



Environmental Health Impact Assessment – Camden Northern Expansion Project

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It is prepared in accordance with the scope of work and for the purpose outlined in the Section 1 of this report.

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- Appendix A Analytical Reports – Coal Seam Gas
- Appendix B Noise Contour Plots – Operational and Drilling Activities (provided by SLR)
- Appendix C Human Health and Ecological Risk Assessment – Hydraulic Fracturing Activities
- Appendix D Human Health and Ecological Risk Assessment – Drilling Chemicals
- Appendix E Human Health and Ecological Risk Assessment – Workover Activities



Glossary of Terms

CGP	AGL Camden Gas Project
CSG	Coal Seam Gas
DoPI	NSW Department of Planning and Infrastructure (also referenced as NSW Planning)
DTIRIS	NSW Department of Trade and Investment, Regional Infrastructure and Services
EMP	AGL Environmental Management Plan
GDE	Groundwater dependent ecosystem
ICM	Illawarra Coal Measures
LGA	Local Government Area
NOW	NSW Office of Water
NSW EPA	NSW Environment Protection Authority
NSW OEH	NSW Office of Environment and Heritage
RPGP	Rosalind Park Gas Plant
SCA	Sydney Catchment Authority
SWGCC	South West Growth Centre

Executive Summary

AGL currently operates the Camden Gas Project (CGP) for the extraction of coal seam gas (CSG) from the Illawarra Coal Measures, within the Southern Coalfields of the Sydney Basin. The CGP includes 144 CSG wells (of which 8 have been plugged and abandoned and 105 are currently in operation), access roads, a high pressure supply pipeline, underground gas gathering lines (GGLs) and the Rosalind Park Gas Plant (RPGP). AGL currently proposes to expand its operations to the north of existing CGP infrastructure, including development of additional gas wells and associated field infrastructure (refer to **Figure 1.2**). The Northern Expansion Project would tie in to the existing CGP network (also shown on **Figure 1.2**). The primary objective of the Northern Expansion Project is to continue gas production from the Illawarra Coal Measures to supply the NSW energy market.

An Environmental Health Impact Assessment (EHIA) has been undertaken to address concerns raised by NSW Health and the local community in relation to the health impacts of the proposed expansion Project. In particular, it is understood that NSW Health made a submission on the Northern Expansion Project stating that the Environmental Assessment was “incomplete without a screening level health risk assessment which would consolidate the likelihood and severity of risks to human health into a single document.” The Environmental Assessment was subsequently voluntarily suspended by AGL. This EHIA provides a screening level health risk assessment that assesses the likelihood and severity of risks to human health from the proposed expansion Project. NSW Health has been consulted in the preparation of this report, and has provided detailed feedback.

The assessment has considered potential for adverse health effects in the community associated with environmental impacts that may be associated with the proposed Project. The assessment has not considered ecological, political, economic or social aspects of the Project. In addition the assessment has addressed the potential for adverse health impacts associated with the Northern Expansion Project only, based on site-specific and project-specific information. Hence the assessment has not addressed other CSG projects that may operate in other parts of Australia or the United States, unless data has been collected that is directly relevant to the Northern Expansion Project.

The potential for risks to health from the Project in terms of noise, air quality, vibration, groundwater, surface water, acute hazards and subsidence has been reviewed in this EHIA. Many aspects of the Project are required to comply with a range of best practice regulatory policies or codes of practice. Also the AGL Environmental Management Plan commits AGL to undertake the works in accordance with other best practice requirements. This assessment has assumed that these best practice requirements will be incorporated into the Project.

Assuming that the Northern Expansion Project is carried out in accordance with best practice, as well as the current policies and codes of practice, the risks posed to the health of the community and to air, noise, groundwater and surface water by all aspects of the project have been found to be low and acceptable.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been commissioned by AGL Energy Limited (AGL) to undertake a screening level environmental health impact assessment (EHIA) in relation to the Northern Expansion of the Camden Gas Project (CGP) (referred to in this report as the “Project”). The CGP is a major coal seam gas (CSG) project involving the extraction of gas from the Illawarra Coal Measures, within the Southern Coalfields of the Sydney Basin, New South Wales (NSW). The Northern Expansion would involve the development of additional gas wells and associated infrastructure in an area within the Camden and Campbelltown Local Government Areas (LGAs).

AGL currently operates the Camden Gas Project (CGP) for the extraction of CSG from the Illawarra Coal Measures, within the Southern Coalfields of the Sydney Basin. The CGP includes 144 CSG wells (of which 105 are currently in operation), access roads, a high pressure supply pipeline, underground gas gathering lines (GGLs) and the Rosalind Park Gas Plant (RPGP). AGL currently proposes to expand its operations to the north of existing CGP infrastructure, including development of additional gas wells and associated field infrastructure (refer to **Figure 1.2**). The Northern Expansion Project would tie in to the existing CGP network (also shown on **Figure 1.2**).

The primary objective of the Northern Expansion Project is to continue gas production from the Illawarra Coal Measures to supply the NSW energy market.

1.2 Purpose of EHIA

The EHIA has been undertaken to address concerns raised by NSW Health and the local community in relation to the health impacts of the proposed Project. The EHIA has been undertaken in consultation with NSW Health, NSW EPA and the NSW Department of Planning and Infrastructure (DoPI or NSW Planning).

The assessment has considered potential for adverse health effects in the community associated with environmental impacts that may be associated with the proposed Project. The assessment has not considered ecological, political, economic or social aspects of the Project. In addition the assessment has addressed the potential for adverse health impacts associated with the Northern Expansion Project only, based on site-specific and project-specific information. Hence the assessment has not addressed other CSG projects that may operate in other parts of Australia or the United States, unless data has been collected that is directly relevant to the Northern Expansion Project.

1.3 Planning and Assessment Process

The Northern Expansion has been declared by the Minister for Planning as a ‘Major Development’ under the provisions of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and *State Environmental Planning Policy (Major Development) 2005* (SEPP 2005), and was therefore subject to the provisions of Part 3A of the EP&A Act. Since public exhibition of the Environmental Assessment for the Northern Expansion Project in 2010, Part 3A of the EP&A Act has been repealed. However, Part 3A continued to apply to the Northern Expansion Project due to the transitional provisions under the EP&A Act. On 19 October 2012, the project was declared to be State significant development by the Minister for Planning and Infrastructure by an order published



in the NSW Gazette on 26 October 2012. Assessment and determination of the Amended Project will therefore now proceed under Division 4.1, Part 4 of the EP&A Act, rather than under (the now repealed) Part 3A.

Project Approval is being sought for the works comprising the Northern Expansion being:

- The construction and operation of gas wells at up to 11 well surface locations containing up to 6 well heads each;
- The construction and operation of associated gas gathering and water lines, including interconnection with the existing gas fields which form part of the CGP (CGP Network), along with central water storage points where required;
- The construction of access roads and ancillary infrastructure, including storage yard(s), where required; and
- Subsurface drilling of horizontal well paths within the boundaries of the Subsurface Project Area.

As part of the Project Approval process, an Environmental Assessment (EA) was prepared by AECOM (2010) on behalf of AGL. As part of this process some details of the Project were amended. Hence a Submissions Report was prepared by AECOM (2012) to provide an updated assessment of the potential environmental impacts of the Amended Project. This included further investigations in relation to ecological and heritage issues, and conduct of a Phase 1 Groundwater Assessment.

The application submitted to the DoPI has been suspended by AGL.

This EHIA has considered all information presented within various chapters and supporting specialist studies undertaken and presented in the EA (AECOM 2010) and the Submissions Report (AECOM 2012).

1.4 Objectives

The overall objective of the EHIA is to provide a structured assessment of potential impacts associated with the proposed Camden Northern Expansion Project on the health of the surrounding community.

The focus of the EHIA relates to impacts to the environment that include air, water (groundwater and surface water) and noise. Other impacts such as visual, economic, traffic or social are not addressed in this assessment.

1.5 Approach

Overall, the EHIA has been undertaken in accordance with the following guidance (and associated references as relevant):

- enHealth - “Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards” (enHealth 2012).
- NEPM - Schedule B(4), “Guideline on Health Risk Assessment Methodology”, 1999 and NEPM Schedule B(5 A,B,C), “Guideline on Ecological Risk Assessment” (NEPC 2010, NEPC 1999).
- enHealth – “Health Impact Assessment Guidelines” (enHealth 2001).
- National Water Quality Management Strategy (ANZECC/ARMCANZ 2000).

- Harris, P., Harris-Roxas, B., Harris, E. & Kemp, L., Health Impact Assessment: A Practical Guide, Centre for Health Equity Training, Research and Evaluation (CHETRE). Part of the UNSW Research Centre for Primary Health Care and Equity. University of New South Wales, Sydney, 2007.

These guidance documents have been endorsed by the NSW EPA for the conduct of health risk assessments in NSW.

The EHIA presented in this report is a desk-top assessment. The term desk-top is used to describe that the EHIA has not involved the collection of any additional data over and above that which has been provided from Project specific EA technical studies, or studies undertaken for existing operations within the CGP or community consultation.

The scope of work associated with the conduct of the EHIA is as follows:

- Review the available specialist/technical reports conducted as part of the EA for the Project. The available specialist/technical reports considered in this assessment are listed in **Section 1.6**.
- Collate available information to develop a community profile of areas potentially impacted by the Project. The profile includes the local community as well as the local environment. Community concerns have been determined from feedback from the community consultation processes conducted as part of the EA process.
- Conduct an EHIA where all the available information from the specialist/technical reports is assessed, the potential for impacts on the community are identified and assessed and relevant risk mitigation measures (that may be required) are identified and summarised.

The EHIA assessment presented in this report is largely qualitative, with some aspects addressed in a quantitative manner, and has been conducted for the purpose of summarising all the environmental health impacts that may be associated with the proposed Project, evaluating those impacts (on a qualitative or quantitative basis where relevant) and where an impact has been identified, determining if it can be mitigated through existing or other management measures.

1.6 Specialist/Technical Reports

Table 1.1 presents a summary of the technical reports/specialist studies available for consideration in the preparation of the EHIA, and the technical areas of the EHIA to which each study is relevant.

Table 1.1 Summary of available specialist/technical reports

Report Title	Technical Areas Addressed in Report
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Appendix D Preliminary Hazard Analysis – Planager Pty Ltd	Acute hazards
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Appendix F Noise and Vibration Impact Assessment	Noise and Vibration
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Appendix G Air Quality Impact Assessment	Air
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Appendix H Greenhouse Gas Assessment	Air
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Appendix K Stage 2 CGP Subsidence Report	Subsidence
AGL Camden Gas Project – Northern Expansion Environmental	Site and Project Description

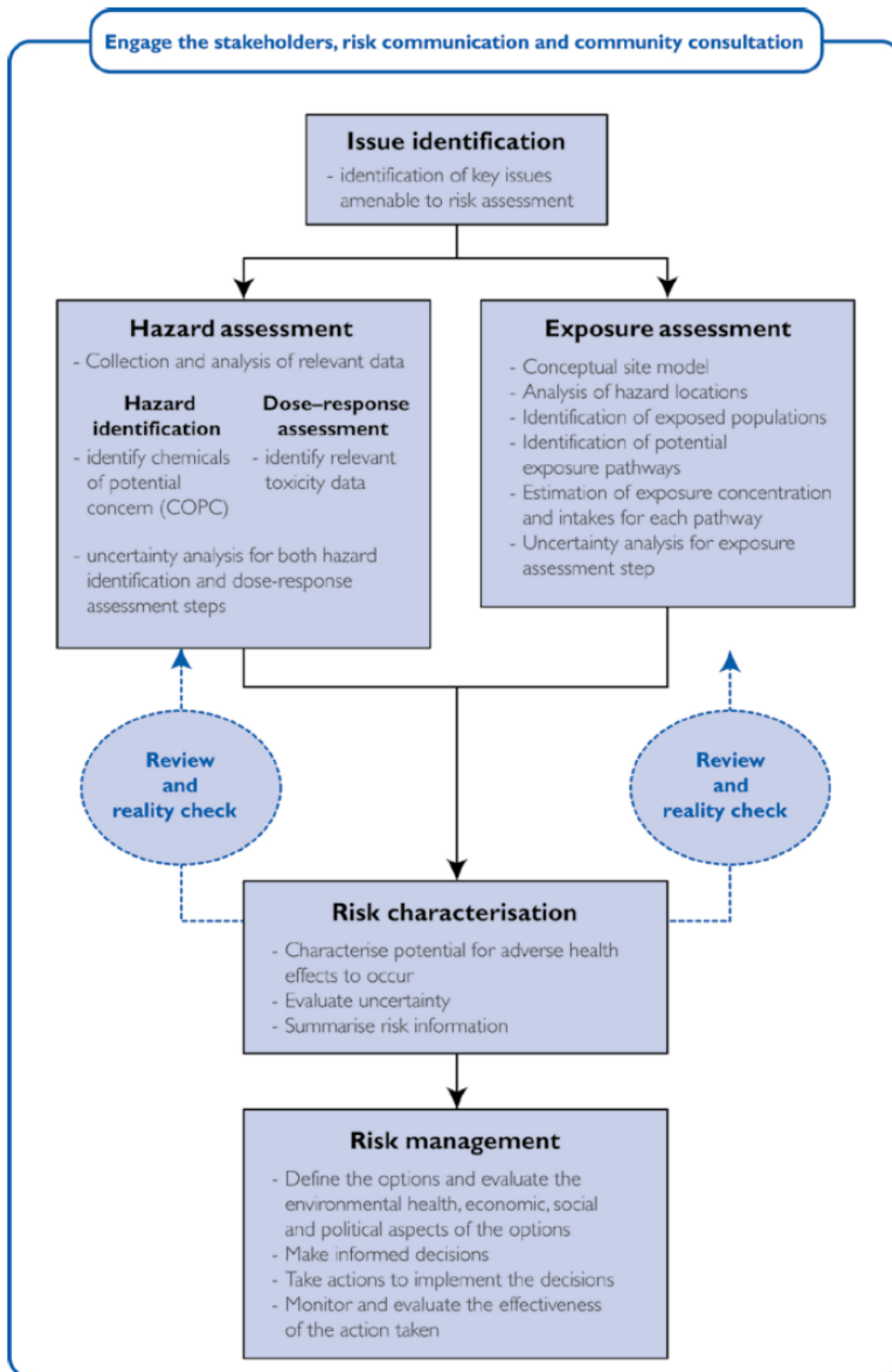
Report Title	Technical Areas Addressed in Report
Assessment (Oct 2010) Chapter 2 and 4	
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Chapter 9	Surface waters
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Chapter 12	Groundwater
AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010) Chapter 18	Geology and Soils
AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012) Appendix B Phase 1 Groundwater Assessment	Groundwater
AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012) Appendix C Baseline Groundwater Monitoring Data	Groundwater
AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012) Appendix D Groundwater Management Plan	Groundwater
AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012) Appendix F Addendum to Noise Assessment	Noise
AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012) Chapter 3	Groundwater and Surface waters
AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012) Chapter 5	Noise, surface waters, groundwater, acute hazards, geology and soils, air quality and greenhouse gases.

1.7 Overview of Risk Assessment Process

Virtually all aspects of life involve exposure to risks (enHealth 2012). Risk assessment is a process that allows the potential impact of a hazard to be estimated on a specified human population or ecological system in a systematic way.

The risk assessment process for environmental health risks was first outlined by the USEPA in the 1980s. The process has remained much the same since then with refinements focused on better ways to conduct each step rather than changing the steps. Health authorities in Australia updated their guidance – Environmental Health Risk Assessment Guidelines – in 2012. The process is outlined in **Figure 1.1**.

Figure 1.1 Environmental Health Risk Assessment Model





A risk assessment includes an assessment of the hazard and an assessment of exposure. For a hazard (e.g. presence of a chemical in a water body) to pose a risk to people there must be a pathway by which a person can be exposed to the chemical in the water body. If there is no exposure pathway then there is no risk.

