan McHenry and offsiders Dean Papierski and Timothy Clifton.

FIGURE 3: Well Schematic



5. OTHER OPERATIONS

5.1 Geophysical Logging

Please refer to accompanying LAS files

6. CONCLUSION

The coals encountered within Craven 6 were found to be of similar quality to those intersected at the Stratford Pilot. Craven 6 is a production test evaluation well designed to test the gas flow potential of coals within the Gloucester Coal Measures.

The well has also provided a valuable dataset in further understanding coal seam methane reservoir characteristics and how better to explore, develop and manage the resource.

7. LIST OF FIGURES

8. LIST OF TABLES

9. APPENDICES

AGL Energy Limited

Well Completion Report

Waukivory 3
(WK03)

Gloucester Production Program

Gloucester Basin
NSW

14 July 2010

Table of Contents

1.EXECUTIVE SUMMARY

Waukivory 3 is a gas production evaluation well that was drilled to test the gas flow potential of coals within the Upper Permian Gloucester Coal Measures. Waukivory 3 is located approximately 7km north of the Stratford Pilot where the same coals have undergone successful production testing from multiple wells.

Waukivory 3 was spudded on the 6th January, 2009 and reached a total depth of 818m on the 9th January, 2009. The well was drilled using McDermott's Rig 16, Drillmech G-55 with 8 5/8" surface casing cemented at 103.16m. The well was drilled using a combination of PDC, bits (11" and 7 7/8"). Water and mud-up was used as the drilling fluid with a gel slurry for hole cleaning.

Geophysical logging of the hole was carried out by Groundsearch Australia upon total depth being reached.

The 5 ½" production casing was set to a depth of 815.95m. Waukivory 3 was one of three wells in the Gloucester Production Program to utilise BJ Services' Opti-Frac SJ method to perforate multiple zones. The intervals were fracture treated by BJ Services from the 6th May, 2009 to the 9th May, 2009 and 2 3/8" tubing was seated in the casing at 674.47m.

A well head with telemetry was fitted allowing AGL to clean out the well until production flow rates were reached and applicable site remediation was carried out.

2. WELL SUMMARY

Table 1: Waukivory 3 Well Summary Sheet

WELL SUMMARY SHEET

WELL	Waukivory 3 (WK03)		**GEOLOGY**	Earth Data	
WELL TYPE	Production				
OPERATOR	Lucas Energy		**GEOPHYSICS**	Groundsearch Australia	
PARTICIPANTS	Lucas Energy Molopo	70.00% 30.00%			
BASIN	Gloucester Basin		**TARGET ZONES**	Gloucester Coal Measures	
BLOCK/LICENCE	PEL 285				
STATE	New South Wales				
LOCATION	-32° 1' 20.339"	*Lattitude*	**REMARKS**		
	151° 58' 35.281"	*Longitude*			
MGA 94 (Zone 56)	403343.01	*X (m)*			
	6456632.88	*Y (m)*			
ELEVATION	111.54 m (KB)				
TD Date/Depth (m MD)	9th January, 2009	818.00	**CASING PROGRAM**		
RIG	DRS056 Rig#16		CASING SIZE	SHOE DEPTH (m MD)	TYPE
SPUD DATE	6th January, 2009		8 5/8"	107.16	Surface
Rig Release Date	11th January, 2009		5 1/2"	815.95	Production

DRILLING PROGRAM

BIT TYPE	SIZE	DEPTH (m MD)	PROGNOSED FORMATION	ACTUAL (m MD)
Reed	11"	107.00		
HC506Z	7 7/8"	818.00		

GEOPHYSICAL LOGGING PROGRAM

RUN NO	RUN NAME	LOG TYPE	INTERVAL (m MD)
N/A	9239 B1	Gamma, Caliper, Density, Resistivity	0.48 - 818.78
N/A	9512 A	Gamma, Conductivity, Resistivity	103.11 - 817.72
N/A	9057 A	T Depth, Deviation, Azimuth, Resisivity, Neutron	105 - 820.37
N/A	9057 A	Gamma, Temp, Resistivity, Neutron	0 - 820.37

WELL TESTING PROGRAM

TEST NO	TEST TYPE	CONFIGURATION On Penetration / Straddle	INTERVAL (m MD)		
			From	To	Thickness (m)
N/A	-	-	-	-	-

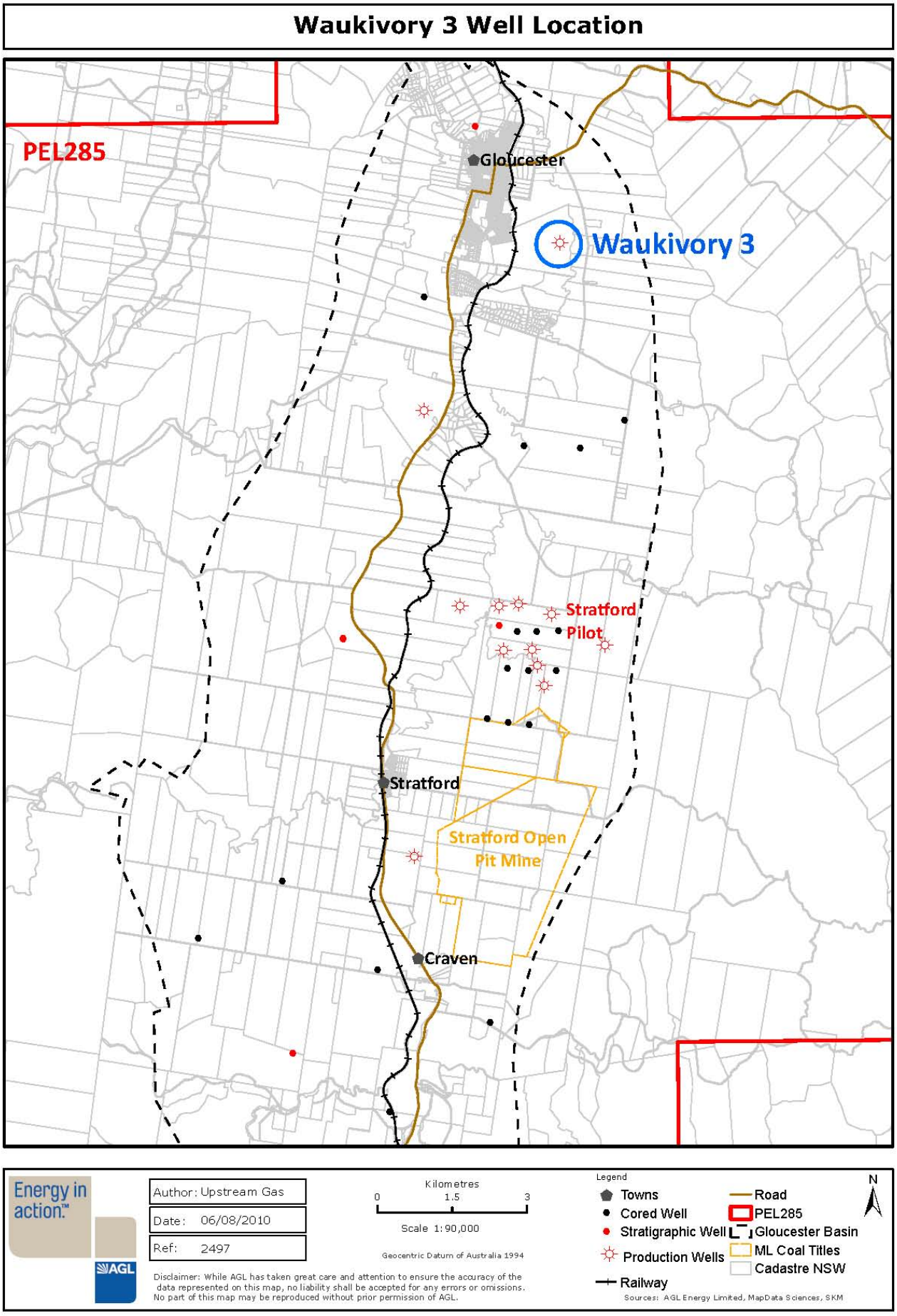
GEOLOGICAL SUMMARY

AGE	GROUP / SUBGROUP	FORMATION / MEMBER	Top Depth (m) MD	Base Depth (m) MD	Gross Thickness (m)	HIGH / LOW
Upper Permian	Gloucester Coal Measures					-
	Craven Sub Group					-
	Leloma Formation		*0.00*	*304.00*	*304.00*	-
	Jilleon Formation	Cloverdale Coal				-
		Roseville Coal	150.31	165.00	14.69	-
		Fairbairns Lane Coal	180.68	251.31	70.63	-
	Wards River Conglomerate					-
	Wenhams Formation	Bowens Rd Coal	269.80	295.87	26.07	-
	Speldon Formation					-
	Avon Sub Group		*304.00*	*818.00*	*514.00*	-
	Dogtrap Creek Formation	Glenview Coal	309.72	327.93	18.21	-
	Waukivory Creek Formation	Avon Coal	434.36	440.72	6.36	-
		Triple	456.70	481.55	24.85	-
		Valley View Coal	508.16			-
		Total Depth	**818.00**			

Table 2 continued: Waukivory 3 Well Summary Sheet

WELL STATUS	Perforated				
CASING TREATMENT					
ZONE	**TYPE**	**Depth (m MD)**	**ZONE**	**TYPE**	**Depth (m MD)**
Z1	Perforation	617 - 621.6	Z4/Z5	Sand Jet Perforation	313
Z1	Perforation	650.4 - 651.3	Z4/Z5	Sand Jet Perforation	298.5
Z2	Sand Jet Perforation	598	Z4/Z5	Sand Jet Perforation	298
Z2	Sand Jet Perforation	597	Z4/Z5	Sand Jet Perforation	296.5
Z3	Sand Jet Perforation	441	Z6	Sand Jet Perforation	280
Z3	Sand Jet Perforation	440	Z6	Sand Jet Perforation	277
Z3	Sand Jet Perforation	437.5	Z6	Sand Jet Perforation	276
Z3	Sand Jet Perforation	437	Z6	Sand Jet Perforation	273
Z4/Z5	Sand Jet Perforation	328			

Figure 1: Well Location Map



Revision DRAFT
Created 24 Nov 2008
Author Toni Laurie

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Kilometres
Map Grid of Australia, Zone 56
Geocentric Datum of Australia 1994

Gloucester Coal Seam Gas Project

Waukivory 3
Access Roads

STRICTLY CONFIDENTIAL

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22 Tate St Gloucester NSW 2422 Australia
Ph 61 2 6558 1169 Fax 61 2 6558 1106

3. GLOUCESTER BASIN GEOLOGY

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3.3.2 Dewrang Group

The Durallie Road Formation contains two distinct facies. The lower part of the formation is predominantly a well sorted fine grained sandstone, while further up this becomes coarser grained. Overlying this is a conglomerate which is particularly prevalent on the eastern side of the basin. The formation is both alluvial and marine influenced and likely represents a near shore environment where braided alluvium such as conglomerate has flowed directly into the sea.