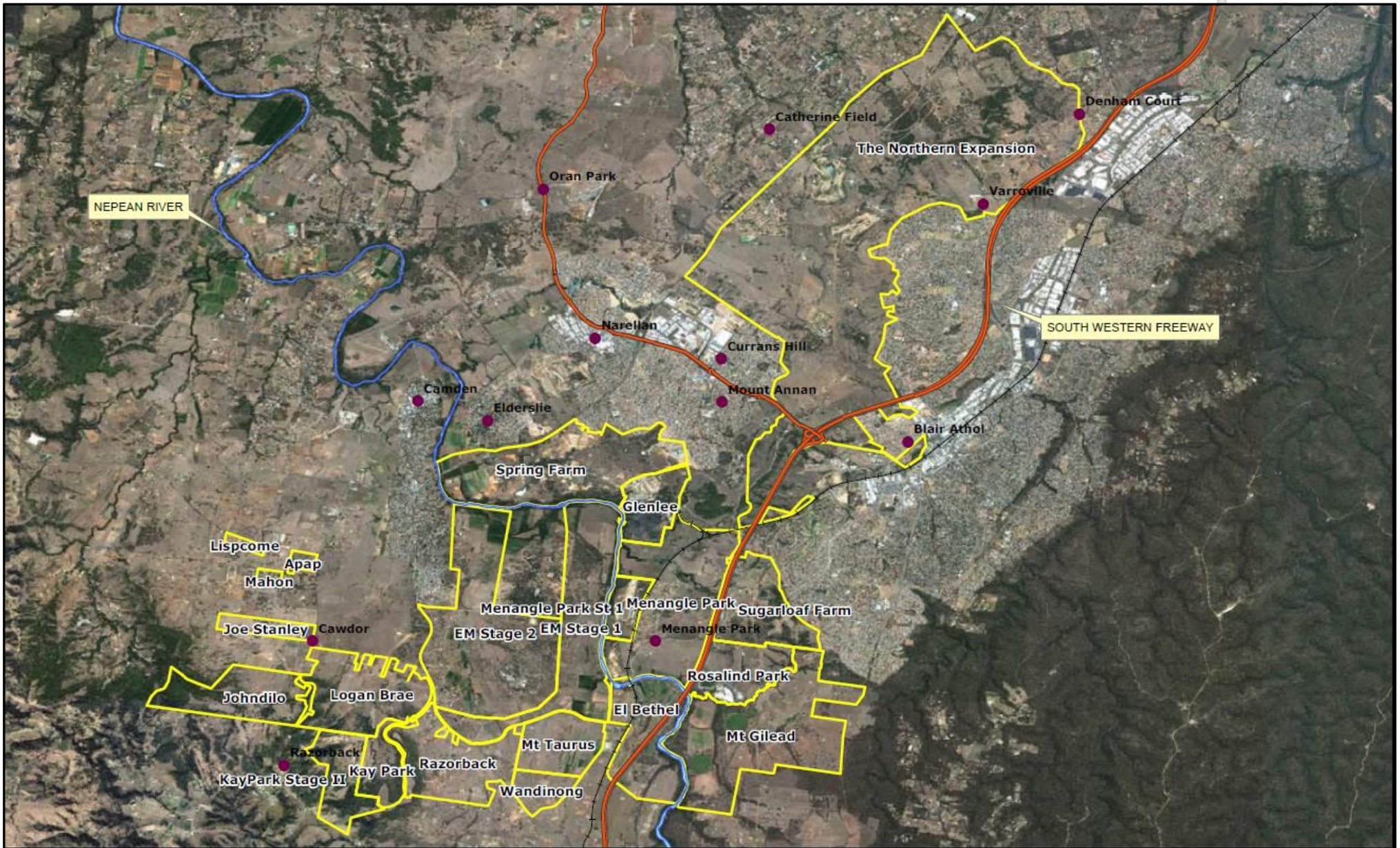
The characteristics of a hazard are often established by its nature and cannot be easily changed. Exposures, on the other hand, depend on the situation in which the hazard arises, how people might be exposed, how much they might be exposed to and how long they might be exposed. Often risk management measures are focused on reducing, changing or removing exposure to a hazard.

In this report a combination of qualitative and quantitative (where relevant) risk assessment has been used to determine the risks posed by this Project. In most of the specialist/technical reports prepared for this assessment hazards have been identified. For each hazard relevant to the Project an estimate has been made of exposure through:

- monitoring data from other parts of the Project already in operation;
- modelling using standardised models (e.g. greenhouse gas estimation); or
- site specific modelling developed based on the characteristics of the Project area.

In the first instance worst case assumptions are included in these estimates of exposure. Once an estimate of exposure has been developed it was compared to appropriate National or International health protective guidelines to determine if the Project poses a risk with regard to each of the hazards. If the exposure from the Project is less than the guideline then there is no unacceptable risk. If the exposure from the Project may be larger than the guideline there is potential for unacceptable risk which can be addressed by refining the worst case assumptions or by recommending control/management measures be included in the Project.

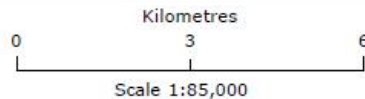
There are also a range of required control/management measures that must be included in projects such as this, which are based on operating the project in terms of best practice. For example, wells must be drilled in accordance with DTIRIS Codes of Practice (DTIRIS 2012a and b). The inclusion of these measures is often assumed in the risk calculations.



Energy in action™

Author: Upstream Gas
Date: 21/10/2010
Ref: 2574

Camden Gas Project Stages
Figure 1.2



Geocentric Datum of Australia 1994

Sources: AGL Energy Limited, MapData Sciences, SKM

Legend

- Towns
- Major Highway
- +— Railway Line
- Neapen River
- Camden Gas Project



Disclaimer: While AGL has taken great care and attention to ensure the accuracy of the data represented on this map, no liability shall be accepted for any errors or omissions. No part of this map may be reproduced without prior permission of AGL.

Section 2. Project Description

2.1 Location

The Project Area for the Northern Expansion has been separated into two distinct areas known as the Subsurface Project Area (within which Project works are limited to subsurface drilling of horizontal wells) and the Surface Project Area where proposed surface infrastructure would be located (refer to **Figure 2.1**).

The Subsurface and Surface Project Areas are situated within the Camden and Campbelltown LGAs, on generally rural land within the suburbs of Currans Hill, Varroville, Raby and Denham Court. The total Project Area covers 17,100 ha of land within this area.

The Subsurface Project Area spans some 13,200 ha of land generally south of Liverpool LGA, west of Minto, and north of Menangle Park as shown on **Figure 2.2**.

The Surface Project Area spans some 3,900 ha of land east of Camden Valley Way and extending from Narellan Road in the south to Denham Court Road in the north. The Surface Project Area also includes part of the Mount Annan Botanical Gardens to the south east as shown on **Figure 2.2**.

2.2 Land Use and Infrastructure

Land use within and surrounding the Northern Expansion is largely rural and used for agricultural purposes such as grazing, with some rural-residential properties scattered throughout the area. The area comprises established residential and rural-residential areas (that comprise of single and double storey detached dwellings) such as Catherine Field to the west, Raby, Eschol Park, Eagle Vale and Claymore to the east, Currans Hill and Mount Annan to the south and Leppington to the north. Other land uses include the Smeaton Grange industrial area and the neighbouring Oran Park Development Area, one of the largest development precincts identified within the South West Growth Centre (SWGC).

The Northern Expansion incorporates certain land identified in the Metropolitan Strategy. The Turner Road and East Leppington Development Areas have been identified for future urban (residential, commercial and industrial) development as part of the SWGC, and are located within the Surface Project Area.

Three further Development Areas identified by the Metropolitan Strategy are located within the Subsurface Project Area, and include Leppington, Catherine Fields and Catherine Fields North. Camden Council has also defined two further development areas known as the El Caballo Blanco and Gledswood (ECBG) and Camden Lakeside Development Areas, which are within the Surface Project Area.

Several golf courses, sporting complexes and recreational reserves are scattered throughout the Subsurface and Surface Project Area. The Smeaton Grange Industrial Park is also located within the Subsurface Project Area.

The Surface Project Area is dissected by the Sydney Upper Canal Water Supply (Upper Canal) which generally runs north-south and forms part of the Upper Nepean Water Supply System. The

Upper Canal is owned by the Sydney Catchment Authority (SCA) and is a heritage item listed on the State Heritage Register (SHR).

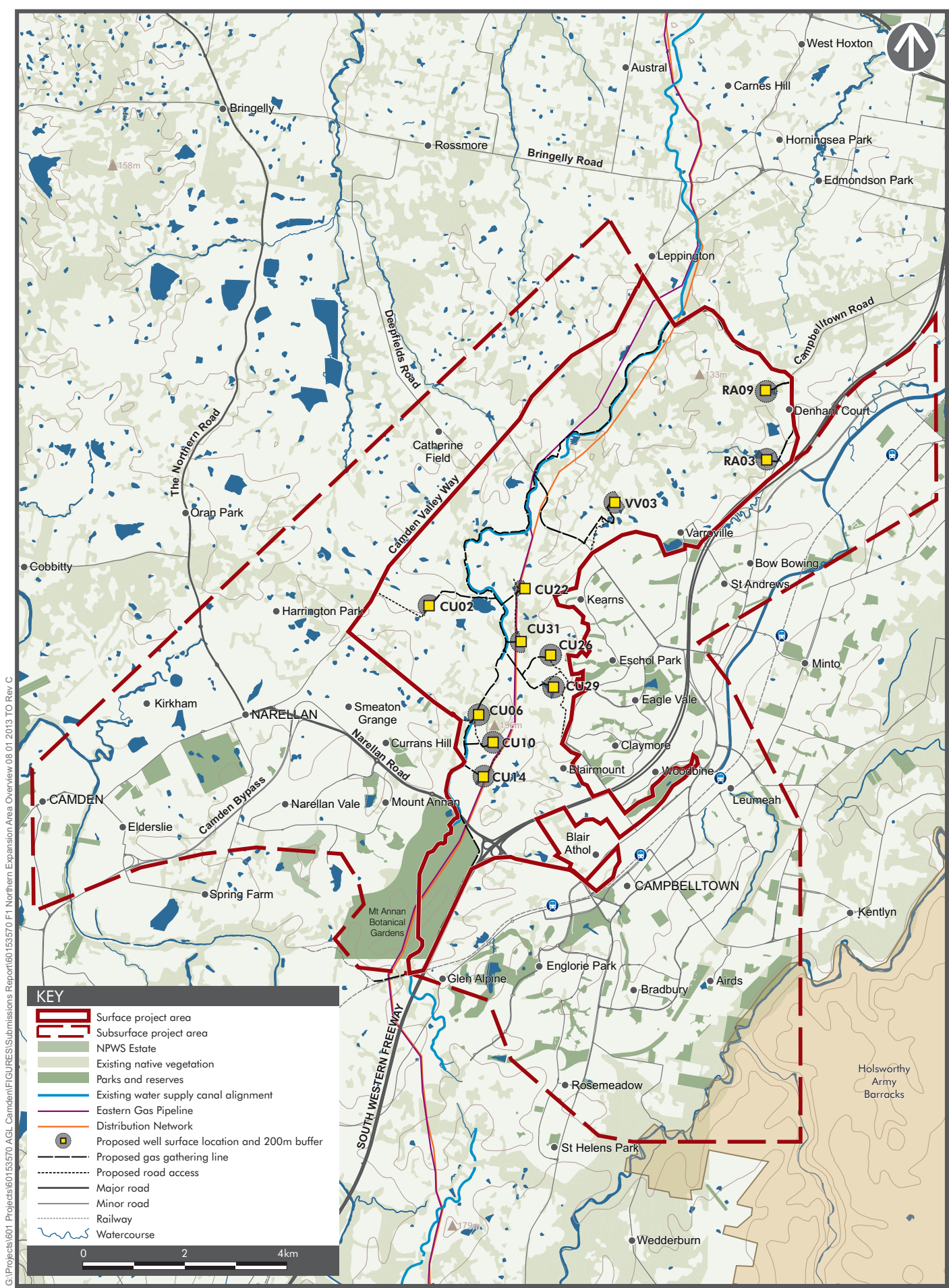
The Eastern Gas Pipeline and Distribution Network also dissect the Subsurface and Surface Project Area and are essential for the sale and delivery of natural gas. Gas gathering lines installed as part of the Northern Expansion would connect directly into the existing infrastructure of the CGP, which connects to the Distribution Network.

Several water mains and transmission lines also run through the Subsurface and Surface Project Area.

2.3 Project Activities

The Project activities can be generally divided into the following:

- Construction: The activities required to physically undertake the drilling of wells and subsurface horizontal well paths, gas gathering and water lines, and construction of access roads and supporting infrastructure;
- Production: Production and delivery of gas from well surface locations to the existing CGP network via gas gathering lines, including commissioning and maintenance activities;
- Post Development: Operational activities which may be needed to maintain production efficiency. It is anticipated that these activities may include the upgrade of gas gathering lines, re-hydraulic fracture stimulation and re-drilling (if required); and
- Closure and Final Rehabilitation: Decommissioning of the Northern Expansion in accordance with statutory requirements and industry best practice.



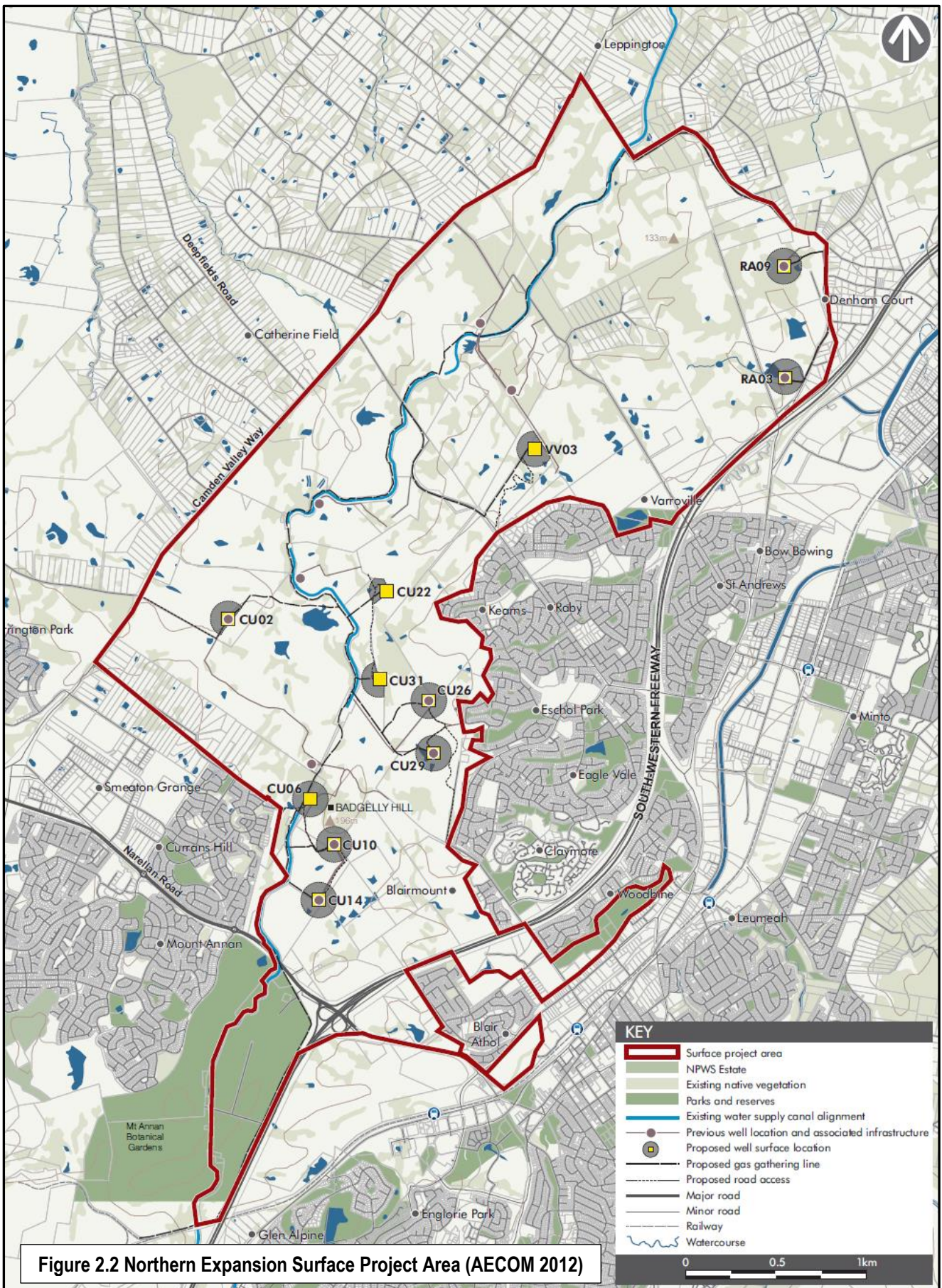
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KEY

- Surface project area
- Subsurface project area
- NPWS Estate
- Existing native vegetation
- Parks and reserves
- Existing water supply canal alignment
- Eastern Gas Pipeline
- Distribution Network
- Proposed well surface location and 200m buffer
- Proposed gas gathering line
- Proposed road access
- Major road
- Minor road
- Railway
- Watercourse

0 2 4km

Figure 2.1



2.4 Geology

The whole of the CGP is located within the Southern Coalfield of the Sydney Geological Basin. The Sydney Basin is sedimentary in origin, with deposition of sediments occurring from the early Permian (290 million years ago) through to the latter part of the Triassic (200 million years ago).