The Weismantel Formation was deposited in a back-barrier lagoonal environment during a regressive phase. The formation's major feature is the thick Weismantel seam which lies at its base. The seam is an average of 10m thick along the flanks of the basin increasing to 25m in the south. The seam continues north along the eastern flank if the basin. The Weismantel seam is overlain by bioturbated siltstone and sandstone.

The Mammy Johnsons Formation consists of fine to medium grained sandstones with laminated siltstone at its top and base. These sandstones are bioturbated in parts and are considered to have been deposited in a shallow marine environment. The Intra Mammy Johnsons Coal is up to 5m thick and was most likely formed in a back barrier swamp or lagoon.

3.3.3 Gloucester Coal Measures

3.3.3.1 Avon Subgroup

The Waukivory Creek Formation represents a change in depositional environment from marginal marine setting of the underlying Dewrang Group to a terrestrial coastal plain. Deposited in a coastal plain environment and represents a shift away from marine

influenced sediments. Units generally fine grained but with occasional 10m thick medium grained beds which are most likely from a meandering river system. The formation contains several substantial coal seams in the Parkers Road, Rombo, Triple and Avon coal seams. These coal seams are best developed on the eastern side of the basin.

The Dogtrap Creek Formation is indentified by its coarsening upward sequences, bioturbated mudstones and crevasse splays. The Dogtrap Creek formation represents the start of a transgressive phase of deposition. The depositional environment was most likely lower delta plain. The Glenview coal is well developed near the top of the sequence.

The Speldon Formation represents the culmination of the marine transgression seam in the Dogtrap Creek formation. The formation contains well bedded medium to fine grained sandstone with minor siltstone and becomes darker and siltier towards its top. The formation is heavily bioturbated and the north eastern part of the basin contains marine fossils.

3.3.3.2 Craven Subgroup

The Wenham Formation contains the Bowens Road Lower seam at its base and the Bowens Road seam at the top. The Bowens Road Lower is generally thin (~2m) while the Bowens Road is up to 14m in the Stratford area. Between the seams is fine grained sandstone which is interspersed with plant debris. The main Bowens Road seam is characterized as being bright at the base and considerably duller and banded towards the top. This is believed to have been caused by a lowering of the water table which led to subaerial oxidation. The formation represents a hiatus after regression.

The Wards River Conglomerate is a major feature of the Gloucester Basin. While it is considered to lie stratigraphically above the Wenham formation and below the Jilleon Formation, this is only the case in its type section in the eastern part of the basin. The conglomerate was deposited as several large alluvial fans whose sediment source was the carboniferous sequence which outcrops to the west of the Gloucester Basin. On the western side of the basin the conglomerate forms the lateral equivalent of all the formations above the Bowens Road seam. In this area at its thickest it consists of matrix supported conglomerate and becomes thinner and finer grained (but generally still conglomeratic) moving east through a braided river system into an interfan or overbank deposit.

The Jilleon Formation onlaps and is eventually replaced by the Wards River Conglomerate in the west of the basin. This formation contains the Roseville seam and Cloverdale seam (at

its top), as well as the less consistent Tereel (or Fairbairns Lane) coals. The Jilleon Formation consists of coarsening upward sandstones with occasional upward fining siltstone. It was deposited in an alluvial plain environment, and was subsiding rapidly which has lead to a lot of thin coal seams forming. The Roseville and Cloverdale seams can be traced across a wide area on the eastern flank. Both seams are several metres thick, and the Cloverdale contains a distinct tuff band which proves useful when correlating wells.

The Leloma Formation outcrops only in the middle of the basin. It contains the Deards, Bindaboo, and Linden seams as well as several thin unnamed coals. These are overlain by a 300m thick homogeneous fine to medium grained sandstone layer deposited in an upper alluvial plain environment. Correlation of coal seams is particularly difficult as they vary in thickness and split across relatively short distances. The coals of the Leloma formation are best developed in the Clear Hill sub basin area on the western flank of the basin. There are several tuff bands throughout the sequence, the largest being the Jo Doth Tuff. The JD Tuff is 15 to 30m thick and is consistent across the formation until it is replaced by the Wards River Conglomerate in the east.

The Crowthers Road Conglomerate marks the top of the Gloucester basin Stratigraphy and as such is the present day erosion surface. It consists of pebble conglomerate and medium to coarse grained sandstone derived from the carboniferous formations to the west and north of the basin. As such it is generally confined to the western and northern part of the basin and imbricated clasts show flow was in an easterly direction. Deposition was due to several large alluvial fans.

Figure 3: Stratigraphic Unit

Stratigraphy of the Gloucester Basin

			Formation		Seam	Depositional Environment
UPPER PERMIAN	GLOUCESTER COAL MEASURES	CRAVEN SUBGROUP	Crowthers Rd Conglomerate		Conglomerate, minor sandstone	Distal Alluvial Fan
			Leloma Formation		Sandstone, minor siltstone and coal	Alluvial Plain
					Linden Coals	
					Marker/JD Coals	
					Jo Doth Tuff	
					Bindaboo Coals	
					Deards Coal	
					Sandstone, minor siltstone and coal	
			Jilleon Formation		Cloverdale Coal	Hiatus Coal
					Conglomerate, sandstone and siltstone	Alluvial Plain
					Roseville Coal	
					Tereel Coals/Fairbairns Lane	
			Wards River Conglomerate		Conglomerate and sandstone	Distal Alluvial Fan
			Wenhams Formation		Bowens Rd Coal	Hiatus Coal
					Siltstone	Marsh
					Bowens Rd Lower Coal	Back Barrier Coal
			Speldon Formation		Marine influenced sandstone	Marginal Marine, prodelta, beach
		AVON SUB GROUP	Dogtrap Creek Formation		Glenview Coal	Back Barrier Coal
					Sandstone, siltstone	Lower Delta Plain
			Waukivory Creek Formation		Avon Coals	Hiatus Coal
					Triple, Rombo, Glen Rd	Upper Delta Plain
					Sandstone and siltstone	Upper Delta Plain
					Parkers Rd and Valley View Coals	Hiatus Coal
					Siltstone and mudstone	Transitional
	DEWRANG GROUP		Mammy Johnsons Formation		Sandstone and siltstone	Marginal Marine, Barrier, Wave Dominated Delta
					Intra Mammy Johnsons Coal	Back Barrier Coal
					Bioturbated sandstone	Marginal Marine, Barrier, Wave Dominated Delta
			Weismantels Formation		Siltstone and mudstone	Back Barrier Lagoon
					Weismantels Coal	Back Barrier Coal
			Duralie Road Formation		Marine Sandstone, conglomerate	Marginal Marine, Fan Delta
LWR PERM			Alum Mountain Volcanics		Clareval Coal	Hiatus Coal
					Conglomerate and coal	Distal Alluvial Fan
					Rhyolite, basalt, welded tuff	Bimodal Terrestrial Volcanics
					Basal Coal	

4. DRILIING, STIMULATION & COMPLETION

4.1 Waukivory 3 Contractor Details

Drilling Contractor:

McDermott Drilling Pty Ltd
P.O Box 6027
Minto, NSW 2566
Contact: Kerry Brydon
Ph: 02 8796 0900
Fax: 02 8795 0633
Mobile: 0416 242 881
E-mail: kerry@mcdermottdrilling.com.au
Website: www.mcdermottdrilling.com.au

Casing:

Surface Casing – McDermott Drilling
Production Casing - AGL Energy Operations Pty Ltd
Contact: Mark Bonisch
Tel: 02 6558 1166
Fax: 02 6558 1066
Mobile: 0427 404 129
Email: MBonisch@agl.com.au

Cementing:

Haliburton
Level 4, 293 Queen Street
Brisbane, QLD 4000
Ph: (07) 3811 6000
Fax: (07) 3811 6099

Geophysical Logging:

Groundsearch Australia
16 Johnston St
Rutherford, 2320
Contact: John Lea
Ph: (02) 4932 3582
Fax: (02) 4932 3529
Mobile: 0427 494 234
Email: geology@groundsearch.com.au

Wireline Services:

Vause Wireline Australia Pty Ltd
179 Raglan St
Roma, Qld 4455
Contact: Paul Nunn
Tel: 07 4622 2511
Fax: 07 4622 2611
Email: paul.nunn@vause.com.au

Perforating /Fracturing Contractor:

BJ Services Company Pty Ltd
Suite 537, Level 5 Towong Tower
9 Sherwood Rd
Towong QLD 4066
Contact: Paul Unwin
Tel: +61 4481 31030
Fax: 07 3310 8753
Email: punwin@bjservices.com.sg

4.2 Drilling

Well Completion Report – ST07 Drilling Summary

Pre-Spud Prognosis

Waukivory 3 was planned as a vertical well. With the drilling plan being:

- RU Rig to drill 279mm (11") PDC OH to 110 m for 8 5/8"surface casing. Run surface casing and cement surface casing back to surface. WOC 8hrs minimum, WOC cement time can be reduced if $CaCl_2$ is used in the mix water.
- Nipple up BOP and pressure test to 350psi for 10 mins and 750 psi for 10mins, formation integrity test to be performed once virgin formation is drilled outside the 8 5/8" casing shoe.
  RU for Production drilling. RIH with 7 7/8" PDC bit and drill with WBM to TD of 850m, it is predicted to intersect the Deards Coal seam at 90m through to Triple Coal seam at 710 m.