The CSG resources are contained within rocks of Permian age and are the upper coal measure sequences known as the Illawarra Coal Measures (ICM). They lie conformably beneath the Triassic age Narrabeen Group of sandstones. The principal geological targets for the CGP are the late Permian Bulli and Balgownie Coal Seams within the ICM. The ICM are composed of shale, quartz-lithic sandstone, conglomerate, chert, sporadically carbonaceous mudstone, coal and torbanite seams mostly deposited in a deltaic plain environment (Herbert and Helby, 1980).

The Bulli and the Balgownie Coal Seams are approximately 2 - 5 m and 1 - 3 m thick, respectively, within the CGP area, and are, on average, 666 m and 683 m deep across the CGP area.

The sedimentary rocks overlying the Illawarra Coal Measures are sandstones and claystones of the Narrabeen Group, which in turn are overlain by the Middle Triassic aged Hawkesbury sandstone, the Mittagong Formation and the shales of the Wianamatta Group. At the surface there are unconsolidated alluvial deposits along the major rivers. The sandstones of these overlying groups of rocks are well recognised throughout the Sydney Basin for their development of spectacular cliffs, and while some individual rock units – largely the Hawkesbury Sandstone – are aquifers containing fresh to brackish water, most of the rock units both immediately above and below the coal measures are quite impermeable and as a consequence, the small volumes of interstitial water present tend to be saline. It is noted that the coal seams in this area do not generally contain large volumes of formation water and the formation water present tends to be slightly to moderately saline.

2.4.1 Structure

The Project area is characterised by a gently dipping sequence relatively unaffected by major faulting apart from a set of NW - NNW trending normal faults that have been identified from exploration and 2D seismic surveys. Very few, if any, of these features affect the entire stratigraphic sequence displaying no expression at surface. The possibility cannot be ruled out that major fault zones could provide a hydraulic pathway through claystone horizons and that some shallow groundwater impacts may be observed close to those structures. However, well surface locations or well sites are determined following extensive geological exploration and analysis. Locations are mostly in areas of undisturbed (essentially flat lying) strata and away from fault systems, in order to achieve required gas rates and minimise the potential for increased water production. The potential for these features to act as conduits for leakage or downward groundwater flow is inferred to be low, based on current data that suggests that regional horizontal stress orientations are orthogonal to these features and they, therefore, act as barriers, rather than conduits to groundwater flow.

2.4.2 Geological Strata

Table 2.1 presents a summary of the local/regional geological strata of the Sydney Basin which is relevant to the Northern Expansion Project Area.

Table 2.1 Stratigraphy of the CGP Area

Age	Unit		Lithology*	Average Thickness # (m)	Average depth to top# (m bgl)	
Quaternary	Alluvium		Quartz and lithic "fluvial" sand, silt and clay	<20	0	
Tertiary	Alluvium		High- level alluvium			
Triassic	Wianamatta Group	Bringelly Shale	Shale, carbonaceous claystone, laminite, lithic sandstone, rare coal	80 (top eroded)	0 -20	
		Michinbury Sandstone	Sandy barrier island complex. Fine to medium-grained lithic sandstone.			
		Ashfield Shale	Black to light grey shale and laminite.			
	Mittagong Formation		Interbedded shale, laminite and medium-grained quartz sandstone.	11	113	
	Hawkesbury Sandstone		Medium to coarse-grained quartz sandstone with minor shale and laminite lenses.	173	114	
	Narrabeen Group	Gosford Subgroup	Newport Formation	Lower part contains quartzose sandstones which are top-sealed by the shaly laminite at the top of the unit.	35	274
			Garie Formation	Clay pellet sandstone.	8	308
		Clifton Subgroup	Bald Hill Claystone	Dominantly red shale and fine to medium-grained sandstone.	34	292
			Bulgo Sandstone	Fine to medium-grained quartz-lithic sandstone with lenticular shale interbeds.	251	331
			Stanwell Park Claystone	Red, green and grey shale and quartz-lithic sandstone.	36	574
Scarborough Sandstone			Quartz-lithic sandstone, pebbly in parts.	20	621	
Wombarra Claystone			Grey shale, minor quartz-lithic sandstone.	32	636	
Illawarra Coal Measures	Sydney Sub-group	Bulli Coal	Shale, quartz-lithic sandstone, conglomerate, chert, sporadically carbonaceous mudstone, coal and torbanite seams.	4	667	
		Loddon Sandstone		12	684	
		Balmain Coal Member		24	737	
		Balgownie Coal		2	684	
		(Remaining Sydney Sub-group)		?	699	
		Cumberland Sub-group		-	-	
Permian	Shoalhaven Group		Sandstone, siltstone, shale, polymictic conglomerate, claystone; rare tuff, carbonate, evaporite.	-	-	
	Lachlan Fold Belt		Intensely folded and faulted slates, phyllites, quartzite sandstones and minor limestones of Ordovician to Silurian age (PB, 2011a)	-	-	

Key: * From Geoscience Australia's Stratigraphic Units Database (http://dbforms.ga.gov.au/www/geodx.strat_units.int); #average thickness and depth to top taken from available information on all wells within CGP

2.5 Hydrogeology

2.5.1 General

As discussed above (**Section 2.4**) the geology of the Subsurface and Surface Project Areas comprise regionally significant and continuous low permeability shale and claystone units that provide an effective barrier between Hawkesbury Sandstone aquifers and the deep Illawarra Coal Measures water bearing zones. Alluvial aquifers only occur in the vicinity of the Nepean River (and its major tributaries) located to the south of the Northern Expansion area, not within the Project area. The presence of this natural barrier and the inherent low permeability of the coal measures are responsible for the low produced water yield of the CSG extraction process. Water quality within the coal formation waters is slightly to moderately brackish in nature, while fresher water can be located within the Hawkesbury Sandstone or alluvial aquifers, located a significant distance above the Illawarra Coal Measures.

Table 2.2 presents a summary of the hydrogeological properties of the stratigraphic units (derived from data collected from existing operations, which is consistent with those in the Northern Expansion) from the shallow alluvial aquifer to the target coal seams approximately 700 m below ground level.

Table 2.2 Hydrogeological properties for stratigraphic units where available (after SCA (2005b), Broadstock (2011), and PB (2011a))

Age/ Stratigraphic unit	Average thickness* (m)	Type of hydro- geological unit	Hydraulic conductivity -		Transmissivity (m ² /day)	Permeability (m/s) [#]	Quality
			Horizontal (m/d)	Vertical (m/d)			
Quaternary/ Tertiary							
Alluvial deposits	<20	Unconfined aquifer	1 - 10		>20		TDS>2000 mg/L
Triassic							
Wianamatta Group	80 (top eroded)	Aquitard - Unconfined / perched	0.01	0.05	<1 - 4 (Ashfield Shale)		TDS>3000 mg/L
Hawkesbury Sandstone (including the Newport and Garie Formations)	217	Unconfined / semi-confined aquifer	0.1	0.05 – 6 x 10 ⁻⁴ (SCA, 2005)	1 – 5 (0.016 – 9.2, mean of 2.8 (McKibbon and Smith, 2000))	3x10 ⁻⁸	TDS <500- 10,000 mg/L
Bald Hill Claystone	34	Aquitard	1.0 x10 ⁻⁵	2.0 x10 ⁻⁵		5x10 ⁻⁹	
Bulgo Sandstone	251	Minor confined aquifer	5.50x10 ⁻⁴	1.10 x10 ⁻⁴	0.1 – 0.5	6x10 ⁻⁸	TDS 1500 – 5000 mg/L
Stanwell Park Claystone	36	Aquitard	3.00x10 ⁻⁵	6.00x10 ⁻⁶		3x10 ⁻⁹	
Scarborough Sandstone	20	Minor confined aquifer	0.01	5.00x10 ⁻³	0.1 - 0.5	2x10 ⁻⁷	
Wombarra Claystone	32	Aquitard	3.00x10 ⁻⁵	6.00x10 ⁻⁶		1x10 ⁻⁹	
Permian							
Illawarra Coal Measures	200	Confined water bearing zones	5.00x10 ⁻² (Bulli)	2.50x10 ⁻² (Bulli)	0.005 – 0.1	1x10 ⁻⁵ (Bulli)	TDS >5000 mg/L

Key: * - inferred from information from all wells across CGP

- from GHD (2007), and is applicable to the Dendrobium mine area, about 30 km south of the CGP area

2.5.2 Beneficial Use Aquifers

There are few beneficial aquifers (used for water supply) across the Subsurface and Surface Project Areas. These are the shallow alluvial aquifers (present outside and not within the expansion area) and the porous and fractured rock aquifers within the Hawkesbury Sandstone to a depth of approximately 300 m below ground level. Within the region there is some sporadic use of the Wianamatta shales that are used as a water source, but quality and yield varies significantly.

Groundwater in these aquifers is used for stock, domestic, garden and minor irrigation uses. The groundwater in these aquifers is limited (i.e. generally very low yields from this fractured rock aquifer) and the quality too variable (from fresh to brackish) to be suitable for drinking water. No groundwater within this area is accessed as a drinking water source and it is noted that NSW Health recommends against the use of groundwater in urban areas for such purposes (NSW Health 2007). All of the Subsurface and Surface Project Areas are connected to a reticulated supply provided by Sydney Water. Due to the poor resource potential of these aquifers, it is not possible to extract large quantities of water for use.

There is no surface expression of any of the deeper groundwater systems and consequently there are no groundwater dependent ecosystems associated with any of the sedimentary rock groundwater systems. It should be noted that although the Cumberland Shale Hills/Plains Woodland is identified as a “highly probable” groundwater dependant ecosystem and is present within the vicinity of the project area (Serov et al., 2012), it appears to be dependent on very shallow, localised perched groundwater in soil (derived from Wianamatta Shale) and local colluvium/alluvium rather than the regional groundwater systems. This perched groundwater is only likely to be located in small pockets, not continuous across the whole region.

2.5.3 Deeper Aquifers

It should be noted that the coal seams targeted as part of the existing CGP and the Northern Expansion are not beneficial aquifers (but are rather water bearing zones, again with limited groundwater available) and are not used as a water supply source for any purpose. The quality of the water within the coal seams is considered poor and is generally brackish to slightly salty.

Even though they are depressurised and dewatered across the project area during the CSG operations, previous studies (Jewell 2001; KBR 2008; PB 2008; SCA 2005b) have concluded that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Permian coal measures in the area will protect shallower aquifers in the Triassic sandstones above and, hence, there are no noticeable impacts on beneficial shallow aquifers and surface water within this area from the depressurisation or dewatering of these coal measures.

2.5.4 Confining Layers

All aquifer systems in the Subsurface and Surface Project Areas are separated by low permeability aquitards. The following claystones and shales act as confining layers and separate/isolate the aquifers noted in **Tables 2.1 and 2.2**.

- Ashfield Shale and Mittagong Formation (located above the Hawkesbury Sandstone and below the Minchinbury Sandstone) – in this area these formations separate the alluvial aquifers (not present in the Project Areas) from the deeper sandstone aquifers;

- Bald Hill Claystone (located below the Hawkesbury Sandstone and above Bulgo Sandstone of the Narrabeen Group) – in this area, this formation separates the Hawkesbury Sandstone from any minor sandstone aquifers in the Bulgo Sandstone;
- Stanwell Park Claystone (located below the Bulgo Sandstone and above the Scarborough Sandstone, both within the Narrabeen Group); and
- Wombarra Claystone (located below the Scarborough Sandstone of the Narrabeen Group, and above the Illawarra Coal Measures).

These claystones and shales are very low permeability layers and are likely to impede the vertical flow of groundwater such that overlying aquifer zones will be hydraulically isolated, experiencing little, if any drawdown impact related to depressurisation of the coal measures.

As stated above, the presence of these extensive and thick claystone formations protect the shallower aquifers of the Triassic sandstones and above.

The Narrabeen Group confining layers form an effective hydraulic barrier between the Hawkesbury Sandstone aquifers and the Illawarra Coal Measures (Jewell 2001). The presence of this barrier is one reason why the CSG wells produce so little water; the other is the inherently low horizontal permeability of the coal measure rocks themselves (Jewell 2001).

Figure 2.3 presents a schematic of the Northern Expansion, illustrating the stratigraphy, depths of the target coal seam and overlying aquifers, including the confining layers.

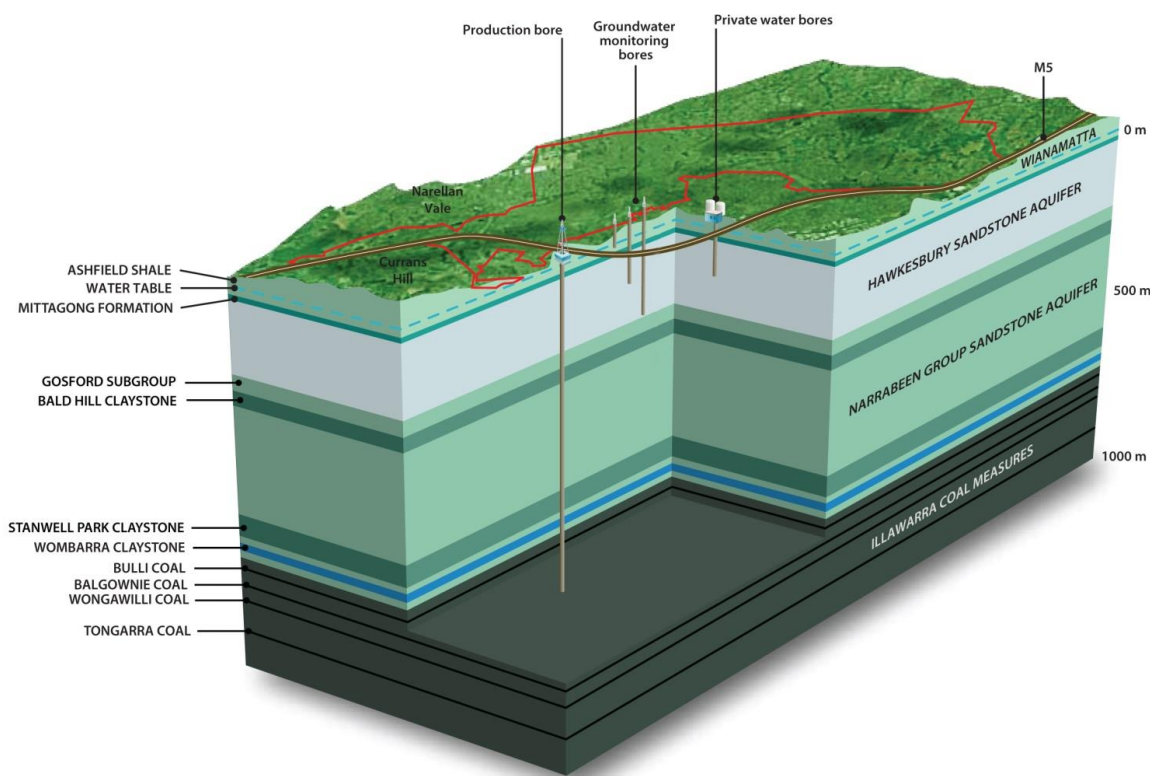


Figure 2.3 Schematic model that represents the stratigraphy of the CGP area and surrounds (PB, 2011b).

2.5.5 Groundwater flow, recharge and discharge

Regional

On a regional scale, groundwater levels and flows are largely controlled by the basin geometry, topography and major hydraulic boundaries. In the southern Sydney Basin, groundwater flow in all sedimentary basin rocks (except for the uppermost Wianamatta Group rocks) is predominantly towards the north or north-east, eventually discharging via the Georges, Parramatta and Hawkesbury River systems, and ultimately also off shore to the east. On a basin wide scale, recharge is via rainfall infiltration on rock outcrop areas, infiltration of stream runoff water in upper catchments and also by inter-aquifer leakage (PB, 2011).

Within the regional Camden area there is rainfall and river recharge to the alluvial sediments (where present) associated with the Nepean River, with very limited rainfall recharge to the Wianamatta Group shales with most rainfall generating stormwater runoff. There is some minor leakage through the Wianamatta Group into the Hawkesbury Sandstone aquifer, however most recharge to the sandstone aquifers is expected to occur via lateral groundwater through-flow from up-gradient and up-dip areas to the south.

Flow occurs within the individual aquifers and there does not appear to be any interaction between the Hawkesbury Sandstone aquifers and the deeper water bearing zones in the Narrabeen Group and the Illawarra Coal Measures.

Northern Expansion Project area

Similar conditions prevail in the Project area with very limited rainfall recharge to the Wianamatta Group shales and most rainfall generating stormwater runoff. There is no evidence of rainfall recharge to the underlying Hawkesbury Sandstone (PB, 2012). There may be some minor leakage through the Wianamatta Group into the Hawkesbury Sandstone aquifer, however by far the majority flow within these sandstone aquifers is expected to occur via lateral groundwater through-flow from up-gradient and up-dip areas to the south.

Carbon dating from Hawkesbury Sandstone monitoring bores (PB, 2012) confirms long residence times, greater than 30,000 years. It is expected that the age of the groundwater in the deeper coal seam water bearing zones will be significantly older again.

Within the surface expression of the northern expansion area of the CGP area, there are only five registered (old) water bores, mostly into the Hawkesbury Sandstone. It is unknown whether these bores are still in existence but, even if all were operational, the total extraction volumes would be small and probably less than 10 ML per year in total.

2.6 Description of Operations

2.6.1 General

In relation to the Northern Expansion Project there are range of activities proposed that are associated with access and establishing the well locations, and constructing gas pipeline infrastructure to connect up with the existing CGP network. These are normal construction type activities that are effectively managed through the implementation of appropriate management plans and controls (as would be applied to any construction project).

The key aspects of the Project that are of concern to the community are associated with activities associated with drilling and extraction of gas and their health impacts. Hence the following discussion has focused on these aspects of the Project.

A gas well generally has four main stages in its life cycle which are outlined below and discussed further in the following sections:

1. Drilling (site construction, drilling operations and fracture stimulation (where required));
2. Commissioning (installation of equipment and install well production facilities, well completion, initial dewatering and flowback, drill site rehabilitation);
3. Production (dewatering, operation and maintenance); and
4. Well closure, abandonment and final rehabilitation.

2.6.2 Coal Seam Gas Extraction Process

CSG refers to gas that is present as a low-pressured, normally water saturated and naturally fractured (or cleated) coal seam reservoir. While a portion of the gas in coal seams may be stored as free gas in the natural fracture cleat system, the majority of the gas is stored in the surface of the coal by 'adsorption'. In simple terms, 'adsorption' in this context means that the gas is bonded to the coal. Adsorption typically accounts for more than 99% of the gas-in-place in CSG reservoirs.

Production from a CSG reservoir is therefore almost exclusively from the *desorption* of gas from the coal by depressurising the coals. Desorption is the opposite process of adsorption, and releases the adsorbed substance (in this case, natural gas) from the surface of the coal. However, because most CSG reservoirs are 90 to 100% water saturated, this water must first be produced, or released from the reservoir, to enable gas production. Dewatering reduces the pressure of the coal seam reservoir, which allows gas to desorb from the coal and to be produced. In the early life of a CSG well it is not uncommon to produce only water, which contains minor amounts of gas.

2.6.3 Well Construction

Each well pad is constructed within a bunded area. All activities associated with drilling and production, including the temporary storage of chemicals used in drilling and maintenance activities, collection and temporary storage of produced water from the well, occur within this bunded area. The bund wall fully encloses the well pad and a small lined sump is constructed in one corner to capture runoff from the pad.

The two types of well development techniques employed by AGL Camden are:

- **Vertical Drilling:** Vertical wells are the primary gas well type in the area. Wells are drilled vertically or at a deviation to a maximum of 45° to intercept the Bulli and Balgownie Coal Seams. Wells have multiple casings with a conductor casing near surface, a surface casing to around 120m to exclude shallow aquifers and a production casing to full depth. All casings are pressure cemented in place.
- **Horizontal Drilling** Horizontal wells are used to increase the drainage area of a reservoir and provide a means of stimulating the reservoir through the drilling process. The well is drilled vertically from the surface and gradually builds angle so as to intersect the seam near parallel with the seam dip angle. Once intersected, this portion of the well bore is cased, cemented, pressure tested and a smaller hole is subsequently drilled through the seam

anywhere from about 1300 to 2500 m. It allows a significant reduction in the number of surface locations along with the ability to access previously sterilised gas reserves. Horizontal wells are the now preferred well development technique for the CGP over vertical wells due to the ability of drilling multiple wells (as many as six) from one site location and accessing a large geographical area sub surface. This drilling technique has eliminated the requirement for vertical wells, and hydraulic fracture stimulation, for the past 5 years in the CGP.

The NSW Department of Trade & Investment, Regional Infrastructure & Services, Resources & Energy Codes of Practice for well integrity and hydraulic fracture stimulation have been adopted by AGL. These codes comply with the American Petroleum Institute (API) standards and best practice for wells (DTIRIS 2012a and b).

Shallow beneficial aquifers (which in this area are mostly less than 150 m from surface in the alluvium and shallow sandstone but occasionally up to 300 m from surface in the Hawkesbury Sandstone) are protected by up to four barriers within the well construction: two steel and two cement barriers, as well as being protected by the impermeable geology that lies between the coal seam at 700m depth and the beneficial use aquifers.

The well construction design incorporates numerous contingencies to ensure zonal isolation between coal seams and other formations including the shallow aquifers.

Aside from the important environmental considerations, zonal isolation is important for gas production, as water migration from any other source will hinder gas production, so all precautions are taken during well construction to ensure no communication between other formations can exist with respect to the well bore.

Figure 2.4 presents cross-sectional illustrations of the well construction demonstrating the level isolation that is achieved with the construction methodology.

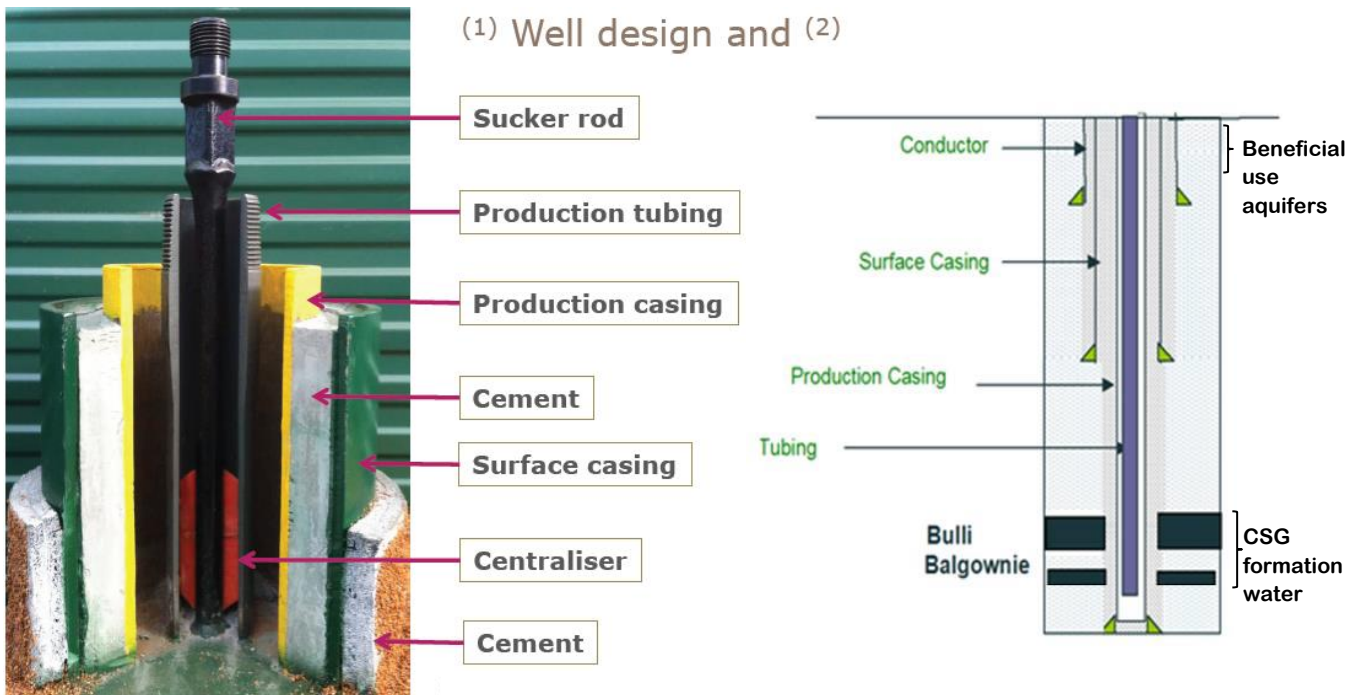


Figure 2.4 Typical Well Construction (from AGL)

During well construction, water and drilling muds are used. The volume of water required for the drilling process varies depending on the type of drilling. The largest predicted volume of water is required for horizontal drilling, for drilling and removal of cuttings during drilling. Anticipated volumes are approximately 200 kL.

Drilling mud is displaced and captured from the well during the pressure cementing operation. The drill mud is then disposed of at an approved licensed facility. Production water is pumped from the well following well completions and temporarily stored in tanks or lined drill pits prior to reuse or disposal where appropriate at a licensed facility.

2.6.4 Hydraulic Fracturing

Hydraulic fracturing has been used in the oil and gas industry since the 1950's as a technique for enhancing the production of gas from coal seams. The fracturing process involves the injection of water and sand at pressures exceeding the maximum strength of the coal. When the injection pressure becomes greater than the coal strength and confining pressures, fractures are propagated through the seam. The fractures propagate outwards from the initiation point along the path perpendicular to minimum stress. As the coal is much softer than the interburden (material that lies between coal seams), the fractures propagate along through the coal rather than into the surrounding rock. Sand is injected with the water to hold the newly formed fractures open, thus maintaining the higher conductive pathways induced by the process of hydraulic fracturing. This enhances the productivity of the reservoir over the life of the well. The fracturing process also reduces the need for a dense well network; fewer wells are required to be drilled to produce the recoverable gas reserves.

The pressure rated steel casing (API) is fully cemented so access to the target coal seam can only be achieved after accessing the seam by means of well perforations. Well perforation services are conducted by a geophysical wireline logging service provider who lower a perforation gun into the well to selected coal seam depth and firing the gun. The gun shoots a series of 10mm holes through the steel casing and cement into the coal seam penetrating the coal from 40 to 60mm into the coal seam. This operation now provides access to the coal seam only while maintaining full well integrity across the rest of the well.

During a hydraulic fracturing stimulation treatment, the selected formation is accessed by perforating the steel casing and cement at the depth (it is isolated from all other formations by the natural geology as well as the steel casing and cement) fluid is pumped down the pressure rated steel casing into the formation by the perforation process. The fluid being forced through the perforations in the steel casing and into the formation generates a pressure as it encounters a resistance to flow through in the formation. When the fluid pressure building in the formation generates a stress that is greater than the stress required to fracture the formation, a fracture is created. Coal formations contain existing fractures referred to as cleats. When fracturing a coal seam, the fracture often follows an existing cleat or pathway into the coal reservoir.

As pumping continues, the fracture extends from the wellbore and penetrates the coal reservoir, typically as two opposing wings at 180 degrees from the cased wellbore. Once the desired geometry of the fracture is created, proppant (fine grained sand) is added to the fluid and placed into the fracture. When all the proppant is placed in the fracture, pumping is stopped. The pressure inside the fracture drops and the stress in the formation reduces such that the fracture closes in on the proppant. The closing fracture traps the proppant inside the formation and helps to maintain a permeable and conductive path through the formation connecting back to the wellbore. The permeable path left in the formation from the fracture stimulation treatment is the main objective. This proppant filled flow path enhances production by allowing CSG formation water and gas to flow from the formation to the wellbore with minimised resistance.

Typical hydraulic fracturing stimulations for AGL create fractures that are less than 15 millimetres wide and extend horizontally (frac length) for 20 to 50 metres perpendicular to the minimum stress direction within the coal seam. The height of the fracture may vary though fractures are contained within the coal seam due to the very low permeability rocks (confining layers) located above and below the coal seam, which are significantly harder than the coal, limiting the vertical height growth of the fracture.

The hydraulic fracturing process requires the use of fracturing fluids (which primarily comprise sand and water, but also include other chemicals, refer to **Section 8.4.2** and **Appendix C**). These fluids are pumped into the well during fracture stimulation and then pumped back out of the well. It is estimated that 100% of the fracturing fluid is recovered plus coal seam formation water. In order to ensure this, AGL logs, tests and disposes (via re-use or recycling) of the volume of fracturing fluid as frac flowback water, ensuring that all fracturing fluid is recovered and identified. After this volume is recovered AGL usual produced water management regime will apply after which time it would revert to produced water.

All water (produced water or flowback water) is temporarily stored at each well pad within aboveground plastic tanks where it is subsequently tested and re-used or recycled.

At this stage AGL does not plan to fracture stimulate any wells in the Northern Expansion Project, though may in the future. Any future fracture stimulation activities would require preparation and approval of a Fracture Stimulation Management Plan, which would describe the measures to be adopted by AGL to ensure that fracture stimulation flowback water is monitored to ensure 100% recovery.

2.6.5 Commissioning and Production

Commissioning a well into production typically includes initial workover to install the well completion, the installation of the surface production equipment including some form of artificial dewatering pump to remove the water from the well and measure any gas flow. Production testing of the CSG resource would be undertaken for all new wells, and include the following program of works:

- Production testing of the well to ascertain the quantities of gas that will flow from the well; and
- Daily checks of gas flow rates carried out at each well surface location.

Gas extracted from wells during production testing would be transported via low pressure pipeline to the existing CGP for filtering, dehumidifying and compression. Once compressed, the gas would subsequently be directed into the Distribution Network. If the gas gathering network was not yet installed at this point, then gas flaring may be required. Should gas flaring be required, AGL would deploy enclosed flares which burn the gas but the flame is contained therefore visually, no flare or bright light is emitted.

During the production phase, gas is transported via low pressure pipeline to the existing CGP network for processing. Operator involvement at the well surface location is minimised by the installation of various automated and remotely operated functions.

Telemetry is connected to all wells so the production data can be accessed and reviewed remotely. The wells have numerous alarms and automatic shutdown functions which are based on a 'Cause and Effect' design. Any well can be shut-in or opened remotely from a control room once the wellhead communication equipment has been installed.

Operational activities at each well surface location during production typically include:

- Routine daily/weekly inspections;
- Formation water disposal; and
- Well workover maintenance.

During the production or operational phase, the wells require an occasional 'workover' to maintain the efficiency of gas production. The work over typically involves a truck or trailer mounted rig to run or remove pipe for clearing the well bore of fill or obstructions. Workover activities generally require a team of up to ten personnel and would typically vary between one day and one week based on experience to date in other gas fields of the CGP. Based on normal or typical operations it is estimated that a workover would be required for each well as follows:

- Twice in the first year;
- Once in the third and fifth years; and
- Once every five years thereafter.

A small number of the existing wells do not fit with the maintenance regime outlined above and this can be the result of production issues, ongoing mechanical problems or blockages. The maintenance of these wells would be specified by the AGL Production Engineer based on the type of production issue.

Workover Activities

Workovers are performed when there is a loss of either gas production or water production from the well and work is required to restore the well's flow. Workovers are generally conducted inside the cased well. The workover rig is brought onto a well whenever anything needs to be lifted from the wellbore and conduct such maintenance works. For all workover activities undertaken by AGL a comprehensive work program, specific for the particular well on which the workover is to be carried out, is put together which outlines the steps to be undertaken and the chemicals which are to be used on the well. These activities may result in water (that includes chemicals used in the well) being produced. This water is collected into aboveground tanks for characterisation and disposal. During these activities a number of products, and chemicals may be used and temporarily stored at the well pad.

Gas Gathering System

The gas gathering system route, as depicted in **Figure 2.2**, would be designed, constructed and operated in accordance with appropriate Australian Standards and industry best practice. The gas gathering system would be buried to a minimum depth of 750 mm (as per Australian Standard AS4645.3-2008) and at up to 1200 mm in some areas, including unsealed and sealed road crossings, and creek and drainage line crossings.

These lines would connect the individual well surface locations to a main spine line proposed to be located in an existing easement alongside the Upper Canal. The main spine line would connect with the existing CGP network to deliver gas for processing at the existing RPGP.

Water traps fitted at low points in the gathering system allow free water to be removed and would be periodically emptied as required.

2.6.6 Post Development

Post development operational activities would be undertaken where required only. The activities related to well surface locations during this phase are limited to re-hydraulic fracturing and re-drilling of wells (if necessary). These activities would generally be conducted in the same way as outlined in the sections above in accordance with the Environmental Management Plan (EMP) and relevant management plan to be produced on a case by case basis.