Drilling Summary

WK03 was spudded on the 6th January 2009 using Lucas McDermott Rig No. 16 a Drillmec G55.

An 11" open hole was drilled to a depth of 107m using a Reed PDC bit with a bentonite gel and PAC based fluid system. The surface hole was then cased off with 8 5/8" 24ppf J-55 casing to a shoe depth of 106m. 25BBl 15.4ppg Class A cement slurry with 2% CACl2 was pumped and displaced with drill fluid. Wait on cement was 6 hours.

A 7 7/8" open hole was drilled to a total depth of 818m using an 7 7/8" 4 blade Hughes Christensen PDC bit with a bentonite gel and PAC based fluid system on the 7th January 2009. A LOT test was performed outside the surface casing shoe and forward drilling using MWD and DHM package progressed to TD. Coal seams intersection intervals are summarised below in Table 3.

It was noted in reports that approximately 50BBLs of drilling fluid losses occurred between 120 and 300m MD. Upon reaching TD the well was circulated and conditioned with a wiper trip back to 400m prior to open hole logging being conducted.

The well was then cased with 5 1/2 " 15.5ppf K-55 casing to a shoe depth of 815.95m. 107BBL 13.5ppg Class A cement slurry containing 4% bentonite, 4% Cal Seal, .3%CFL, 2%Pheno Seal, .9% Hallad-344 was pumped and displaced with fluid.
Rig was released on the 11th January 2009

The surface casing string and production casing (long string) cement job was conducted by Halliburton. Refer to Appendix 1 (Daily Drilling Reports) for surface and production casing cement report.

GroundSearch Australia performed Density, Gamma, Neutron, Temperature, Sonic, Verticality and Caliper OH logs.

A summary bit table is presented below.

Table 3: Bit Summary Table

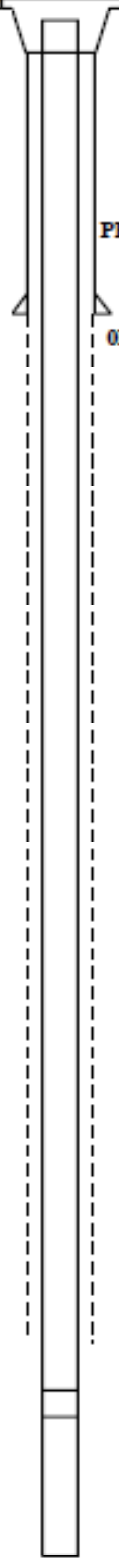
Bit No.	1	2
Size (in)	11	7 7/8
Manufacturer	Reed	Hughes
Type	4 blade PDC	4 blade PDC
Serial No.	101755	HC506Z
Jets	5x11.1	4 x 10.3
TFA (in2)	0.752	0.518
RPM	100	110
WOB (lbs)	10000	10000
Depth Drilled (m)	107	711
ROP (m/hr)	14.3	18.6

Figure 3: Well Summary and Schematic

LUCAS ENERGY

Final Well Summary & Schematic

Well Name :	Waukivory 3 N 6456001.50 E 405300.40	**Licence No. :**	PEL 285
Wellsite Supervisor :	Lance Larsen	**Mobile # :**	0409-487-166
Spud Date :	Tue. Jan 6/09	**Release Date :**	Sun Jan 11/09
Well Status :	Drilled, cased & cemented		



Wellhead :

Serial #:
Size : 279.4 mm
Rating : 21000 kpa
Slip Assy : N/A man/auto

Surface Casing

Size : 219.1 mm
Weight : 35.7 kg/m
Range : 2
Make : Baosteel
Thread : SRD
Set at : 106.0 m.

Surface Cement

Type : Class"A"
Volume: 4.0 m3
Additives : 2% CaCl2
Excess used : 50.0 %
Cmt Returns : 3.0 m3

Intermediate Casing

Size : mm
Weight : kg/m
Range :
Make :
Thread :
Set at : m.

Intermediate Cement

Lead Cmt :
Volume: m3
Additives :
Excess : %
Tail Cmt :
Volume: m3
Additives :
Excess : %

Production Casing

Size : 139.7 mm
Weight : 23.1 kg/m
Range : 2
Make : aosteel
Thread : BTC
Set at : 816.0 m.

Production Cement

Lead Cmt : Class"A"
Volume: 17.0 m3
Additives :
Excess : 30.0 %
Tail Cmt :
Volume: m3
Additives :
Excess : %

Evaluation Data

Cores Cut : Number of cores cut :

1. Formation : Interval :
2. Formation : Interval :
3. Formation : Interval :
4. Formation : Interval :

Total cored : m. Recovery :
Coring Time : hours. Hole Size :
Bit Type : Bit Size :

Drill Stem Tests : Number of DSTs :

1. Formation : Interval :
2. Formation : Interval :
3. Formation : Interval :
4. Formation : Interval :

DST #	IF	ISI	FF	FSI	Comments
1					
2					
3					
4					

Elevations :

Surveyed Ground Elevation :	92.00	m.
Cut (-) or Fill (+) :	0.00	m.
Actual Ground Elevation :	92.00	m.
KB - Ground Level :	2.10	m.
KB Elevation :	94.10	m.
KB - Casing Flange :	2.30	m.

Abandonment Plugs :

			Cement	Felt at
Plug #1 :		to		
Plug #2 :		to		
Plug #3 :		to		
Plug #4 :		to		
Plug #5 :		to		

Logged plugs with :

Liner :

Size : mm.
Weight : kg/m.
Range:
Make:
Thread:
Type:
Top: m.
Bottom: m.

Formation Tops	Measured Depth	TVD
Deards	66.0	66.0
Cloverdale	135.0	135.0
Roseville	183.0	183.0
Fairburneslane	220.0	220.0
Bowens Road	438.0	438.0
Bowens Road Lower	462.0	462.0
Glenview	524.0	524.0
Avon	600.0	600.0
Triple	734.0	734.0

Comments:

Class"A" + 4% Bent. + 4%Cal Seal+.9% CFL-3

Top of marker joint = 415.40 m.

4.3 Lithology – Logging

Please refer to Geological Report (Appendix 3)

4.4 Fracture Stimulation

Please refer to Frac Report (Appendix 4)

4.5 Well Completion

Waukivory 3 was one of three wells in the Gloucester Production Program that utilises BJ Services' Opti-frac SJ method. The aim of this method is to remove skin damage caused by cement and mud invasion, thereby achieving good connection to the formation for methane gas production. BJ Services' Optic-frac method was used to conduct the fracture stimulation by slotting the casing and fraccing by utilising coiled tubing and a sand jet tool.

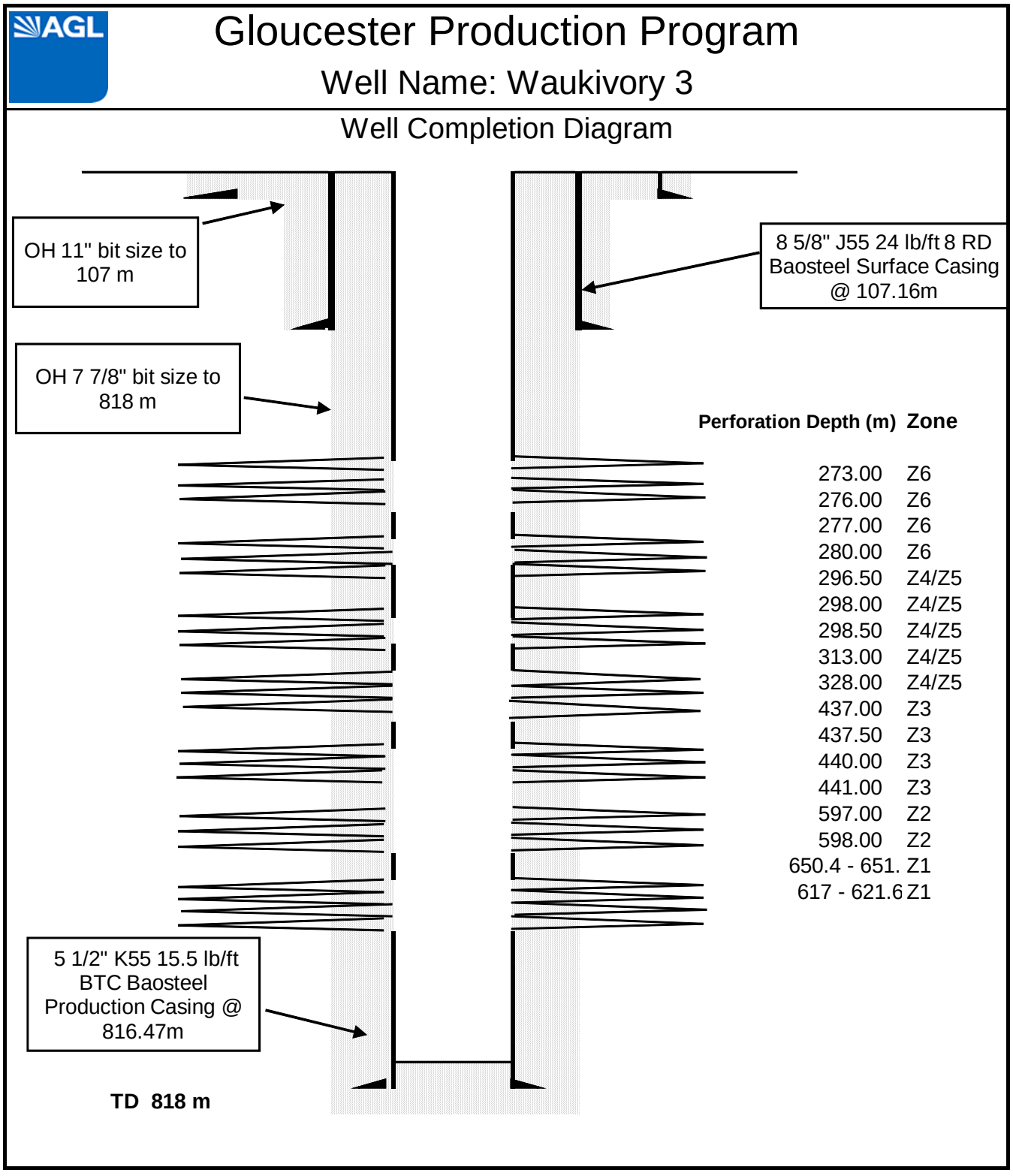
Vause Wireline and BJ Services were used to perforate and fracture the Gloucester Coal Measures. Vause perforated Zone 1 (617 – 621.6m, 650.4 – 651.3 m) and BJ Services conducted the perforation and fracture operations using the Opti-frac SJ method from 273.00 – 598 m. The completion fracturing operations conducted on WK03 began on 4th May, 2009. The completion prognosis was as follows;.