Re-hydraulic fracturing of wells may be required after a period of operation, and would involve the same process as the initial hydraulic fracturing of the wells. It is noted that re-hydraulic fracturing of the wells would only be undertaken where a production or operational issue is identified. There may be instances where existing wells need to be re-drilled for a variety of operational, geological, or production reasons. As a result re-hydraulic fracturing and re-drilling are therefore unlikely to be undertaken at all wells.

The gas gathering route would be inspected annually by a specialist third party Gas Detection inspection service that performs a leakage survey of the below ground pipelines. The survey is

conducted at 10 parts per million (ppm) sensitivity for gases and the 10 ppm sensitivity reflects the measurement capability of the equipment used to check for leaks.

In-field compression

In-field compression occurs in the vicinity of well heads or along gas gathering lines to increase capacity and production.

During the production phase of existing well surface locations, the initial high gas pressure at the well heads would decrease over time. As a result, pressure drops for gas flow from the well head across the gas gathering system and results in a reduction in the overall production rate delivered to the existing CGP network. In order to maintain gas production, there may be the need to boost the pressure in the gathering system by in-field compression. Generally, it is anticipated that wells in the southern part of the Project Area would be able to flow through to the CGP network without the need for in-field compression. The need for in-field compression may not arise for some two to five years from project commencement, when production reaches a rate of some 20-30 TJ/day. As in-field compression would not be immediately required for the production of gas from the Project and the optimal location for in-field compression has not yet been determined, approval for this activity has not been sought as part of the Project Application that was prepared for the DoPI.

2.6.7 Closure and Rehabilitation

On completion of operations, impacted areas would be cleaned up and rehabilitated to return the land to the condition it is currently in (prior to the Project) or better in accordance with the EMP. This work would involve:

- sealing/ plugging and abandonment of wells in accordance with relevant guidelines;
- removing plant and equipment from wellheads and removal of fenced compounds;
- filling in excavation; and
- rehabilitation, contouring, and regrassing/revegetation.

The preferred method of rehabilitation for the gas gathering system would be to purge with water in order to remove remaining gas, seal and then leave in situ to prevent further disturbance. This method would be subject to consultation with the land owner and would typically be approached on a property by property basis. Should removal of the gas gathering system be required, the excavated trench would be backfilled and rehabilitated, including contouring and revegetation.

Decommissioned and abandoned wells would be backfilled with cement to avoid inter-mingling of aquifers once production has ceased, and casing cut and removed approximately 1 m below ground level. The integrity of the well (once filled with cement) is tested to ensure that it is properly sealed. The well casing (constructed with 2 layers of steel and 2 layers of cement) remains in place and hence there are no mechanisms that are created during the decommissioning of the well that would create a pathway by which groundwater aquifer interactions may occur.

By cementing the well head casing to the surface, inundation of the well with surface water is not possible.

2.7 Environmental Management

AGL currently implements an Environmental Management Plan (EMP), and a number of sub plans, for operations within the Camden Gas Project. The EMP will be updated to include the Northern Expansion Project.

The objective of the EMP is to describe the overall environmental management framework for the Project, setting out what AGL is required to do (to meet legislative requirements, requirements of approvals, licences, permits and leases), how it will be done and the monitoring used to ensure compliance and improve operations.

The EMP includes a number of sub-plans that include monitoring and reporting requirements for:

- Noise;
- Flora & fauna;
- Soil and water (surface water and groundwater) management;
- Air quality;
- Waste;
- Traffic;
- Dangerous goods and hazardous materials; and
- Emergency response.

Section 3. Community Profile

3.1 Local Area of Interest

The Northern Expansion Project is located within the Camden and Campbelltown LGAs.

Camden LGA has a total land area of some 201 km² and comprises a mix of agricultural lands, country towns and new residential areas with associated commercial and industrial developments.

Camden LGA has experienced rapid growth since 1981 with an annual growth rate of approximately 7.8%. Due to the future development of release areas, it is expected that Camden LGA will continue to experience significant growth.

Campbelltown LGA has an area of some 311.5 km² and comprises largely rural residential lands, with some higher density residential and employment areas near the city centre. Overall, Campbelltown LGA experienced a slight increase in population between 1996 and 2001, however, many of the smaller areas within the LGA experienced population decline during this period.

The Northern Expansion encounters land ear-marked for future urban (residential, commercial and industrial) development and as such is likely to experience a change from a rural to an urban environment. Population growth between 2001 and 2031 is predicted by the DoPI to be 190% in Camden LGA and 20% in Campbelltown LGA.

The population distribution in these areas, compared with greater Sydney, based on 2011 Census Data (available from the Australian Bureau of Statistics), is summarised in **Table 3.1**.

Table 3.1 Population Distribution for Campbelltown and Camden LGAs

Age groups:	Camden LGA		Campbelltown LGA		Greater Sydney	
	All	% total	All	% total	All	% total
0-4 years	4,576	8%	10,893	7%	298,900	7%
5-14 years	9,188	16%	21,120	14%	544,315	12%
15-19 years	4,239	7%	11,576	8%	275,786	6%
20-24 years	3,510	6%	10,994	8%	307,257	7%
25-34 years	7,475	13%	20,672	14%	676,894	15%
35-44 years	9,151	16%	19,093	13%	653,490	15%
45-54 years	7,470	13%	20,428	14%	594,978	14%
55-64 years	5,604	10%	17,579	12%	475,608	11%
65-74 years	3,086	5%	8,385	6%	298,140	7%
75-84 years	1,654	3%	3,861	3%	185,238	4%
85 years and over	767	1%	1,367	1%	81,067	2%
All persons	56,720		145,967		4,391,674	

Based on the above the population distribution in Camden and Campbelltown LGAs are consistent with that across greater Sydney.

Specific future residential development projects proposed in the Subsurface and Surface Project Areas include:

- Turner Road Development Area – can accommodate up to 4000 new homes. Well location CU02 is located within this development precinct, near an area earmarked for business development.

- East Leppington Development Area – can accommodate between 2000 and 3000 new homes. No new surface wells are located within this proposed development area.
- Leppington – this area has not yet been released, however the Development Area is expected to accommodate 12000 new homes. No new surface wells are located within this proposed development area.
- Catherine Fields - can accommodate up to 8000 new homes. No new surface wells are located within this proposed development area.
- Catherine Fields North - can accommodate up to 9500 new homes. No new surface wells are located within this proposed development area.
- Camden Lakeside – the proposed development involves the redevelopment of the Camden Valley Golf Resort into a residential estate that includes a new golf course, mixed entertainment and business areas. No CSG infrastructure is planned for this proposed development area.
- El Caballo Blanco and Gledswood (ECBG) – The ECBG area has been rezoned for general residential (up to 860 homes), open space and potential hotel/resort. No CSG infrastructure is planned for this proposed development area.

3.2 Location of Sensitive Populations

The Subsurface and Surface Project Areas comprise a mix of rural and residential (low density) areas. In relation to the proposed Project, the closest sensitive populations comprise residential homes located (or potentially located following future development) near to the proposed wells.

Table 3.2 presents a summary of the distance from each proposed well location to the nearest residential home (currently and following redevelopment of areas designated for future residential development as outlined in **Section 3.1**). **Table 3.2** also includes the distance from each proposed well location to the nearest water body.

Table 3.2 Distance from Proposed CSG Wells to Residential Homes and Water Bodies/Dams

CSG Well	Well Number	Distance from Proposed CSG Well to		
		Closest Water Body/Dam	Existing Residential Home	Future Residential Home
RABY 9	RA09	63m up-Hill, 100m down-hill	299m	None proposed
RABY 3	RA03	79 m up-hill	274m	None proposed, however could be 50m. Info from draft development plan.
CURRANS HILL 2	CU02	320m level	564m	250m
CURRANS HILL 6	CU06	172m – down-hill	421m	353m
CURRANS HILL 10	CU10	439m various	691m	None proposed
CURRANS HILL 14	CU14	146m various	441m	None proposed
CURRANS HILL 26	CU26	310m various	400m	None proposed, however could be 50m. Info from draft development plan.
CURRANS HILL 29	CU29	102m up-hill	410m	None proposed
CURRANS HILL 22	CU22	184m down-hill	351m	D.A. currently lodged for re-zoning. Could be within 50m pending final development plan
VARROVILLE 3	VV03	178m down-hill	665m	None proposed
CURRANS HILL 31	CU31	212m	915m	392m - however D.A. currently lodged for re-zoning. Could be within 50m pending final development plan

In addition to the neighbouring residential homes, the following sensitive community populations are located within the Surface Project Area:

- St Gregory's College;
- Mt Annan Christian College and Mt Annan Church;
- Mt Annan Botanic Garden;
- Blairmount Public School; and
- Mt Carmel High School.

3.3 Community Concerns

As part of the EA submission process, a number of community engagement sessions have been run by AGL since June 2011. These activities have included:

- Meetings with the Camden Community Consultative Committee;
- Attending community events, in particular the Camden Show, Campbelltown Show and running the AGL Roadshow;
- Engagement with Camden Council and Wollondilly Council, State Members for Wollondilly, Camden and the Federal Member for Macarthur;
- Hosting Camden Gas Project Open Days, an Industry Open Day, Media open day;
- Engagement with Country Women's Association, Australian Energy Regulators;
- Conducting letterbox drops and door knocks;
- Personal contact via letters, emails and phone;
- Website updates; and
- Preparation of fact sheets and advertorials.

The following presents a summary of the key issues identified by the local community in relation to the proposed Project:

- Flora and fauna- loss of habitat;
- The chemicals used in hydraulic fracturing are dangerous to health, cause birth defects, leak into our waterways;
- The Southern Cross University study- high levels of methane (relating to data collected in Tara, Queensland);
- Carcinogens in our drinking water;
- Fugitive emissions are everywhere;
- Truck movements- dust;
- Effects on water;
- Community sick in Tara;
- How is a well decommissioned- potential for fugitive emissions;
- There are high levels of produced water and high levels of salt;
- Methane is twice as deadly as CO₂;
- No proof that the CSG does not cause harm;
- Toxicology reports;
- Methane is a noxious and toxic gas;
- Noise during construction;
- Radioactive and links to leukemia;
- Fugitive emissions;



- Properties devalued;
- Rehabilitation;
- Subsidence issues; and
- Concerns with the health of 100,000 people in Campbelltown.

A number of these concerns relate to potential health impacts of the proposed Project. These are further addressed in this report.

Section 4. Assessment of Impacts – Air

4.1 Introduction

An air quality impact assessment has been undertaken by PAE Holmes in accordance with regulatory guidance. The report for this assessment is included as Appendix G to the EA and it is summarised in Section 14 of the main EA report.

The Project is in a largely undeveloped rural area with pockets of rural residential, recreational and proposed future development. The area is mostly cleared landscape. There is an industrial park nearby and a number of roads which carry heavy vehicles. The air quality is expected to be quite good.

4.2 Overview of Specialist Studies

The NSW Government undertakes routine monitoring of air quality around Sydney. One of the monitoring locations was at the UWS Campbelltown Campus (named Macarthur). This site was commissioned in 2004 and closed in 2008. The data from this monitoring location was used in this air quality assessment. Another monitoring location was opened nearby – Campbelltown West at Campbelltown TAFE and this site is currently active. Data for this site was not used in this assessment as final reports for recent years, which would contain data for this site, have not been published yet.

The data indicates that the regional air quality is in line with other areas of Sydney with some occasional high levels of particulates and nitrogen oxides probably due to bushfires with all other standard parameters well below national criteria.

Table 4.1 EPA air quality monitoring data collected at Macarthur in 2007 ($\mu\text{g}/\text{m}^3$)

	NO ₂		PM ₁₀		SO ₂			CO	
	1 hr	Monthly Average	24 hr	Monthly Average	1 hr	24 hr	Monthly Average	1 hr	8 hr
Maximum	97	64	52	47	43	11	9	2400	2300
Annual Average		48		30			7		
EPA Criteria	246	62	50	30	570	228	60	30000	10000
Days of exceedances	0	0	1	0	0	0	0	0	0

The activities that would be undertaken as part of this Project have the potential to lead to a number of potential impacts on air quality. These potential impacts have been assessed in this investigation. The main pollutants of potential concern are nitrogen oxides and particulates, both of which derive from combustion in diesel engines. Particulates also arise from earthworks. These pollutants have many other sources not related to this Project including petrol engines, bushfires, and other earthworks.

During construction, pollution sources include:

- Combustion emissions from mobile industrial equipment and vehicles (diesel engines);
- Dust generation from earthworks during construction of wells, gas gathering lines and access roads;
- Emissions of CSG from leakages during drilling of wells; and

- Odours if oxygenation of anoxic groundwater occurs.

During operations, the pollution sources include:

- Venting of gas during well commissioning;
- Combustion emissions from diesel or dual (gas/diesel) engines in mobile equipment and vehicles; and
- Dust generation from unsealed roads.

The assessment looked at these sources and the control measures to estimate the likely contribution of the Project to the regional air quality. There are standard approaches for estimating these emissions developed by the USEPA and other national and international sources which have been used in the assessment. A wide range of best practice control measures have been assumed to be in place at this development.

4.3 Potential for Impacts to Community

Developments must be assessed for their potential to cause significant changes to regional air quality. Such assessments are conducted in accordance with guidance from the NSW EPA which explains how to undertake the modelling required to estimate increases in pollutants in air from a variety of activities. Poor air quality contributes to impacts on people's health.

Australia has a National Environment Protection Measure for ambient air quality which includes a series of Goals for various pollutants designed for the adequate protection of human health and wellbeing. The criteria listed in the NSW EPA guidance are based on achieving the goals outlined in the National Environment Protection Measure.

A project is considered to not have significant air quality impacts if the emissions from the development contribute a small fraction to the regional air quality or if it remains below the National Goals.

4.4 Assessment of Impacts

4.4.1 Criteria Air Pollutants

During construction, the main potential impacts result from dust (including fine particulates PM₁₀) from earthworks and vehicle movements along access roads, and combustion emissions from other engines. Emissions from construction are not likely to be above national goals. A series of control measures are to be put in place for the development that to further control the potential emissions of these pollutants. These include:

- Minimising land clearing to the maximum extent practical;
- Remediate surfaces as soon as possible after disturbance;
- Use water carts and other measures to control dust directly at the source each day;
- Keep stockpiles and unsealed surfaces from generating dust with water sprays and other methods when needed;
- During high winds minimise/cease all dust generating activities and ensure dust control measures are adequate;
- Keep plant and equipment in good working order to minimise emissions;

- Keep traffic movements around the area to a minimum and control traffic well including reduced speed limits to minimise dust;
- Design well areas to ensure the minimum amount of vegetation is removed during construction;
- All welding done in accordance with relevant Australian Standards and guidelines;
- Ongoing communication with affected residents so they know when activities are likely; and
- Where required during well commissioning, flare gas instead of venting gas.

During production emissions are assessed to be even lower than those during construction and considered to be negligible.

It is noted that controls put in place during construction will be continued into the production phase including the traffic controls to minimise dust from unsealed surfaces, use of water carts and minimising any additional land clearing.

In relation to the potential operation of generators at the well locations, these emissions have been considered to be low to negligible in the Air Quality Impact Assessment and Greenhouse Gas Assessment in comparison to other combustion sources in the area. To further quantify how low these emissions are likely to be, a screening level assessment has been undertaken on the basis of the following:

- The generators likely to be utilised at the well locations are 30 kVA dual (gas/diesel) generators. These generators are not expected to be run on a continual basis, with the operating hours likely to be dependent on the location with the potential for noise generation of prime concern (which will limit operations particularly during the night-time).
- For a 30 kVA generator (i.e. 40 hp) potential (uncontrolled – i.e. without emission controls as would be required on current/new generators) emissions of criteria pollutants (in particular PM₁₀, CO, NO_x [assumed to be 100% NO₂] and SO_x [assumed to be 100% SO₂]) can be estimated on the basis of emission factors presented in Table 3.4-1 of the USEPA AP-42 document. The emission factors adopted from this reference are based on operation 24 hours per day for 365 days per year.
- The calculated emission rate has been modelled using the USEPA SCREEN model based on emissions from a point source (the generator exhaust) at 1.5 m height. The exhaust emission parameters have been adopted from published specifications for dual 30 kVA generators, namely the exhaust is 64 mm in diameter, the exhaust flow rate is 250 m³/min and at a temperature of 1270 °F. The model has been run to include all meteorological conditions including the worst-case dispersion conditions (that typically occur at night-time), rural, flat terrain.
- Ground level concentrations of the criteria pollutants have then been estimated (i.e. 1.5 m above the ground at breathing height) at a minimum distance of 50 m from the generator. This is the closest distance to any existing or potential future residential premises from each well location. These predicted concentrations, which are the worst-case/maximum 1 hour average air concentrations, have been compared with the NSW EPA air criteria (refer to **Table 4.1**).