- RIH and clean out wellbore.
- Perform coil tube fracture stimulation as described in fracture program
- RIH 2 3/8" 4.7 lb/ft and 2 7/8" production tubing set at 690.48m.

In total 71 joints of 2 7/8" 4.7lb/ft production tubing were used, including a pump seat nipple. Well completion operations were completed on the 15th May, 2009

Well was circulated with water. Bottom was first tagged at 613.4 prior to BJ coil tube perforation/fracturing operations, refer to Appendix 3, 4 & 5– Events Log and BJ Post Job Reports.

Figure 3: Well Schematic



5. OTHER OPERATIONS

5.1 Geophysical Logging

Please refer to accompanying LAS files

6. CONCLUSION

The coals encountered at Waukivory 3 were found to be of good thickness and quality, similar to those intersected at the Stratford Pilot.

This well forms part of the Gloucester exploration drilling program which is designed to delineate the extent of the productive gas field or identify prospective new areas for further testing.

The well has also provided a valuable dataset in further understanding coal seam methane reservoir characteristics and how better to explore, develop and manage the resource within the Gloucester Basin.

7. LIST OF FIGURES

8. LIST OF TABLES

9. APPENDICES

1. **Daily Drilling Reports**
2. **Geological Report**
3. **Events Log**
4. **Fracture Post Job Reports**
5. **Perforation Post Job Report**
6. **Work Over Completion Reports**
7. **GR/CCL Log**
8. **Deviation Survey**
9. **Cement Bond Log**

Appendix B

Water quality summary tables and RDP's

Summary Table - Water quality data and Relative Percentage Differences (RDP)

	Units	LOR	ANZECC 2000 Guidelines	CR06			WK03			CR06			WK03		
Sample date				**28/06/2013**	**13/08/2013**	**1/10/2013**	**28/06/2013**	**13/08/2013**	**1/10/2013**	**1st & 2nd**	**2nd & 3rd**	**1st & 3rd**	**1st & 2nd**	**2nd & 3rd**	**1st & 3rd**
General Parameters															
pH (field)	pH units	0.01	6.5 - 8.0*	7.52	9.63	7.53	7.55	5.73	7.57			-0.13			-0.26
pH (lab)	pH units	0.01	6.5 - 8.0*	7.64	7.84	8.14	7.55	7.60	8.15	-2.58	-3.75	-6.34	-0.66	-6.98	-7.64
Conductivity (field)	µS/cm	1	125 - 2200*	6,549	6,746	5,439	4,391	4,487	4,464	-2.96	21.45	18.52	-2.16	0.51	-1.65
Conductivity (lab)	µS/cm	1	125 - 2200*	6,920	7,200	5,550	4,650	4,450	4,520	-3.97	25.88	21.97	4.40	-1.56	2.84
Temperature	°C	0.01	-	18.08	13.9	22.6	22.06	23.54	24.58	26.14	-47.67	-22.22	-6.49	-4.32	-10.81
Dissolved oxygen	% sat	0.01	80 - 110%*	42.8	80.2	42.6	100.6	33.1	57.8	-60.81	61.24	0.47	100.97	-54.35	54.04
Total Dissolved Solids (calc.) (field)	mg/L	1	-	na	4,385	3,530	na	2,918	2,912	nc	21.60	nc	nc	0.21	nc
Total Dissolved Solids (calc.) (lab)				na	4,680	na	na	2,890	na	nc	nc	nc	nc	nc	nc
Total Dissolved Solids (measured)				3,870	4,510	3,120	2,640	2,660	2,610	-15.27	36.44	21.46	-0.75	1.90	1.14
Suspended Solids	mg/L	1	-	197	276	170	67	84	11	-33.40	47.53	14.71	-22.52	153.68	143.59
Turbidity	NTU	0.1	-	na	507	177	na	413	46.7	nc	96.49	nc	nc	159.36	nc
Redox	mV	-	-	-61.8	-153.4	-172.8	-171.3	-153.7	-96.0	-85.13	-11.89	-94.63	10.83	46.22	56.34
Water type #	-	-	-	$Na\text{-}Cl\text{-}HCO_3$	$Na\text{-}Cl\text{-}HCO_3$	$Na\text{-}Cl\text{-}HCO_3$	$Na\text{-}HCO_3\text{-}Cl$	$Na\text{-}HCO_3\text{-}Cl$	$Na\text{-}HCO_3\text{-}Cl$	nc	nc	nc	nc	nc	nc
Laboratory Analytes															
Hydroxide Alkalinity as $CaCO_3$	mg/L	1	-	<1	<1	<1	<1	<1	<1	nc	nc	nc	nc	nc	nc
Carbonate Alkalinity as $CaCO_3$	mg/L	1	-	<1	<1	<1	<1	<1	<1	nc	nc	nc	nc	nc	nc
Bicarbonate Alkalinity as $CaCO_3$	mg/L	1	-	1,880	2,020	1,360	1,810	2,100	1,770	-7.18	39.05	32.10	-14.83	17.05	2.23
Total Alkalinity as $CaCO_3$	mg/L	1	-	1,880	2,020	1,360	1,810	2,100	1,770	-7.18	39.05	32.10	-14.83	17.05	2.23
Sulphate as SO_4^{2-}	mg/L	1	-	14	<1	<1	4	<1	<1	nc	nc	nc	nc	nc	nc
Chloride	mg/L	1	-	958	1,270	1,020	394	437	432	-28.01	21.83	-6.27	-10.35	1.15	-9.20
Calcium	mg/L	1	-	12	9	14	6	7	6	28.57	-43.48	-15.38	-15.38	15.38	0.00
Magnesium	mg/L	1	-	3	4	3	1	2	2	-28.57	28.57	0.00	-66.67	0.00	-66.67
Sodium	mg/L	1	-	1,550	1,710	1,270	1,090	1,230	1,110	-9.82	29.53	19.86	-12.07	10.26	-1.82
Potassium	mg/L	1	-	11	12	6	12	8	5	-8.70	66.67	58.82	40.00	46.15	82.35
Reactive silica/silicon as SiO_2	mg/L	0.1	-	15.2/na	na/13.7	na/14	19.1/na	na/19.9	na/18.1	nc	-2.17	nc	nc	9.47	nc
Total Cyanide	mg/L	0.004	0.007	<0.004	na	na	<0.004	na	na	nc	nc	nc	nc	nc	nc
Fluoride	mg/L	0.1	-	1.4	1.4	1.5	0.3	0.3	0.2	0.00	-6.90	-6.90	0.00	40.00	40.00
Ions															
Total Anions	meq/L	0.01	-	64.9	76.2	56.0	47.4	54.3	47.6	nc	nc	nc	-13.57	13.15	-0.42
Total Cations	meq/L	0.01	-	68.6	75.5	56.3	48.1	54.2	48.9	nc	nc	nc	-11.93	10.28	-1.65
Ionic Balance	%	0.01	-	2.7	0.52	0.31	0.72	0.12	1.31	nc	nc	nc	142.86	-166.43	-58.13
Dissolved Metals															
Aluminium	mg/L	0.01	0.055	0.05	0.01	0.06	0.02	0.06	0.02	133.33	-142.86	-18.18	-100.00	100.00	0.00
Antimony	mg/L	0.001	-	<0.001	na	na	<0.001	na	na	nc	nc	nc	nc	nc	nc
Arsenic	mg/L	0.001	0.013 (As V)	<0.001	0.001	0.004	<0.001	<0.001	<0.001	nc	-120.00	nc	nc	nc	nc
Barium	mg/L	0.001	-	3.65	<0.001	<0.001	1.11	<0.001	<0.001	nc	nc	nc	nc	nc	nc
Beryllium	mg/L	0.001	ID	<0.001	4.3	2.46	<0.001	2.02	1.48	nc	54.44	nc	nc	30.86	nc
Cadmium	mg/L	0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	nc	nc	nc	nc	nc	nc
Chromium	mg/L	0.001	0.001	0.007	0.004	0.007	<0.001	0.006	0.001	54.55	-54.55	0.00	nc	142.86	nc
Cobalt	mg/L	0.001	ID	<0.001	<0.001	0.002	<0.001	0.001	<0.001	nc	nc	nc	nc	nc	nc
Copper	mg/L	0.001	0.0014	0.002	0.001	0.002	<0.001	0.001	0.001	66.67	-66.67	0.00	nc	0.00	nc
Lead	mg/L	0.001	0.0034	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	nc	nc	nc	nc	nc	nc
Manganese	mg/L	0.001	1.9	0.233	0.475	0.190	0.155	0.32	0.086	-68.36	85.71	20.33	-69.47	115.27	57.26
Mercury	mg/L	0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	nc	nc	nc	nc	nc	nc
Molybdenum	mg/L	0.001	ID	0.003	0.005	0.006	0.003	0.003	0.001	-50.00	-18.18	-66.67	0.00	100.00	100.00
Nickel	mg/L	0.001	0.011	0.003	0.001	0.006	0.002	0.004	<0.001	100.00	-142.86	-66.67	-66.67	nc	nc
Selenium	mg/L	0.01	0.011 (total)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	nc	nc	nc	nc	nc	nc
Strontium	mg/L	0.001	-	3.36	3.06	2.15	0.986	1.01	0.960	9.35	34.93	43.92	-2.40	5.08	2.67
Uranium	mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	nc	nc	nc	nc	nc	nc
Vanadium	mg/L	0.01	ID	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	nc	nc	nc	nc	nc	nc
Zinc	mg/L	0.005	0.008	0.045	0.006	0.041	0.024	0.03	0.016	152.94	-148.94	9.30	-22.22	60.87	40.00
Boron	mg/L	0.05	0.37	0.33	0.27	0.20	0.23	0.19	0.15	20.00	29.79	49.06	19.05	23.53	42.11
Iron	mg/L	0.05	ID	4.26	37.8	6.83	2.20	27.2	1.76	-159.49	138.79	-46.35	-170.07	175.69	22.22
Bromine	mg/L	0.1	ID	2.4	2.8	2	0.9	1.0	0.9	-15.38	33.33	18.18	-10.53	10.53	0.00
Nutrients															
Ammonia as N	mg/L	0.01	0.02*	1.9	na	na	1.46	na	na	nc	nc	nc	nc	nc	nc
Nitrite as N	mg/L	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	nc	nc	nc	nc	nc	nc
Nitrate as N	mg/L	0.01	0.7	<0.01	<0.01	0.02	<0.01	<0.01	0.03	nc	nc	nc	nc	nc	nc
Total Phosphorous	mg/L	0.01	0.05*	1.26	na	na	0.51	na	na	nc	nc	nc	nc	nc	nc
Reactive Phosphorous	mg/L	0.01	0.02*	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	nc	nc	nc	nc	nc	nc
Total Organic Carbon	mg/L	1	-	9	na	na	22	na	na	nc	nc	nc	nc	nc	nc
Dissolved Gases															
Methane	µg/L	10	-	13,000	na	na	6,940	na	na	nc	nc	nc	nc	nc	nc
Ethene	µg/L	10	-	<10	na	na	<10	na	na	nc	nc	nc	nc	nc	nc
Ethane	µg/L	10	-	14	na	na	384	na	na	nc	nc	nc	nc	nc	nc
Propene	µg/L	10	-	<10	na	na	<10	na	na	nc	nc	nc	nc	nc	nc
Propane	µg/L	10	-	<10	na	na	70	na	na	nc	nc	nc	nc	nc	nc
Butene	µg/L	10	-	<10	na	na	<10	na	na	nc	nc	nc	nc	nc	nc
Butane	µg/L	10	-	<10	na	na	<10	na	na	nc	nc	nc	nc	nc	nc
Phenolic compounds															
Phenol	µg/L	1	320	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2-Chlorophenol	µg/L	1	490	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2-Methylphenol	µg/L	1	-	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
3-&4-Methylphenol	µg/L	2	-	<2.0	na	na	<3.7	na	na	nc	nc	nc	nc	nc	nc
2-Nitrophenol	µg/L	1	ID	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2.4-Dimethylphenol	µg/L	1	ID	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2.4-Dichlorophenol	µg/L	1	160	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2.6-Dichlorophenol	µg/L	1	ID	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
4-Chloro-3-Methylphenol	µg/L	1	-	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2.4.6-Trichlorophenol	µg/L	1	20	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
2.4.5-Trichlorophenol	µg/L	1	ID	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Pentachlorophenol	µg/L	2	ID	<2.0	na	na	<3.7	na	na	nc	nc	nc	nc	nc	nc
Polycyclic aromatic hydrocarbons															
Naphthalene	µg/L	1	16	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Acenaphthylene	µg/L	1	-	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Acenaphthene	µg/L	1	-	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Fluorene	µg/L	1	-	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Phenanthrene	µg/L	1	ID	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Anthracene	µg/L	1	ID	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Fluoranthene	µg/L	1	ID	<1.0	na	na	1.9	na	na	nc	nc	nc	nc	nc	nc
Pyrene	µg/L	1	-	<1.0	na	na	8.6	na	na	nc	nc	nc	nc	nc	nc
Benz(a)anthracene	µg/L	1	-	<1.0	na	na	7.2	na	na	nc	nc	nc	nc	nc	nc
Chrysene	µg/L	1	-	<1.0	na	na	17.5	na	na	nc	nc	nc	nc	nc	nc
Benzo(b)fluoranthene	µg/L	1	-	<1.0	na	na	5	na	na	nc	nc	nc	nc	nc	nc
Benzo(k)fluoranthene	µg/L	1	-	<1.0	na	na	2	na	na	nc	nc	nc	nc	nc	nc
Benzo(a)pyrene	µg/L	0.5	ID	<1.0	na	na	8.2	na	na	nc	nc	nc	nc	nc	nc
Indeno(1.2.3.cd)pyrene	µg/L	1	-	<1.0	na	na	<1.9	na	na	nc	nc	nc	nc	nc	nc
Dibenz(a.h)anthracene	µg/L	1	-	<1.0	na	na	2.3	na	na	nc	nc	nc	nc	nc	nc
Benzo(g.h.i)perylene	µg/L	1	-	<1.0	na	na	4.7	na	na	nc	nc	nc	nc	nc	nc
Sum of PAHs	µg/L	0.5	-	<0.5	na	na	57.4	na	na	nc	nc	nc	nc	nc	nc
Total petroleum hydrocarbons															
C6-C9 Fraction	µg/L	20	ID	30	na	na	30	na	na	nc	nc	nc	nc	nc	nc
C10-C14 Fraction	µg/L	50	ID	270	na	na	100	na	na	nc	nc	nc	nc	nc	nc
C15-C28 Fraction	µg/L	100	ID	500	na	na	14,400	na	na	nc	nc	nc	nc	nc	nc
C29-C36 Fraction	µg/L	50	ID	130	na	na	11,400	na	na	nc	nc	nc	nc	nc	nc
C10-C36 Fraction (sum)	µg/L	50	-	900	na	na	25,900	na	na	nc	nc	nc	nc	nc	nc
Total recoverable hydrocarbons															
C6-C10 Fraction	µg/L	20	-	20	na	na	20	na	na	nc	nc	nc	nc	nc	nc
C6-C10 Fraction minus BTEX (F1)	µg/L	20	-	<20	na	na	<20	na	na	nc	nc	nc	nc	nc	nc
>C10-C16 Fraction	µg/L	100	-	420	na	na	600	na	na	nc	nc	nc	nc	nc	nc
>C16-C34 Fraction	µg/L	100	-	470	na	na	22,800	na	na	nc	nc	nc	nc	nc	nc
>C34-C40 Fraction	µg/L	100	-	<100	na	na	6,860	na	na	nc	nc	nc	nc	nc	nc
>C10-C40 Fraction (sum)	µg/L	100	-	890	na	na	30,300	na	na	nc	nc	nc	nc	nc	nc
Aromatic Hydrocarbons															
Benzene	µg/L	1	950	3	na	na	7	na	na	nc	nc	nc	nc	nc	nc
Toluene	µg/L	2	ID	8	na	na	4	na	na	nc	nc	nc	nc	nc	nc
Ethyl Benzene	µg/L	2	ID	<2	na	na	<2	na	na	nc	nc	nc	nc	nc	nc
m&p-Xylenes	µg/L	2	ID	5	na	na	4	na	na	nc	nc	nc	nc	nc	nc
o-Xylenes	µg/L	2	350	<2	na	na	<2	na	na	nc	nc	nc	nc	nc	nc
Total xylenes	µg/L	2	-	5	na	na	4	na	na	nc	nc	nc	nc	nc	nc
Sum of BTEX	µg/L	1	-	16	na	na	15	na	na	nc	nc	nc	nc	nc	nc
Naphthalene	µg/L	5	-	<5	na	na	<5	na	na	nc	nc	nc	nc	nc	nc

exceeds guideline limits | ID - Insufficient data | na - not analysed | nc - not calculated | RDP >50% significant change

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems.

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems

Calculated using Aquachem

PARSONS BRINCKERHOFF

Appendix C

ALS results

Environmental Division

CERTIFICATE OF ANALYSIS

Work Order	: **ES1314616**	Page	: 1 of 8
Client	: **PARSONS BRINCKERHOFF AUST P/L**	Laboratory	: Environmental Division Sydney
Contact	: MR JAMES DUGGLEBY	Contact	: Loren Schiavon
Address	: GPO BOX 5394 SYDNEY NSW, AUSTRALIA 2001	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
E-mail	: jduggleby@pb.com.au	E-mail	: loren.schiavon@alsglobal.com
Telephone	: +61 02 9272 5100	Telephone	: +61 2 8784 8503
Facsimile	: +61 02 9272 5101	Facsimile	: +61 2 8784 8500
Project	: 2162406E	QC Level	: NEPM 1999 Schedule B(3) and ALS QCS3 requirement
Order number	: ----		
C-O-C number	: ----	Date Samples Received	: 28-JUN-2013
Sampler	: SM	Issue Date	: 08-JUL-2013
Site	: ----		
		No. of samples received	: 2
Quote number	: SY/394/09	No. of samples analysed	: 2

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **EG020: Bromine quantification may be unreliable due to its low solubility in acid, leading to variable volatility during measurement by ICPMS.**
- **EK082: Sulfur dioxide content is expressed as sulfite as sulfur dioxide gas forms sulfite when dissolved in water**
- **EP075(SIM) :Particular samples required dilution due to the presence of high level contaminants. LOR values have been adjusted accordingly.**

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	Position	Accreditation Category
Ankit Joshi	Inorganic Chemist	Sydney Inorganics
Celine Conceicao	Senior Spectroscopist	Sydney Inorganics
Hoa Nguyen	Senior Inorganic Chemist	Sydney Inorganics
Merrin Avery	Supervisor - Inorganic	Newcastle - Inorganics
Phalak Inthaksone	Laboratory Manager - Organics	Sydney Organics
		Sydney Organics