Table 4.2 presents a summary of the calculated worst-case emission rate, worst-case down-wind concentration 50 m from the generator and comparison with the NSW EPA criteria.

Table 4.2 Screening Level Assessment of Generator Emissions

Pollutant	Emission Factor from AP-42 for dual generator (lb/hp-hr)	Estimated Worst-Case Emission Rate from AP-42 based on 40 hp dual generator (lb/hr)	Estimated Worst-Case Emission rate (g/s)	Modelled worst-Case/Maximum Air Concentration at 50 m Downwind ($\mu\text{g}/\text{m}^3$)	NSW EPA Guideline ($\mu\text{g}/\text{m}^3$)	Contribution of Worst-Case Emissions to Criteria
PM ₁₀	7.0E-04 ^a	0.03	0.0035	0.16	50 (24 hour)	0.3%
SO _x ^b	2.99E-04	0.01	0.0015	0.067	570 (1 hr)	0.01%
NO _x	0.018	0.72	0.091	4.0	246 (1 hr)	1.6%
CO	7.5E-03	0.30	0.038	1.7	30000 (1 hr)	0.006%

a = Based on emission factor for diesel generators as no factor is available for dual generators. It is assumed that the maximum 1 hour average occurs for 24-hours for the purpose of initial comparison against the guideline

b = It is assumed low sulfur fuel (0.5% in diesel and 0.01% in gas) is used. Assumed that the SO_x generated is 100% SO₂

c = VOCs are non-methane VOCs. Based on analysis of gas it is assumed this is primarily C8-C10 aliphatics and the guideline adopted is relevant to this fraction.

Based on the screening level assessment presented above even the worst-case emissions from a generator, under the worst-case atmospheric dispersion conditions would result in a negligible increase or contribution to the relevant air guidelines for criteria pollutants. On this basis the operation of generators at the well locations will have no significant or measureable impact on air quality at the closest residential areas.

4.4.2 Coal Seam Gas

Gas Composition

Another potential impact on air quality is leakage of the CSG, also termed fugitive emissions or uncontrolled emissions.

The gas found in the coal seams in Camden is quite clean with very little of the other potential components mixed in with the methane. Analysis of gas from existing CSG wells indicates that it is principally comprised of methane (approximately 90%) with lower levels of nitrogen (3-5%), oxygen (0.7-1.5%), carbon dioxide (2.6-3.2%) and argon (<1%, normally found in ambient air) and very low levels of ethane (<0.2%) and propane (<0.01%) (refer to 2 analytical reports from CSG from existing operations in **Appendix A**). No other chemicals were detected in CSG analysed from the area.

It is noted that the composition of gas received at the Rosalind Park Gas Plant (RPGP), in relation to the content of methane, ethane, propane, butanes, pentane, hydrocarbons C6+ (which would pick up trace hydrocarbons should they be present), carbon dioxide and other inert gases (as sum of nitrogen, carbon monoxide and carbon dioxide), is monitored continually by Jemena (the purchaser of gas from the plant). This data is continually reported as the composition of the gas is important as the purchaser of the gas has the ability to cease purchase if the gas composition drifts out of their pipeline specification. Data reported from the continuous monitoring is consistent with that reported in the laboratory reports and is within the purchasers specifications. A screen shot of the continuous monitoring system at the RPGP is included in **Appendix A**. This shows the parameters that are continuously monitored. In relation to trace hydrocarbon contaminants these are reported as hydrocarbons C6+. Review of the online monitoring of C6+ over the period 1 July to 23 September (included as a graph in **Appendix A**) has not reported any detection of these compounds.

The data collected from analysis of gas from the RGP is consistent with the typical composition of CSG (refer to **Table 4.3**). CSG is just another source of the natural gas that is used for cooking and heating in homes. Natural gas comprises gas from a range of sources, not just CSG and typically includes a range of other compounds. **Table 4.3** presents a summary of the typical composition of CSG and natural gas.

Table 4.3 Typical Composition of CSG and Natural Gas

Gas Composition (mol %)	CSG (mol %) (typical) ¹	Natural Gas (mol %) (typical) ¹	Natural Gas – (mol %) - Australia ²
Methane	95	83	88 to 96
Carbon dioxide	3	2.5	0.9 to 3.2
Nitrogen	2	1.5	0.5 to 1.2
Ethane	Trace	6.5	2.0 to 6.8
Propane	Absent	3.0	0.5 to 2.0
Butanes	Absent	1.5	0.03 to 0.8
Condensate (C5+)	Absent	0.5	NA
Hydrogen sulfide	Absent	1.5	NA

¹ Data provided in document: Unsworth N.J., LNG from http://www.fwc.com/publications/tech_papers/files/LNG%20from%20CSG.pdf

The above information suggests that if a supply of natural gas as supplied to homes in NSW were tested, as it is likely to comprise a mix of CSG and natural gas from other sources, a range of compounds would be expected to be present. Most of these compounds, however (such as propane and butanes) are derived from natural gas from other sources, not CSG. The assessment presented in this report has only focused on the composition of CSG, which is dominated by the presence of methane and low levels of only a few other components. These have been reported in the analytical reports provided in **Appendix A**.

Further more detailed analysis of the CSG found in Camden was undertaken on two samples collected from the RGP (where the gas sampled provide a measure of the average gas quality from the existing CSG extraction field). The samples were collected by AGL, one sample in the morning and one in the afternoon, using evacuated canisters and sent under chain of custody protocols to the National Measurement Institute (NMI) analytical laboratory for analysis using the USEPA TO-15 methodology. The laboratory reports are included in **Appendix A**. The analysis covers a wide range of volatile organic compounds including benzene, toluene, ethylbenzene and xylenes (BTEX) and total petroleum hydrocarbons (TPH) as aromatic and aliphatic fractions. **Table 4.4** presents the compounds that were detected in these samples.

Table 4.4 Detected Compounds in CSG Samples from RPGP

Detected Compounds	Sample 1 ($\mu\text{g}/\text{m}^3$)	Sample 2 ($\mu\text{g}/\text{m}^3$)
Acetone	not detected	180
Ethanol	550	510
Hexane	250	240
Cyclohexane	250	260
TPH C5-C6 aliphatic*	3420	3380
TPH >C8-C10 aliphatic*	40600	33000
TPH >C10-12 aliphatic	4770	4160

* TPH >C6-C8 aliphatic compounds were not detected in either of the samples analysed

It is noted that natural gas has been in use for many decades and the potential health effects and potential for explosion are well understood.

Potential for Fugitive Emissions to Occur

In relation to the potential fugitive emissions from the project PAE Holmes undertook a greenhouse gas assessment as part of the Environmental Assessment. This assessment looked at the loss to atmosphere of methane, nitrous oxide and carbon dioxide through all stages of this Project.

Fugitive emissions of methane from the wells being proposed were estimated to be approximately 0.1-1% in the PAE Holmes evaluation. This compares to 1.3% fugitive losses from the natural gas distribution system throughout the suburbs and into homes and through the pipeline from Camden, both of which have been operating for many years. The estimated losses in terms of tonnes of carbon dioxide equivalents per annum are 3-30 tonnes for fugitives from the wells in the Northern Expansion area, 522 tonnes for losses from the pipeline from Camden and 55 000 tonnes for losses in the distribution system across NSW. The losses from the wells are very small compared to the volume of gas delivered through the distribution system.

The Commonwealth Government provides guidance on estimating methane emissions from a variety of sources as part of determining the greenhouse gas emissions inventory for Australia. The guidance is detailed in the Technical Guidelines for the estimation of greenhouse gas emissions by facilities in Australia under the National Greenhouse and Energy Reporting System Measurement (NGER 2013). These guidelines were first established in 2008 and are updated each year as required. These guidelines indicate that fugitive losses from gas production and processing are assumed to be 0.12%. This emission factor has been in place since 2008.

Reviews of these methods and the information available to improve these methods have been undertaken by CSIRO (Day et al. 2012) and pitt&sherry (Saddler 2012).

Saddler (2012) found that there was little information available that was relevant for Australia and the most recent methodologies used in establishing wells. They noted that there is considerable guidance in the US but that most of it is based on measurements or investigations undertaken in the 1990s so may not be relevant for equipment used (or proposed to be used) now. The much higher use of shale gas rather than CSG also limits the relevance of this information for use in Australia. It was recommended that a study be undertaken in Australia to provide data on which to base the National Guidelines (Saddler 2012).

CSIRO (Day et al. 2012) also noted that the basis of much of the guidance on estimating fugitive emissions is a comprehensive study undertaken in the US in the early 1990s. This study showed that the fugitive emissions from the entire US gas industry were 1.4% - this would have included conventional gas as well as unconventional gas. Recent work in the US has been undertaken given the large changes that have taken place in the industry since the early 1990s. This study estimated emissions were of the order of 2% but this is for the US industry which comprises a high proportion of gas from shale, which is not used at all in Australia, and which is thought to have more potential for fugitive emissions. This report also recommends measurement be undertaken given that the US estimates are unlikely to be relevant for Australian conditions (Day et al. 2012).

One study has been undertaken in Australia to look at actual leaks from wellheads and associated equipment. The Qld Department of Employment, Economic Development and Innovation (DEEDI 2011) undertook a wellhead safety program in 2011 focusing on concentrations of methane in air at the aboveground equipment. The sampling methodology focused on concentrations of methane in air, not an evaluation of a fugitive emission release rate (as a percentage of the gas supplied). Hence while the data provides useful information it is not directly comparable to the fugitive release rates noted in the discussion above.

The DEEDI required all CSG operators in Queensland to test their wellheads and associated equipment for leaks of methane. In the study 2179 wells were tested and from those tested the following were identified (DEEDI 2011):

- 5 wells were found to have significant leaks resulting in more than 5% methane in the air around the wellhead. These wells had been installed for quite some time and were all repaired.
- 29 wells were found to have small leaks resulting in 0.5% to 5% methane in the immediate vicinity of the wellheads. These wells were also all repaired.
- Some of the remaining wells were found to have very small leaks resulting in between 0.0001% and 0.5% methane. For these wells the methane could be detected when the meter was held onto the wellhead but could not be detected when the meter was held 30 cm from the wellhead.
- The majority of the wells had no detectable methane at the limit of reporting for the meter (<0.0001%).

Most of the meters used for this investigation had a limit of reporting of 1 ppm or 0.0001% methane. A detection of 0.5% methane at the wellhead would reach non-detect levels by dilution into a box 10 m x 10 m x 10 m. A code of practice for leak detection at CSG wells was developed as a result of this work (http://mines.industry.qld.gov.au/assets/petroleum-pdf/code_practice_well_leak_class.pdf). This study indicates that only a small number of wells had significant leaks (about 1% of wells) and that they were readily repaired once identified.

This study found that leaks most commonly occurred from threaded connections on the wellhead and related equipment. Repairs involved re-tensioning these connections or adding sealing tape into these connections. Some wells were found to be leaking at ground level. These wells required a well workover to repair.

Hazards Associated with Methane

Methane is also produced by cows and sheep during their digestive processes, by volcanos, by rotting vegetation and in landfills from rotting food. It is also present in the sewage system. It is naturally present in the atmosphere at about 0.0002% (OSM 2001).

Hazards that are associated with the presence of methane in air relate to the potential to form explosive mixtures and the fact that methane is a simple asphyxiant. No other toxicity effects have been shown in relation to exposure to methane other than those derived from the displacement of oxygen and explosive potential (HSDB 2013 and UK HPA 2010).

When high levels of methane are present it can displace oxygen from the atmosphere which can cause symptoms of oxygen deprivation/asphyxiation that include the following:

- 12-16% oxygen – breathing and pulse rate elevated with slight loss of muscular coordination;
- 10-14% oxygen – emotional upsets, abnormal fatigue from exertion, disturbed respiration;
- 6-10% oxygen – nausea and vomiting, inability to move freely, collapse, possible loss of consciousness; and
- Below 6% oxygen – convulsive movements, gasping, possible respiratory collapse and death.

There is no data to suggest increased sensitivity for children or that exposure during pregnancy is likely to cause damage to the unborn child, however, if the mother is exposed to enough methane to have some asphyxiant effect this can also impact on the child (UK HPA 2010).

Methane is lighter than air having a specific gravity about half that of air. When methane is released it will rise away from the source. If released outdoors it would be easily diluted in the atmosphere due to both its specific gravity and the wind that is likely to be present. If such a release occurs indoors (inside a building or inside an equipment enclosure) it can accumulate to levels of concern (OSM 2001). The only buildings that would be sufficiently close are those that would house the well infrastructure. A residential home located at least 50 m from the well (source) would not be able to accumulate methane to a level of potential concern due to the amount of mixing/dispersion (particularly for a compound that is lighter than air) in the atmosphere between the well and the residential home.

There is a severe risk of fire and explosion if methane levels reach 5 to 15% (i.e. 50 000 to 150 000 ppm) and a source of ignition is present. In Australia the occupational guideline for methane is based on maintaining an atmosphere with sufficient oxygen to prevent asphyxiation (SafeWork Australia 2013). In the USA an 8 hour time weighted average value has been developed – 1 000 ppm (0.1%).

Screening Level Assessment of Fugitive Emissions

To further evaluate the potential for fugitive emissions from the wells to be of potential concern, a simple screening level assessment on all detected (as reported in existing CSG, refer to **Appendix A**) compounds in CSG (regardless of composition) has been undertaken to calculate a conservative concentration in air. The screening level air assessment has been undertaken on the basis of the following approach, and assumptions:

- Based on the Greenhouse Gas Assessment (PAE Holmes 2010) fugitive emissions from the wells have been estimated to be 7 tonnes as CO₂ equivalents per year from 11 proposed well locations, resulting in the release of 0.64 tonnes per year/well location.
- It is assumed that all of the fugitive losses occur at the same spot (i.e. 1 well) at each well location resulting in an emission rate of 0.020 g/s/well of CO₂ equivalents.
- An emission of 0.020 g/s of CSG (assumed to be equal to 100% of the CO₂ equivalents) has been modelled using USEPA SCREEN on the basis that it is a fugitive release, volume source, located 0.5 m above the ground (with 0.1 m initial lateral spread and 0.5 m initial vertical spread, flat terrain, rural dispersion, all stability classes and wind-speeds including those representing poor dispersion night-time conditions).
- From this screening level model, concentrations of CSG in air close to the well and 50 m downwind of the well location have been estimated. The location close to the well was selected to determine how comparable the estimated air concentrations are to those measured in Queensland (DEEDI 2011). The location 50 m from the well represents the closest residential receptor (current or at some point in the future).
- It has been assumed that the CSG reported as CO₂ equivalents are 100% equivalent to the individual components in the CSG. For methane this is conservative as methane is considered to be 23 times more potent than CO₂ hence 1% CO₂ equivalents is (1/23)% methane. It is also noted that the modelling undertaken does not account for the buoyancy of CSG (being lighter than air) and hence the down-wind predicted air concentrations are conservative.
- Based on the modelled downwind concentration of CSG (as a total), the concentration of individual compounds detected in CSG have been calculated on the basis of their proportion of the total gas. The predicted concentrations for total CSG and the individual compounds detected are presented in **Table 4.5**.

Table 4.5 Screening Level Review of Fugitive Emissions from Proposed Wells – Northern Expansion

Component of CSG (all compounds detected)	Composition from Analysis (%)**	Predicted Worst-case Downwind Air Concentration		Screening Level Guideline
		At well head (within 5 m)	50 m from well	
Total gas release as CO ₂ equivalents	100% - 0.026 g/s emission	22000 µg/m ³	1678 µg/m ³	NA
Methane	90%	19800 µg/m ³ or 0.003%	1510 µg/m ³ or 0.0002%	>0.5% in buildings ^V 5% explosive risk
Nitrogen	up to 5%	1100 µg/m ³ or 0.00006%	83.9 µg/m ³ or 0.000005%	NA - Negligible contribution to ambient levels
Oxygen	1.5%	330 µg/m ³ or 0.00003%	25 µg/m ³ or 0.000002%	Negligible contribution to ambient levels
Carbon dioxide	3.2%	704 µg/m ³ or 0.00004%	54 µg/m ³ or 0.000003%	0.5% in buildings ^V
Argon	<1%	<220 µg/m ³ or 0.00001%	<17 µg/m ³ or 0.000001%	NA - Negligible contribution to ambient levels
Ethane	<0.2%	<44 µg/m ³	<3.3 µg/m ³	NA – TLV = 1 230 000 µg/m ³ (ACGIH), HSDB does not report effects in the few studies available at higher levels of exposure. No public health guideline
Propane	<0.01%	<2.2 µg/m ³	<0.17 µg/m ³	NA – TLV = 1 800 000 µg/m ³ (ACGIH), HSDB lists no effects in other studies up to this level of exposure. No public health guideline available
Acetone	180 µg/m ³ 0.000008%	0.0018 µg/m ³	0.00013 µg/m ³	30000 µg/m ³ based on chronic public health guideline from ATSDR
Ethanol	550 µg/m ³ 0.00003%	0.0066 µg/m ³	0.00050 µg/m ³	100000 µg/m ³ based on chronic public health guideline from OEHHA
Hexane	250 µg/m ³ 0.000007%	0.0015 µg/m ³	0.00012 µg/m ³	700 µg/m ³ based on chronic public health guideline from USEPA*
Cyclohexane	260 µg/m ³ 0.000008%	0.0018 µg/m ³	0.00013 µg/m ³	6000 µg/m ³ based on chronic public health guideline from USEPA*
TPH C5-C6 aliphatics	3420 µg/m ³ 0.0001%	0.022 µg/m ³	0.0017 µg/m ³	18400 µg/m ³ based on chronic public health guideline from TPHCWG
TPH >C8-C10 aliphatics	40600 µg/m ³ 0.0008%	0.18 µg/m ³	0.013 µg/m ³	1000 µg/m ³ based on chronic public health guideline from TPHCWG
TPH >C10-C12 aliphatics	4770 µg/m ³ 0.00007%	0.015 µg/m ³	0.0012 µg/m ³	

Notes for Table 4.5

* chronic air guideline based on no adverse health effects associated with inhalation by the general public all day, every day for a lifetime. Values obtained from USEPA (IRIS), ATSDR, OEHHA (California) and the TPHCWG (1999).

** maximum from analyses presented in **Appendix A**. The concentrations reported in **Appendix A** have been converted to a % on the basis of the molecular weight of each compound using the units conversion calculator presented at <http://www.airtoxics.com/cclasses/unitcalc.html>

V - Guideline on buildings and structures from Victorian EPA Guidelines on Siting, design, operation and rehabilitation of landfills, Publication 788.1, September 2010.

M – Massachusetts Department of Environmental Protection Ambient Air Guidelines (24 hour average) available from: <http://www.mass.gov/eea/agencies/massdep/toxics/sources/air-guideline-values.html>

Review of the screening level assessment presented in **Table 4.5** indicates the following:

- Review of the methane level predicted at the well head, 0.003% is within the range measured at some of the well heads in Queensland (DEEDI 2011), however it is noted that at most of the wells where measurements were collected in Queensland methane was not detected, i.e. was <0.0001%. This suggests that the screening level assessment undertaken is predicting air concentrations that are consistent, but fairly conservative, with actual data collected from CSG operations in Queensland.
- Based on the screening level assessment the potential concentration of all detected compounds at the closest residential location, 50 m from the well location, are well below all available guidelines (or an insignificant contribution above ambient levels).
- Based on the screening level assessment the potential concentration of all detected compounds close to the well are below all available guidelines (or an insignificant contribution above ambient levels).
- Even if fugitive emissions were 10 to 1000 times higher than evaluated in the screening level assessment, all concentrations at the closest residential area would remain well below all available guidelines that are protective of health or other hazards (explosive hazards).

It is noted that the fugitive losses from the wells will occur outdoors which will mean there is a very low potential that levels could build up to levels that would exceed occupational guidance or cause a risk of explosion, as illustrated in **Table 4.5**. Any losses from the gas gathering lines would also be outdoors and be similarly dispersed such that no levels that were potentially explosive or that exceeded available guidelines could be present in the closest residential home.

The only scenario where methane gas could accumulate is if it accumulated inside the well head housing. Such enclosures are not sealed and presumably any fugitive losses would dissipate quickly.

4.5 Recommendations

The impacts of the Project on air quality in the surrounding area are estimated to be very small. It is recommended that the following best practice control measures be implemented during construction and operation of the Project to ensure this remains the case:

- Minimising land clearing to the maximum extent practical;
- Remediate surfaces as soon as possible after disturbance;
- Use water carts and other measures to control dust directly at the source each day;
- Keep stockpiles and unsealed surfaces from generating dust with water sprays and other methods when needed;

- During high winds minimise/cease all dust generating activities and ensure dust control measures are adequate;
- Keep plant and equipment in good working order to minimise emissions;
- Keep traffic movements around the area to a minimum and control traffic well including reduced speed limits to minimise dust;
- Design well areas to ensure the minimum amount of vegetation is removed during construction;
- All welding done in accordance with relevant Australian Standards and guidelines;
- Ongoing communication with affected residents so they know when activities are likely; and
- Where required during well commissioning, flare gas instead of venting gas.

In addition to the above, AGL will prepare a summary Leak Detection and Repair Summary Report and submit to the EPA as part of the EPL Annual Return.

Section 5. Assessment of Impacts – Noise

5.1 Introduction

A noise and vibration impact assessment was undertaken for the Project by Heggies Pty Ltd in-line with the Director-Generals requirements. This assessment is detailed in Appendix F of the EA and summarised in Section 13 of the Main Report. A revision of the assessment was undertaken by SLR Consulting Australia Pty Ltd (SLR Consulting) as part of the Submissions Report due to the change in well locations in response to the comments received.

5.2 Overview of Specialist Study

The assessment was conducted in line with regulatory guidance including the NSW Industrial Noise Policy, the Interim Construction Noise Guideline and the NSW Environmental Noise Control Manual.

A background monitoring survey was undertaken to determine the level of noise existing in the area. This survey involved both operator attended monitoring and unattended continuous monitoring. The survey found that the existing noise was typical of a suburban area. The noise was from traffic, birds, animals and domestic activities.

Table 5.1 Summary of Existing Ambient Noise Levels (dBA)

Location	Locality (Noise Amenity Area)	Period	Rating Background Level (RBL)
1a	Catherine Field (suburban)	Day	42
		Evening	45
		Night	36
1b	Catherine Field (suburban)	Day	49
		Evening	48
		Night	33
2	Leppington (suburban)	Day	45
		Evening	43
		Night	37
3	Leppington (suburban)	Day	35
		Evening	37
		Night	35
4	Raby/Kearns (suburban)	Day	33
		Evening	37
		Night	33
5	Currans Hill (suburban)	Day	35
		Evening	42
		Night	40

The potential increase in noise arising from the development was assessed during all stages of the development – construction of the wells, construction of the gas gathering systems and operations. It is possible that temperature inversions occur at times in the area so the assessment assumed temperature inversion conditions when assessing what sort of noise might arise from the development at night. This corresponds with worst case conditions.

Noise goals for the Project were developed in line with regulatory guidance and these goals have been used in interpreting the noise modelling and the development of the noise contour diagrams.

The NSW Industrial Noise Policy guides proponents in developing noise goals for industrial projects. The goals developed in accordance with this Policy cover both intrusive noise based on how much higher the noise from the development is above the background noise in an area and the local amenity based on land use.

The NSW Environmental Noise Control Manual identifies how to assess the potential for sleep disturbance from activities and this assessment has used this approach.

The NSW Construction Noise Policy sets out how to assess noise from construction activity. It is assumed that construction activity should only occur during the day Monday to Friday, during Saturday mornings and not at all on Sundays and public holidays. Such construction activity is usually short-term (over a few months) instead of being a permanent change in the noise environment in an area. The first goal is based on a noise level 10 dBA above existing ambient noise levels. The second level classifies a location as highly affected if noise is estimated to be above 75 dBA at the nearest houses or other receivers.

Considering all these different ways of estimating noise goals for the Project has resulted in noise goals ranging from 38 to 55 dBA depending on the location, the type of noise and the type of receiver.

5.3 Potential for Impacts to Community

Elevated noise has the potential to cause health effects in the local community if the noise from a development does not comply with regulatory guidance.

Guidance that outlines the potential health effects from excess noise include:

- World Health Organisation- Guidelines on Community Noise – Health effects of noise; and
- Environmental Health Council of Australia - The health effects of environmental noise – other than hearing loss.

These reviews are the major source of guidance on the relationship between health and noise. The criteria developed in this assessment for control of noise come from policy documents developed by the NSW Government including the NSW Industrial Noise Policy, the NSW Interim Construction Noise Policy, and the NSW Environmental Noise Control Manual. All of these policies consider the health effects of noise and use the WHO and enHealth reviews as a basis for setting the noise criteria.

The World Health Organisation recognises that there is sufficient evidence that noise causes impacts on health. Adverse effects for which the evidence of health impacts is strong/sufficient include:

- Sleep disturbance;
- Annoyance;
- Children's school performance (through effects on memory and concentration); and
- Cardiovascular health.

Other effects for which evidence of health impacts exists, but for which the evidence is weaker, include:

- increasing difficulty in understanding what others are saying;
- effects on mental health (usually in the form of exacerbation of issues for vulnerable populations rather than direct effects); and
- some evidence of indirect effects such as impacts on the immune system.

5.4 Assessment of Impacts

5.4.1 General

Noise modelling has been undertaken to determine noise levels at the ambient noise locations as well as surrounding each of the well locations. The modelling has been undertaken for the worst-case conditions identified for each phase of the project. The approach adopted in the noise assessment was to model noise impacts without mitigation (i.e. installation of noise barriers) and then, where noise impacts were identified, the assessment was revised to include noise barriers (that can lower noise impacts by 10 dBA). The modelling presented in the noise assessment has incorporated noise barriers where required at each of the well locations. **Figure 5.1** shows a noise barrier used to mitigate noise during construction activities.



Figure 5.1 Noise wall used during construction activities at previous sites

Noise impacts at all other times (outside of the worst-case conditions considered) will be less than that estimated in this assessment.

5.4.2 Impacts during Construction

Construction activities include ground surface (and access road) preparation and earthworks, construction of compound and drilling pads, drilling (and associated activities over 24 hours per day where required), installation and testing/commissioning of infrastructure. It is expected that at each of the well locations where there may be up to 6 wells the duration of construction works is expected to be approximately 150 days.

During construction works the worst-case conditions for noise impacts occurs at night-time during temperature inversions. Under these conditions noise impacts have been predicted at the ambient noise monitoring locations and in the vicinity of each well location.

Table 5.2 presents the predicted noise impacts at the ambient noise monitoring locations during construction at each of the proposed well locations. **Appendix B1** presents noise contours under the worst-case conditions at each of the well locations. These plots show contours relevant to various noise levels surrounding each of the well locations and the levels predicted (under worst-case conditions) at existing (and potentially future) residential homes. Where required these noise contours have incorporated noise barriers as noted on each of the contour plots provided.

Table 5.2 Predicted Noise Levels and Ambient Locations (dBA) during Construction

Receiver	Existing Night-time Background (RBL dBA)	Construction Night-time Noise Criteria	Construction (Drilling) at											
			CU10	CU14	CU06	CU02	CU22	CU26	CU29	CU31	RA03	RA09	VV03	
1a	36	38	<30	<30	<30	30	<30	<30	<30	<30	<30	<30	<30	<30
1b	33	38	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
2	37	40	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
3	35	42	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
4	33	38	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
5	40	40	<30	<30	31	<30	<30	<30	<30	<30	<30	<30	<30	<30

Review of the noise impacts predicted in areas close to each of the proposed well locations during construction has indicated the following:

- Noise during construction of all the wells is expected to be slightly higher than noise levels once the wells are in operation. At some of the wells temporary noise barriers have been considered to mitigate noise impacts.
- There may be short term elevated noise during the excavation and earth moving activities that are required for constructing the roads and the gas gathering systems. The pipes that are required for the gas gathering system must be buried which requires trench digging and backfilling. This work can only be conducted during the day and the elevated noise will only occurs for short periods.

5.4.3 Impacts during Operation

Operational activities include the operation of 6 wells at each location assuming the wells are pump assisted. This included noise that may be generated from pumps and generators that may operate 24 hours per day. For the assessment of worst-case noise impacts the well-heads were not

enclosed. It is proposed that following construction the well-heads (and associated pumps) would be enclosed which will result in lower noise impacts than presented in the noise assessment.

As the pump assisted wells were considered to operate 24 hours per day the worst-case conditions for noise impacts occurred at night-time during temperature inversions. Under these conditions noise impacts have been predicted at the ambient noise monitoring locations and in the vicinity of each well location.

Table 5.3 presents the predicted noise impacts at the ambient noise monitoring locations. **Appendix B2** presents noise contours under the worst-case conditions at each of the well locations. These plots show contours relevant to various noise levels surrounding each of the well locations and the levels predicted (under worst-case conditions) at existing (and potentially future) residential homes. Where required these noise contours have incorporated noise barriers as noted on each of the contour plots provided.

Table 5.3 Predicted Noise Levels and Ambient Locations (dBA) during Operations

Receiver	Existing Night-time Background (RBL dBA)	Operations Night-time Noise Criteria	Predicted Worst-Case Noise From Operations
1a	36	38	<30
1b	33	38	<30
2	37	40	<30
3	35	42	<30
4	33	38	<30
5	40	40	<30

In addition to the ongoing operation of the wells, workover activities associated with the maintenance of the wells will also occur. These activities only occur during the daytime and hence the worst-case conditions for the assessment of noise impacts during these activities is during calm meteorological conditions during the day. **Appendix B3** presents noise impact contours associated with these worst-case conditions during workover activities at each well location. These plots show contours relevant to various noise levels surrounding each of the well locations and the levels predicted (under worst-case conditions) at existing (and potentially future) residential homes. Where required these noise contours have incorporated noise barriers as noted on each of the contour plots provided.

Review of the noise impacts predicted in areas close to each of the proposed well locations during the operational phase of the project has indicated the following:

- All future operational noise would remain less than 5 dB above the background noise levels determined at the time of the assessment.
- Meeting these noise goals would be expected as a project approval condition, and is consistent with other existing project approvals for the Spring Farm area.
- Additional mitigation measures would be implemented by AGL, where required, to ensure that operational noise levels do not exceed project limits.
- The Noise Management Plan will address this, including a program of noise monitoring to ensure compliance.

5.4.4 Proposed Future Residential Developments

New developments in the Turner Road Development Area could increase the number of houses in the area near some of the wells. There is potential for elevated noise in this area if the developments proceed. If the developments go ahead a few additional noise control measures installed at the wells may be required to minimise noise at these new houses.

The additional assessment undertaken for the Submissions Report to check on noise impacts for the wells that were moved has shown that the noise impacts from the amended development will be lower than for the original design given that some of the wells closest to houses (or proposed development areas) have been removed from the Project while others have been moved from the originally proposed locations.

The noise contour plots presented in **Appendix B** enable review of worst-case noise impacts for both existing and proposed future residential developments. It is noted that review of new residential developments in the area, resulting in the more urbanised use of the area, will result in increased levels of ambient background noise levels (above those measured in the existing area that is currently predominantly rural). Hence review of impacts associated with new developments utilising the noise criteria established in this noise assessment report is a very conservative approach.

5.5 Recommendations

The Project is not expected to exceed noise control goals established by regulatory guidance.

The noise assessment assumed that a number of noise management measures will be instigated as part of the Project. This will ensure noise emissions from all aspects of the work will be acceptable. These measures include:

- Effective communication with people who live nearby and may be affected
- Communication with the local Council about proposed new developments to allow for proactive noise management;
- Maintaining all equipment in good order particularly those related to noise control like mufflers and sound enclosures;
- Locating equipment and plant carefully. This would include placing equipment and plant to maximise acoustic shielding through existing structures and terrain;
- Scheduling short term noisy work during times when people are least likely to be affected; and
- Establishing an effective complaints handling system.

Section 6. Assessment of Impacts – Vibration

6.1 Introduction

A noise and vibration impact assessment was undertaken for the Project by Heggies Pty Ltd in-line with the Director-Generals requirements. This assessment is detailed in Appendix F of the EA and summarised in Section 13 of the Main Report. A revision of the assessment was undertaken as part of the Submissions Report due to the change in well locations in response to the comments received.

6.2 Overview of Specialist Study

Guidance about how to assess the potential for vibration from a project is available from a number of sources. The NSW Dam Safety Committee has set vibration limits near dams and other relevant structures – *DSC33 Mining in Notification Areas of Prescribed Dams*. The German Standard DIN4150-3:1999 *Structural Vibration Part 3: Effects of Vibrations in Structures* outlines guideline values for evaluating the effects of vibration on structures. The NSW Government also has guidance on vibration assessment – DECCW’s *Assessing Vibration: a technical guidance*. This guidance has been based on the British Standard BS6472-1992 which guides assessment of vibration in terms of impacts on human comfort.

The assessment has used the relevant sections of each of these guidance documents.

6.3 Potential for Impacts to Community

Vibration can be strong enough to cause damage to structures like houses or the Upper Canal which has been identified as a potentially fragile heritage structure. People are also very sensitive to vibration and can be disturbed at vibration levels lower than those that might damage structures.