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	C6	W3	----	----	----
			Client sampling date / time	28-JUN-2013 08:00	28-JUN-2013 09:00	----	----	----
Compound	CAS Number	LOR	Unit	ES1314616-001	ES1314616-002	----	----	----
EA005: pH								
pH Value	----	0.01	pH Unit	**7.64**	**7.55**	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	**6920**	**4650**	----	----	----
EA015: Total Dissolved Solids								
Total Dissolved Solids @180°C	----	10	mg/L	**3870**	**2640**	----	----	----
EA025: Suspended Solids								
Suspended Solids (SS)	----	5	mg/L	**197**	**67**	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	**1880**	**1810**	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	**1880**	**1810**	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	**14**	**4**	----	----	----
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	1	mg/L	**958**	**394**	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	**12**	**6**	----	----	----
Magnesium	7439-95-4	1	mg/L	**3**	**1**	----	----	----
Sodium	7440-23-5	1	mg/L	**1550**	**1090**	----	----	----
Potassium	7440-09-7	1	mg/L	**11**	**12**	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	**0.05**	**0.02**	----	----	----
Antimony	7440-36-0	0.001	mg/L	<0.001	<0.001	----	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	----	----	----
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	----	----	----
Barium	7440-39-3	0.001	mg/L	**3.65**	**1.11**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	----	----	----
Chromium	7440-47-3	0.001	mg/L	**0.007**	<0.001	----	----	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.002**	<0.001	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.233**	**0.155**	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	C6	W3	----	----	----
				Client sampling date / time	28-JUN-2013 08:00	28-JUN-2013 09:00	----	----	----
Compound	CAS Number	LOR	Unit		ES1314616-001	ES1314616-002	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Molybdenum	7439-98-7	0.001	mg/L		**0.003**	**0.003**	----	----	----
Nickel	7440-02-0	0.001	mg/L		**0.003**	**0.002**	----	----	----
Selenium	7782-49-2	0.01	mg/L		<0.01	<0.01	----	----	----
Strontium	7440-24-6	0.001	mg/L		**3.36**	**0.986**	----	----	----
Uranium	7440-61-1	0.001	mg/L		<0.001	<0.001	----	----	----
Vanadium	7440-62-2	0.01	mg/L		<0.01	<0.01	----	----	----
Zinc	7440-66-6	0.005	mg/L		**0.045**	**0.024**	----	----	----
Boron	7440-42-8	0.05	mg/L		**0.33**	**0.23**	----	----	----
Iron	7439-89-6	0.05	mg/L		**4.26**	**2.20**	----	----	----
Bromine	7726-95-6	0.1	mg/L		**2.4**	**0.9**	----	----	----
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	----	----	----
EG052G: Silica by Discrete Analyser									
Reactive Silica	----	0.10	mg/L		**15.2**	**19.1**	----	----	----
EK026SF: Total CN by Segmented Flow Analyser									
Total Cyanide	57-12-5	0.004	mg/L		<0.004	<0.004	----	----	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**1.4**	**0.3**	----	----	----
EK055G: Ammonia as N by Discrete Analyser									
Ammonia as N	7664-41-7	0.01	mg/L		**1.90**	**1.46**	----	----	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	----	0.01	mg/L		<0.01	<0.01	----	----	----
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		<0.01	<0.01	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		<0.01	<0.01	----	----	----
EK067G: Total Phosphorus as P by Discrete Analyser									
Total Phosphorus as P	----	0.01	mg/L		**1.26**	**0.51**	----	----	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01	<0.01	----	----	----
EN055: Ionic Balance									
Total Anions	----	0.01	meq/L		**64.9**	**47.4**	----	----	----
Total Cations	----	0.01	meq/L		**68.6**	**48.1**	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	C6	W3	----	----	----
			Client sampling date / time	28-JUN-2013 08:00	28-JUN-2013 09:00	----	----	----
Compound	CAS Number	LOR	Unit	ES1314616-001	ES1314616-002	----	----	----
EN055: Ionic Balance - Continued								
Ionic Balance	----	0.01	%	**2.70**	**0.72**	----	----	----
EP005: Total Organic Carbon (TOC)								
Total Organic Carbon	----	1	mg/L	**9**	**22**	----	----	----
EP033: C1 - C4 Hydrocarbon Gases								
Methane	74-82-8	10	µg/L	**13000**	**6940**	----	----	----
Ethene	74-85-1	10	µg/L	<10	<10	----	----	----
Ethane	74-84-0	10	µg/L	**14**	**384**	----	----	----
Propene	115-07-1	10	µg/L	<10	<10	----	----	----
Propane	74-98-6	10	µg/L	<10	**70**	----	----	----
Butene	25167-67-3	10	µg/L	<10	<10	----	----	----
Butane	106-97-8	10	µg/L	<10	<10	----	----	----
EP075(SIM)A: Phenolic Compounds								
Phenol	108-95-2	1.0	µg/L	<1.0	<1.9	----	----	----
2-Chlorophenol	95-57-8	1.0	µg/L	<1.0	<1.9	----	----	----
2-Methylphenol	95-48-7	1.0	µg/L	<1.0	<1.9	----	----	----
3- & 4-Methylphenol	1319-77-3	2.0	µg/L	<2.0	<3.7	----	----	----
2-Nitrophenol	88-75-5	1.0	µg/L	<1.0	<1.9	----	----	----
2.4-Dimethylphenol	105-67-9	1.0	µg/L	<1.0	<1.9	----	----	----
2.4-Dichlorophenol	120-83-2	1.0	µg/L	<1.0	<1.9	----	----	----
2.6-Dichlorophenol	87-65-0	1.0	µg/L	<1.0	<1.9	----	----	----
4-Chloro-3-Methylphenol	59-50-7	1.0	µg/L	<1.0	<1.9	----	----	----
2.4.6-Trichlorophenol	88-06-2	1.0	µg/L	<1.0	<1.9	----	----	----
2.4.5-Trichlorophenol	95-95-4	1.0	µg/L	<1.0	<1.9	----	----	----
Pentachlorophenol	87-86-5	2.0	µg/L	<2.0	<3.7	----	----	----
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	1.0	µg/L	<1.0	<1.9	----	----	----
Acenaphthylene	208-96-8	1.0	µg/L	<1.0	<1.9	----	----	----
Acenaphthene	83-32-9	1.0	µg/L	<1.0	<1.9	----	----	----
Fluorene	86-73-7	1.0	µg/L	<1.0	<1.9	----	----	----
Phenanthrene	85-01-8	1.0	µg/L	<1.0	<1.9	----	----	----
Anthracene	120-12-7	1.0	µg/L	<1.0	<1.9	----	----	----
Fluoranthene	206-44-0	1.0	µg/L	<1.0	**1.9**	----	----	----
Pyrene	129-00-0	1.0	µg/L	<1.0	**8.6**	----	----	----

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	C6	W3	----	----	----
			Client sampling date / time	28-JUN-2013 08:00	28-JUN-2013 09:00	----	----	----
Compound	CAS Number	LOR	Unit	ES1314616-001	ES1314616-002	----	----	----
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons - Continued								
Benz(a)anthracene	56-55-3	1.0	µg/L	<1.0	7.2	----	----	----
Chrysene	218-01-9	1.0	µg/L	<1.0	17.5	----	----	----
Benzo(b)fluoranthene	205-99-2	1.0	µg/L	<1.0	5.0	----	----	----
Benzo(k)fluoranthene	207-08-9	1.0	µg/L	<1.0	2.0	----	----	----
Benzo(a)pyrene	50-32-8	0.5	µg/L	<0.5	8.2	----	----	----
Indeno(1.2.3.cd)pyrene	193-39-5	1.0	µg/L	<1.0	<1.9	----	----	----
Dibenz(a.h)anthracene	53-70-3	1.0	µg/L	<1.0	2.3	----	----	----
Benzo(g.h.i)perylene	191-24-2	1.0	µg/L	<1.0	4.7	----	----	----
^ Sum of polycyclic aromatic hydrocarbons	----	0.5	µg/L	<0.5	57.4	----	----	----
^ Benzo(a)pyrene TEQ (WHO)	----	0.5	µg/L	<0.5	12.2	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	30	30	----	----	----
C10 - C14 Fraction	----	50	µg/L	270	100	----	----	----
C15 - C28 Fraction	----	100	µg/L	500	14400	----	----	----
C29 - C36 Fraction	----	50	µg/L	130	11400	----	----	----
^ C10 - C36 Fraction (sum)	----	50	µg/L	900	25900	----	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2010 Draft								
C6 - C10 Fraction	----	20	µg/L	20	20	----	----	----
^ C6 - C10 Fraction minus BTEX (F1)	----	20	µg/L	<20	<20	----	----	----
>C10 - C16 Fraction	----	100	µg/L	420	600	----	----	----
>C16 - C34 Fraction	----	100	µg/L	470	22800	----	----	----
>C34 - C40 Fraction	----	100	µg/L	<100	6860	----	----	----
^ >C10 - C40 Fraction (sum)	----	100	µg/L	890	30300	----	----	----
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	3	7	----	----	----
Toluene	108-88-3	2	µg/L	8	4	----	----	----
Ethylbenzene	100-41-4	2	µg/L	<2	<2	----	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	5	4	----	----	----
ortho-Xylene	95-47-6	2	µg/L	<2	<2	----	----	----
^ Total Xylenes	1330-20-7	2	µg/L	5	4	----	----	----
^ Sum of BTEX	----	1	µg/L	16	15	----	----	----
Naphthalene	91-20-3	5	µg/L	<5	<5	----	----	----
EP075(SIM)S: Phenolic Compound Surrogates								

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	C6	W3	----	----	----
			Client sampling date / time	28-JUN-2013 08:00	28-JUN-2013 09:00	----	----	----
Compound	CAS Number	LOR	Unit	ES1314616-001	ES1314616-002	----	----	----
EP075(SIM)S: Phenolic Compound Surrogates - Continued								
Phenol-d6	13127-88-3	0.1	%	33.8	29.6	----	----	----
2-Chlorophenol-D4	93951-73-6	0.1	%	77.9	69.6	----	----	----
2.4.6-Tribromophenol	118-79-6	0.1	%	97.8	83.5	----	----	----
EP075(SIM)T: PAH Surrogates								
2-Fluorobiphenyl	321-60-8	0.1	%	77.6	73.5	----	----	----
Anthracene-d10	1719-06-8	0.1	%	82.9	80.6	----	----	----
4-Terphenyl-d14	1718-51-0	0.1	%	70.8	75.2	----	----	----
EP080S: TPH(V)/BTEX Surrogates								
1.2-Dichloroethane-D4	17060-07-0	0.1	%	81.8	82.8	----	----	----
Toluene-D8	2037-26-5	0.1	%	89.4	94.8	----	----	----
4-Bromofluorobenzene	460-00-4	0.1	%	97.8	105	----	----	----

Surrogate Control Limits

Sub-Matrix: **WATER**

Compound	CAS Number	Recovery Limits (%) Low	High
EP075(SIM)S: Phenolic Compound Surrogates			
Phenol-d6	13127-88-3	10.0	44
2-Chlorophenol-D4	93951-73-6	15.9	102
2.4.6-Tribromophenol	118-79-6	17	125
EP075(SIM)T: PAH Surrogates			
2-Fluorobiphenyl	321-60-8	20.4	112
Anthracene-d10	1719-06-8	29.6	118
4-Terphenyl-d14	1718-51-0	21.5	126
EP080S: TPH(V)/BTEX Surrogates			
1.2-Dichloroethane-D4	17060-07-0	71	137
Toluene-D8	2037-26-5	79	131
4-Bromofluorobenzene	460-00-4	70	128

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **ES1318203**	Page	: 1 of 13
Amendment	: **1**		
Client	: **PARSONS BRINCKERHOFF AUST P/L**	Laboratory	: Environmental Division Sydney
Contact	: MR JAMES DUGGLEBY	Contact	: Client Services
Address	: GPO BOX 5394 SYDNEY NSW, AUSTRALIA 2001	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
E-mail	: jduggleby@pb.com.au	E-mail	: sydney@alsglobal.com
Telephone	: +61 02 9272 5100	Telephone	: +61-2-8784 8555
Facsimile	: +61 02 9272 5101	Facsimile	: +61-2-8784 8500
Project	: 2162406C	QC Level	: NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Order number	: ----		
C-O-C number	: ----	Date Samples Received	: 15-AUG-2013
Sampler	: CR/CS	Issue Date	: 01-NOV-2013
Site	: ----		
		No. of samples received	: 17
Quote number	: EN/008/13	No. of samples analysed	: 17

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.**
- **EP005 : NPOC analysis was carried out for sample ID (TMB04) due to high inoganic carbon content**
- **This report has been amended and re-released to allow the reporting of additional analytical data.**

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	Position	Accreditation Category
Ankit Joshi	Inorganic Chemist	Sydney Inorganics
Ashesh Patel	Inorganic Chemist	Sydney Inorganics
Celine Conceicao	Senior Spectroscopist	Sydney Inorganics
Hoa Nguyen	Senior Inorganic Chemist	Sydney Inorganics

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Client sample ID	CR06	WK03	----	----	----
			Client sampling date / time	13-AUG-2013 07:30	13-AUG-2013 08:15	----	----	----
Compound	CAS Number	LOR	Unit	ES1318203-016	ES1318203-017	----	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	7.84	7.60	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	7200	4450	----	----	----
EA015: Total Dissolved Solids								
Total Dissolved Solids @180°C	----	1	mg/L	4510	2660	----	----	----
EA016: Non Marine - Estimated TDS Salinity								
Total Dissolved Solids (Calc.)	----	1	mg/L	4680	2890	----	----	----
EA025: Suspended Solids								
Suspended Solids (SS)	----	1	mg/L	276	84	----	----	----
EA045: Turbidity								
Turbidity	----	0.1	NTU	507	413	----	----	----
EA065: Total Hardness as CaCO3								
Total Hardness as CaCO3	----	1	mg/L	39	26	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	2020	2100	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	2020	2100	----	----	----
ED040F: Dissolved Major Anions								
Silicon as SiO2	14464-46-1	0.1	mg/L	13.7	19.9	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	<1	<1	----	----	----
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	1	mg/L	1270	437	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	9	7	----	----	----
Magnesium	7439-95-4	1	mg/L	4	2	----	----	----
Sodium	7440-23-5	1	mg/L	1710	1230	----	----	----
Potassium	7440-09-7	1	mg/L	12	8	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.01	0.06	----	----	----
Arsenic	7440-38-2	0.001	mg/L	0.001	<0.001	----	----	----
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	----	----	----

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)

Compound	CAS Number	LOR	Unit	Client sample ID	CR06	WK03	----	----	----
				Client sampling date / time	13-AUG-2013 07:30	13-AUG-2013 08:15	----	----	----
					ES1318203-016	ES1318203-017	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued									
Barium	7440-39-3	0.001	mg/L		**4.30**	**2.02**	----	----	----
Cadmium	7440-43-9	0.0001	mg/L		<0.0001	<0.0001	----	----	----
Chromium	7440-47-3	0.001	mg/L		**0.004**	**0.006**	----	----	----
Copper	7440-50-8	0.001	mg/L		**0.001**	**0.001**	----	----	----
Cobalt	7440-48-4	0.001	mg/L		<0.001	**0.001**	----	----	----
Nickel	7440-02-0	0.001	mg/L		**0.001**	**0.004**	----	----	----
Lead	7439-92-1	0.001	mg/L		<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L		**0.006**	**0.030**	----	----	----
Manganese	7439-96-5	0.001	mg/L		**0.475**	**0.320**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L		**0.005**	**0.003**	----	----	----
Selenium	7782-49-2	0.01	mg/L		<0.01	<0.01	----	----	----
Strontium	7440-24-6	0.001	mg/L		**3.06**	**1.01**	----	----	----
Uranium	7440-61-1	0.001	mg/L		<0.001	<0.001	----	----	----
Vanadium	7440-62-2	0.01	mg/L		<0.01	<0.01	----	----	----
Boron	7440-42-8	0.05	mg/L		**0.27**	**0.19**	----	----	----
Iron	7439-89-6	0.05	mg/L		**37.8**	**27.2**	----	----	----
Bromine	7726-95-6	0.1	mg/L		**2.8**	**1.0**	----	----	----
EG035F: Dissolved Mercury by FIMS									
Mercury	7439-97-6	0.0001	mg/L		<0.0001	<0.0001	----	----	----
EK040P: Fluoride by PC Titrator									
Fluoride	16984-48-8	0.1	mg/L		**1.4**	**0.3**	----	----	----
EK057G: Nitrite as N by Discrete Analyser									
Nitrite as N	----	0.01	mg/L		<0.01	<0.01	----	----	----
EK058G: Nitrate as N by Discrete Analyser									
Nitrate as N	14797-55-8	0.01	mg/L		<0.01	<0.01	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser									
Nitrite + Nitrate as N	----	0.01	mg/L		<0.01	<0.01	----	----	----
EK071G: Reactive Phosphorus as P by discrete analyser									
Reactive Phosphorus as P	14265-44-2	0.01	mg/L		<0.01	**0.02**	----	----	----
EN055: Ionic Balance									
Total Anions	----	0.01	meq/L		**76.2**	**54.3**	----	----	----
Total Cations	----	0.01	meq/L		**75.5**	**54.2**	----	----	----
Ionic Balance	----	0.01	%		**0.52**	**0.12**	----	----	----

CERTIFICATE OF ANALYSIS

Work Order	: **ES1321591**	Page	: 1 of 4
Amendment	: **1**		
Client	: **PARSONS BRINCKERHOFF AUST P/L**	Laboratory	: Environmental Division Sydney
Contact	: MR JAMES DUGGLEBY	Contact	: Client Services
Address	: GPO BOX 5394 SYDNEY NSW, AUSTRALIA 2001	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
E-mail	: jduggleby@pb.com.au	E-mail	: sydney@alsglobal.com
Telephone	: +61 02 9272 5100	Telephone	: +61-2-8784 8555
Facsimile	: +61 02 9272 5101	Facsimile	: +61-2-8784 8500
Project	: 2162406C	QC Level	: NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Order number	: ----		
C-O-C number	: ----	Date Samples Received	: 02-OCT-2013
Sampler	: ----	Issue Date	: 01-NOV-2013
Site	: ----		
		No. of samples received	: 2
Quote number	: EN/008/13	No. of samples analysed	: 2

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA Accredited Laboratory 825

Accredited for compliance with ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Sydney Inorganics
Celine Conceicao	Senior Spectroscopist	Sydney Inorganics
Hoa Nguyen	Senior Inorganic Chemist	Sydney Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **EA016: Calculated TDS is determined from Electrical conductivity using a conversion factor of 0.65.**
- **This report has been amended and re-released to allow the reporting of additional analytical data.**

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)				Client sample ID	CR06	WK03	----	----	----
				Client sampling date / time	01-OCT-2013 15:00	01-OCT-2013 15:00	----	----	----
Compound	CAS Number	LOR	Unit		ES1321591-001	ES1321591-002	----	----	----
EA005P: pH by PC Titrator									
pH Value	----	0.01	pH Unit		8.14	8.15	----	----	----
EA010P: Conductivity by PC Titrator									
Electrical Conductivity @ 25°C	----	1	µS/cm		5550	4520	----	----	----
EA015: Total Dissolved Solids									
Total Dissolved Solids @180°C	----	10	mg/L		3120	2610	----	----	----
EA025: Suspended Solids									
Suspended Solids (SS)	----	5	mg/L		170	11	----	----	----
EA045: Turbidity									
Turbidity	----	0.1	NTU		177	46.7	----	----	----
EA065: Total Hardness as CaCO3									
Total Hardness as CaCO3	----	1	mg/L		47	23	----	----	----
ED037P: Alkalinity by PC Titrator									
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L		<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L		<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L		1360	1770	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L		1360	1770	----	----	----
ED040F: Dissolved Major Anions									
Silicon as SiO2	14464-46-1	0.1	mg/L		14.0	18.1	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA									
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L		<1	<1	----	----	----
ED045G: Chloride Discrete analyser									
Chloride	16887-00-6	1	mg/L		1020	432	----	----	----
ED093F: Dissolved Major Cations									
Calcium	7440-70-2	1	mg/L		14	6	----	----	----
Magnesium	7439-95-4	1	mg/L		3	2	----	----	----
Sodium	7440-23-5	1	mg/L		1270	1110	----	----	----
Potassium	7440-09-7	1	mg/L		6	5	----	----	----
EG020F: Dissolved Metals by ICP-MS									
Aluminium	7429-90-5	0.01	mg/L		0.06	0.02	----	----	----
Arsenic	7440-38-2	0.001	mg/L		0.004	<0.001	----	----	----
Strontium	7440-24-6	0.001	mg/L		2.15	0.960	----	----	----
Beryllium	7440-41-7	0.001	mg/L		<0.001	<0.001	----	----	----
Barium	7440-39-3	0.001	mg/L		2.46	1.48	----	----	----

Analytical Results

Sub-Matrix: **WATER** (Matrix: **WATER**)

Compound	CAS Number	LOR	Unit	Client sample ID: CR06	WK03	----	----	----
				Client sampling date / time: 01-OCT-2013 15:00	01-OCT-2013 15:00	----	----	----
				ES1321591-001	ES1321591-002	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued								
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	----	----	----
Uranium	7440-61-1	0.001	mg/L	<0.001	<0.001	----	----	----
Chromium	7440-47-3	0.001	mg/L	**0.007**	**0.001**	----	----	----
Copper	7440-50-8	0.001	mg/L	**0.002**	**0.001**	----	----	----
Cobalt	7440-48-4	0.001	mg/L	**0.002**	<0.001	----	----	----
Nickel	7440-02-0	0.001	mg/L	**0.006**	<0.001	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.041**	**0.016**	----	----	----
Manganese	7439-96-5	0.001	mg/L	**0.190**	**0.086**	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	**0.006**	**0.001**	----	----	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----
Boron	7440-42-8	0.05	mg/L	**0.20**	**0.15**	----	----	----
Iron	7439-89-6	0.05	mg/L	**6.83**	**1.76**	----	----	----
Bromine	7726-95-6	0.1	mg/L	**2.0**	**0.9**	----	----	----
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	----	----	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	**1.5**	**0.2**	----	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N	----	0.01	mg/L	<0.01	<0.01	----	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N	14797-55-8	0.01	mg/L	**0.02**	**0.03**	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**0.02**	**0.03**	----	----	----
EK071G: Reactive Phosphorus as P by discrete analyser								
Reactive Phosphorus as P	14265-44-2	0.01	mg/L	<0.01	<0.01	----	----	----
EN055: Ionic Balance								
Total Anions	----	0.01	meq/L	**56.0**	**47.6**	----	----	----
Total Cations	----	0.01	meq/L	**56.3**	**48.9**	----	----	----
Ionic Balance	----	0.01	%	**0.31**	**1.31**	----	----	----

Appendix D

GNS Stable Isotope Laboratory results

STABLE ISOTOPE RESULTS

National Isotope Centre
30 Gracefield Road
Lower Hutt 5010
PO Box 31 312
Lower Hutt 5040
New Zealand
T +64-4-570 1444
F +64-4-570 4657
www.gns.cri.nz

Parsons Brinckerhoff
Level 27, 680 George St
World Square, Sydney
NSW 2001
Australia

Project Title	2162406C - Waukivory	**Invoice**	**Parsons Brinckerhoff**
SIL Order No.:		**Attn:**	**Ellen Kwantes**
Client Ref.:			**Level 27, 680 George St**
Date Received:	3/09/2013		**World Square, Sydney**
Date Measured:			**NSW 2001**
Approved By:			**Australia**
Date Reported:	1/10/2013		

Sample Type: **water (H & O)**

SIL ID	External ID	δD Value	δ18O Value	Analysis Type	Overseas or NZ	State or Province	Country Code	Collection Date/Time (Start)	Other Info
W-1302056	CR06	-38.2	-6.58	D, O18	OS	New South Wales	AS	28/06/2013 8:00	groundwater
W-1302057	WK03	-34.4	-6.46	D, O18	OS	New South Wales	AS	28/06/2013 9:00	groundwater

Appendix E

Rafter Radiocarbon Laboratory results

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 54479
R 40358/1
Job No: 196625
Measured: 12/09/2013
TW No: 2885
Date issued: 30 Sep 2013

Sample ID	CR06
Description	Groundwater
Fraction dated	Water
Submitter	Ellen Kwantes Parsons Brinckerhoff

Conventional Radiocarbon Age (years BP)	**34222**	±	**284**	
$\delta^{13}C$ and Source of measurement	26.5	±	0.2	C13
Fraction modern	0.0141	±	0.0005	
$\Delta^{14}C$ (‰) and collection date	-986.0	±	0.5	28 Jun 2013

Measurement Comment: Unusually-enriched d13C, but a search of the stable isotope literature indicates that it is not unprecedented.

Sample Treatment Details

Sample was submitted in a fully capped plastic bottle with a layer of orange brown precipitate at bottom with no head space. Sample was colourless. CO2 was generated by phosphoric acid evolution, and carbonate content was 477.5 mgC/kgH2O, total dissolved inorganic carbon (TDIC) 39.8 mmol/kgH2O. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach, Radiocarbon 19:355-363 (1977) and $\Delta^{14}C$ is decay corrected to the collection date given, and not reported if no collection date was supplied. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25 permil, defined by Donahue, D. J., T. Linick, and A. T. Jull, *Radiocarbon*, *32* (2):135-142 (1990). $\delta^{13}C$ was obtained from the source indicated. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard. Further details of pretreatment and analysis are available on request.

National Isotope Centre, GNS Science
PO Box 31-312 Lower Hutt, New Zealand Fax +64 4 570 4657 Phone +64 4 570 4644
Email radiocarbon@gns.cri.nz Website www.RafterRadiocarbon.co.nz

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 54610
R 40358/2
Job No: 196626
Measured: 23/09/2013
TW No: 2888
Date issued: 30 Sep 2013

Sample ID	WK03
Description	Groundwater
Fraction dated	Water
Submitter	Ellen Kwantes Parsons Brinckerhoff

Conventional Radiocarbon Age (years BP)	**35162**	±	**403**	
$\delta^{13}C$ and Source of measurement	9.0	±	0.2	C13
Fraction modern	0.0126	±	0.0006	
$\Delta^{14}C$ (‰) and collection date	-987.5	±	0.6	28 Jun 2013

Measurement Comment:

Sample Treatment Details

Sample was submitted in a fully capped plastic bottle with a layer of orange brown precipitate and black splinters at bottom but no head space. Water was colourless. CO2 was generated by phosphoric acid evolution, and carbonate content was 461.4 mgC/kgH2O, total dissolved inorganic carbon (TDIC) 38.5 mmol/kgH2O. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach, Radiocarbon 19:355-363 (1977) and $\Delta^{14}C$ is decay corrected to the collection date given, and not reported if no collection date was supplied. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25 permil, defined by Donahue, D. J., T. Linick, and A. T. Jull, *Radiocarbon*, *32* (2):135-142 (1990). $\delta^{13}C$ was obtained from the source indicated. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component based on the analysis of an ongoing series of measurements on an oxalic acid standard. Further details of pretreatment and analysis are available on request.

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Appendix F

UC Davis Stable Isotope Facility - Carbon 13 and methane results

Sample	$\delta^{13}C_{VPDB}$	µg C/mL	Comments
CR06	25.77	396.5	
WK03	8.27	380.4	

Project: 2162406C

CHECK STD

0.2 ml 10mM Li2CO3 (Acros)

MEASURED	KNOWN
-13.39	-13.37
-13.34	MEAN
-13.37	-13.38
-13.43	SD
	0.04

Sample	$\delta^{13}C_{VPDB}$	Comments
CR06	-38.29	Below LOQ
WK03	-41.57	

CHECK STD (10 ppm)	MEASURED	KNOWN
UCDM3	-36.87	-36.7
UCDM3	-36.66	-36.7
UCDM3	-36.68	-36.7
UCDM3	-36.97	-36.7
UCDM3	-36.63	-36.7
UCDM3	-36.66	-36.7
avg	-36.74	
sd	0.14	

CALIBRATION STDS	MEASURED	KNOWN
NG1	-34.00	-34.2
NG1	-34.08	-34.2
NG2	-69.11	-68.9
NG2	-69.38	-68.9

2nd CHECK STDS	MEASURED	KNOWN
H iso	-23.70	-23.9
H iso	-23.62	-23.9
L iso	-66.11	-66.5
L iso	-66.31	-66.5
B iso	-54.66	-54.5
B iso	-54.89	-54.5
T iso	-38.50	-38.3
T iso	-38.63	-38.3

Sample	δ^2H_{VSMOW}	Comments
CR06	-135.9	Below LOQ
WK03	-193.8	

CHECK STD (10 ppm)	MEASURED	KNOWN
UCDM3	-149.4	-149.0
UCDM3	-150.5	-149.0
UCDM3	-149.1	-149.0
UCDM3	-149.6	-149.0
UCDM3	-144.6	-149.0
UCDM3	-147.6	-149.0
avg	-148.5	
sd	2.1	

CALIBRATION STDS	MEASURED	KNOWN
NG1	-188.1	-185.1
NG1	-185.7	-185.1
NG2	-236.4	-237.0
NG2	-236.4	-237.0
NG3	-168.0	-167.6
NG3	-164.8	-167.6

2nd CHECK STDS	MEASURED	KNOWN
Mamm	-184.7	-189.1
H iso	-153.9	-155.7
B iso	-266.6	-269.1

Appendix G

ANU Department of Nuclear Physics - Chlorine-36 results

Wheel C251 - 03 September 2013

Sample	$^{36}Cl/Cl$ ($x10^{-15}$)	Error
Carolina Sardella, Parsons Brinckerhoff		
WK03	30.1	1.6
CR06	23.1	1.5