The German DIN standard recommends the guideline values listed in **Table 6.1**.

Table 6.1 Guideline Values for vibration velocity for evaluating short-term vibration on structures

Type of Structure	Guideline Values for Velocity (mm/s)		
	1 to 10 Hz	10 to 50 Hz	50 to 100 Hz
Buildings used for commercial purposes, industrial buildings and similar	20	20 to 40	40 to 50
Dwellings and buildings of similar design and occupancy	5	5 to 15	15 to 20
Structures that are particularly sensitive to vibration (e.g. Heritage listed)	3	3 to 8	8 to 10

6.4 Assessment of Impacts

The assessment determined that the goal to be achieved by the Project to protect the Upper Canal should be a vibration velocity level no greater than 3 mm/sec based on the German guidance. For residential areas the DECCW guidance indicates that the vibration velocity (termed V_{rms}) at the houses should not exceed 0.4 mm/sec and 12 mm/sec for impulsive vibration (e.g. dropping heavy equipment).

The various construction equipment to be used in the Project have vibration velocities of 0.1-0.2 mm/sec at 10 m.

When constructing a trench near the Upper Canal it is estimated that the maximum vibration velocity in the area will be 0.3 mm/sec when digging 3 m from the Canal which is 10 times lower than the guideline value outlined above. It is possible that under boring will occur in the vicinity of the Upper Canal. If it is proposed that such work will occur, a more site-specific assessment will be undertaken. Vibration trigger levels have been determined for work in this area which will indicate when works should cease until the cause of the vibration is determined.

Residential and commercial receivers in the area of the Project are unlikely to be affected by vibration for this equipment. The equipment to be used at the Project is already below the goal for the Project at 10m from where the equipment is being used. The receivers are much further than 10m from the works areas so vibration velocities will be below the goal at houses.

Once the wells are drilled and in operation there is very little equipment that causes vibration. Consequently, it is expected that once the Project is in the operational phase will easily meet the vibration goals for the Project.

6.5 Recommendations

During works near the Upper Canal the trigger levels developed for the Project should be used to manage the works to ensure no vibration based damage to this sensitive structure. Otherwise, no further work to manage potential vibration impacts is required for the Project.

Section 7. Assessment of Impacts – Groundwater

7.1 Introduction

Groundwater impacts associated with the Project are presented in Section 12 of EA (AECOM 2010) with additional information available in the Submissions Report (AECOM 2012) including additional information provided in the following specialist reports (attached to the Submissions Report):

- Phase 1 Groundwater Assessment and Conceptual Hydrogeological Model, Northern Expansion of Camden Gas Project (Appendix B AECOM 2012); and
- Update on the Camden North Phase 2 Groundwater Program (Appendix C AECOM 2012).

The information provided in these reports has been reviewed to determine the key issues that may require further evaluation within this report. Any additional information used in the assessment of these impacts has been referenced in this section.

7.2 Overview of Specialist Study

The specialist studies have presented information relating to the existing groundwater systems and conceptual hydrogeological model of the area (as summarised in **Section 2.5**).

Activities which are likely to encounter groundwater and potentially alter the hydrogeological regime in the vicinity of the Project Area comprise:

- Installation and operation of the gas production wells;
- Hydraulic fracturing (if required) within the coal seams; and
- Subsurface drilling of horizontal well paths and extraction of methane and associated groundwater from the coal seam.

The EA has concluded that adverse impacts to the beneficial aquifers as a result of these activities are not considered likely. Past experience (within the existing operations) has shown that the standard procedures used for the construction of CSG wells mitigate the potential of negative impacts occurring.

However, the assessment conducted has further considered these potential impacts to ensure appropriate management and mitigation measures are put in place to further minimise the likelihood of their occurrence.

Impacts with the potential to result from the above activities include:

- Increased permeability and subsequent flow rate locally within the coal measures water bearing zones (restricted to a less than 50m radius around each gas well);
- Dewatering and depressurisation of the coal measures water bearing zones; and
- Changes in groundwater quality within the coal measures water bearing zones.

These impacts, and the potential for these to adversely impact on the health of the local community, are discussed in the following section.

7.3 Potential for Impacts to Community

7.3.1 Increased Aquifer Permeability and Flow Rate

The water bearing zones within the coal measures will have increased (local) permeability as a result of hydraulic fracturing (if required) and subsurface drilling activities, which would subsequently result in increased (lateral) groundwater flow rates within the coal seams, within close proximity of the CSG wells.

Technical review and modelling of fracture lengths in existing production wells within the Project Area indicate an average fracture length of approximately 50 metres. Fracture heights are generally confined to the coal seam due to the large stress contrast between the coal and interburden.

Hydraulic fracturing (if required) would be conducted at depths below ground level of approximately 700 metres within the targeted coal measures.

Subsurface drilling for the purposes of the Project involves the continued penetration of the underlying geology where the drilling deviates from a central point on the surface and continues along a subsurface horizontal path some distance from its origin (refer **Section 2.6.3**).

Subsurface drilling will be conducted from a point of origin, being each well surface location, and follow a horizontal in-seam well path for up to 2,500 m.

All of these impacts relate specifically to the target coal seam which is located at 700 m depth. This is not a beneficial use aquifer and hence these impacts (while they are important for the extraction of gas from the coal seam) are not relevant to the assessment of impacts to human health or the environment.

7.3.2 Depressurisation and Dewatering

Extraction of CSG and associated groundwater in the deeper Illawarra Coal Measures will lead to depressurisation of the coal seam water bearing zones at depth for the duration of the gas extraction operations. As the number of operational wells increase there will be an initial increase in the volume of groundwater extracted, however, these volumes will quickly decline as the water in the coal seams is removed

Of key relevance to understanding whether this may adversely affect the shallow groundwater resources, and surface water, is the degree to which the Illawarra Coal Measures are in vertical connection with overlying aquifer zones within the Narrabeen Group, Hawkesbury Sandstone and thin alluvial deposits (which are the beneficial use aquifers in the regional area, although no alluvial aquifers exist within the Project area, refer to **Section 2.5**).

While there are no specific monitoring, controlled flow tests or test pumping data that demonstrates this degree of vertical connection or disconnection, inferences can be drawn from studies conducted elsewhere in the southern Sydney Basin, including impacts from long wall coal mining (Merrick, 2009) and nearby groundwater resource investigations (KBR 2008; PB 2008; SCA 2005b).

Based on these previous studies, it is concluded that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Permian coal measures in the area will protect shallower aquifers in the Triassic sandstones and above. These very low permeability layers

(refer to **Table 2.2** for their hydrogeological properties) will impede the vertical flow of groundwater such that overlying aquifer zones will be hydraulically isolated, experiencing little, if any drawdown impact related to depressurisation of the coal measures.

It is noted that where extraction of methane and groundwater from the 105 operating CSG wells has already resulted in dewatering of the targeted coal seams in some areas, these operations have demonstrated isolation of these water bearing zones from the much shallower sandstone aquifers as there have been no recorded impacts on private water supply bores. Currently more than 73 of the 105 operational wells produce very little or no groundwater.

7.3.3 Fracture Issues

Reservoir stimulation is critically important for economically recovering CSG in most operations and hydraulic fracturing is widely considered the base level stimulation technology as it is widely applicable to a range of coal seam conditions. Fracture geometry is important in determining the effectiveness of gas recovery. Coal contains numerous fractures known as cleats, but these fractures, which give the blocky nature to coal, may not individually extend vertically or laterally over large distances. Consequently, it is essential to create and maintain open fractures which widely transect these inherent cracks in the coal to promote the transport of fluids from the coal reservoir. The propagation and orientation of these fractures is controlled by:

- the orientation of the major fracture system in the coal; and
- the orientation of the horizontal stress field existing in the coal.

Evidence is that confining of hydraulic fractures to the coal seam and minimising penetration into the roof and floor of the seam depends very largely on the in-situ stress contrast between the coal and the bounding rock layers, and rock mechanics.

The Camden Gas Project has been subjected to drilling and geotechnical studies over many years for coal exploration and coal mining, while CSG exploration has been active since the mid-1990s and CSG extraction has been active since 2001. These geotechnical studies indicate that fractures in the Bulli Coal Seam would have a propensity to be vertical and or T-shaped fractures with good containment given the stress contrast that exists between the coal and the bounding shale and sandstone layers.

Further to the available geotechnical information, AGL conducted post fracture analysis with CSIRO to confirm post fracture geometry within the target coal seam to support these findings. The following is taken from the CSIRO report (Jeffrey, 2011).

- Significant height growth of fractures is unlikely in the Illawarra Coal Measures because the coals contain horizontal minimum stresses that are less than the vertical stress while the overlying rocks appear to contain horizontal minimum stresses equal to or greater than the vertical stress. Thus there is a stress barrier above the Bulli Coal Measure.
- Height growth into the roof above the Bulli Coal Measure would likely result in the fracture orienting to become horizontal either because the minimum horizontal stress magnitude in the rock is higher than the vertical stress magnitude or because these two stresses are about equal and any horizontal weakness (bedding plane etc.) will act to offset and slow vertical fracture growth or divert the fracture into a bedding interface or other weakness.

- Treating pressures experienced are high and instantaneous shut-in pressures (ISIPs) are consistent with T-shaped fracture growth or X-shaped fracture growth in the seam.
- Closure pressures, when they can be picked, are consistent with a horizontal fracture which, again, is consistent with T-shaped growth. However, analysis of closure pressure by itself cannot rule out vertical fracture growth if the minimum horizontal stress in the overlying rock is consistently less than the vertical stress magnitude.
- Fractures initiated in seams below the Bulli Coal Measure are unlikely to grow very far vertically upward because they have stiffer and more highly stressed rock layers and other coal seams above them.

It is important that hydraulic fracturing operations be conducted remotely from known cross cutting features such as faults and volcanic intrusions. Not only may the potential for methane CSG be diminished and/or be contaminated with other gases such as CO₂ in these locations, such cross cutting features could, in some circumstances, potentially act as conduits for fractures and hydraulic fracturing fluids to penetrate into surrounding rock units. These issues are addressed by AGL through undertaking seismic surveys to identify such cross cutting features and ensure CSG wells are located to avoid them. Further to this, the nature of stress fields within the CGP are such that the forces upon the fault act to seal them, further reducing the risk of any fluid migration

On the basis of the available information there seems a very low probability that, if carefully engineered and managed, hydraulic fracturing operations would produce fractures which would penetrate and significantly affect the strata both immediately above and below the coal seams. Hence the possibility of fractures from these activities affecting the more shallow beneficial use aquifers in strata such as the Hawkesbury Sandstone is negligible.

7.3.4 Existing Groundwater Quality in Aquifers above Coal Measures

An initial Phase 2 groundwater investigation was undertaken in 2011/12 to support the conceptual model presented in the Phase 1 report (Appendices B and C AECOM 2012). An enhanced monitoring program, commencing in 2013, will add to the number of dedicated water monitoring bores. The initial investigation included monitoring water levels in 3 groundwater monitoring bores installed at Raby (Denham Court). In addition water quality was assessed in these bores and in surface water from 2 local farm dams in the area. The investigation found that:

- Groundwater quality in all aquifers and water bearing zones is poor and of limited beneficial use mostly due to its salinity;
- Yields are low in all aquifers and generally do not constitute useful water supply sources;
- Water levels are deep, and the age of the water is 30,000+ years within the Hawkesbury Sandstone, and there is no apparent interaction with the surface environment;
- Groundwater quality in the Hawkesbury Sandstone is very different to the surface water quality in nearby farm dams indicating farm dams are not groundwater fed (refer to **Table 7.1** that summarises key water quality data from 2 groundwater bores, RMB02 and RMB03, and 2 local farm dams, SW1 and SW2); and
- No major fractures or faulting appear to be present.

Table 7.1 Summary of Groundwater and Farm Dam Water Quality (sampled October and November 2011, refer to PB 2012 for full table of data)

Parameters	Units	ANZECC 2000 guidelines	Groundwater Wells		Surface Water from Local Farm Dams	
			RMB02	RMB03	SW1	SW2
Field water quality parameters						
EC	µS/cm	125-2200	9517	5713	182	151
pH	pH units	6-8	6.52	7.42	7.78	8.93
Temperature	0C	-	27.55	na	24.82	25.02
Dissolved oxygen	%sat	80-110*	5.8	5.6	111.6	112.5
Redox	mV	-	-10	-136	-5.8	-71.4
Laboratory water quality parameters						
Major	ions					
Calcium	mg/L	-	121	385	9	5
Magnesium	mg/L	-	40	95	6	5
Sodium	mg/L	-	1580	2090	27	17
Potassium	mg/L	-	25	35	2	9
Chloride	mg/L	-	2350	3980	20	18
Sulfate	mg/L	-	39	86	2	2
Total alkalinity as CaCO ₃	mg/L	-	606	743	72	47

7.3.5 Potential for Impacts and Contamination During Drilling, Hydraulic Fracturing and Maintenance Activities

Drilling and Well Installation

Drilling CSG wells is completed using an overbalanced mud drilling system. That is, there is a higher head of water and drill fluids in the wellbore (i.e. a higher pressure) compared to the piezometric heads in the different formations. Using this technique there is no potential for natural groundwater systems (at any depth) to leak into the well while it is drilled and constructed.

The natural formations are also low permeability (refer to **Table 2.2**) so there is minimal potential for drilling fluids to migrate into the natural formations. Typically, the well is drilled and held open against the beneficial aquifers for only 1-2 days prior to the surface casing being installed and pressure cemented in place, prior to drilling deeper. Typically, surface casing in existing wells is installed to around 120-140m below the surface for safety and environmental purposes. At no point in time is the well bore open to both the beneficial aquifers and deeper water bearing zones (i.e. the coal seams).

CSG wells in NSW require the isolation of water resource aquifers from hydrocarbon bearing zones. All gas production wells have been or will be completed with multiple casings and pressure cemented (with cement manufactured to API specifications) in place to ensure that aquifers remain isolated (refer to **Section 2.6.3** and **Figure 2.4**). A cement bond log will be run downhole to provide a representation of the integrity of the cement job.

Cementing operations in CSG wells are a critical application which must be designed properly to restrict fluid movement between the formations (zonal isolation) and to bond and support the casing. The integrity of the well cement and casing as well as the naturally occurring hydraulic separation of

the shallow beneficial aquifers from the Permian Illawarra Coal Measures by the confining layers prevents potential migration paths of the groundwater from the target coal seams through to beneficial aquifers, wells, bores, springs (if present), and watercourses.

On this basis there is no mechanism by which the target coal seam water bearing zones and the shallow beneficial use aquifers can be interconnected during drilling or well construction.

For the purpose of this assessment, however, a scenario where a pathway did exist between the coal seam and the shallow beneficial aquifer has been assumed to be present. The potential impact of the migration of water from the coal seam into a shallow beneficial aquifer has been assessed in the following section.

Potential for Well Failure

The potential for well failure and potential consequences have been evaluated in the Preliminary Hazard Analysis, PHA (Planager 2010). Wells may fail for a range of reasons that include:

1. Corrosion
2. Construction defect/material failure
3. Equipment being backed into the wellhead or pipeline and breaking the well or pipeline (minimised by limiting access and installing wells at distance from railways or roads)
4. Earthquake
5. Subsidence due to other mining in the area
6. Vandalism

If a well fails this may result in major, intermediate or minor leaks of either the wells or the gas gathering system.

The range of failure rates for each different type of equipment, and probabilities for human error (when conducting inspections and routine maintenance) have been identified and evaluated in the PHA (Planager 2010) to determine the risk of fatality close to a location with 6 well heads in early and established operations.

For such a fatality to occur the well head or pipeline must fail and the escaping gas must be ignited to cause a jet fire, a flash fire or explosion of a vapour cloud.

At 20 m from the well heads the risk of fatality per year is less than 1×10^{-6} during early operations which is in compliance with the NSW Planning guidelines. For established operations the risk of fatality decreases to 1×10^{-7} per year which is also in compliance with the NSW Planning guidelines.

To manage and minimise the potential for well failure, AGL will remotely monitor all wells on a continuous 24/7 basis via the SCADA system. AGL will also inspect each well a minimum of once per week in accordance with best industry practice. Leak testing will also be undertaken on at least a 12 monthly basis, and more often if the well or pipeline is close to residential areas. In the unlikely event that a well failure occurred, AGL would immediately respond in accordance with the Project's Emergency Response Plan.

Storage and Use of Fluids

Operations at the well pad require the use of a number of different fluids (for drilling, hydraulic fracturing and workover activities) as well as the extraction of these fluids from the well, along with extraction of groundwater from the target coal seam.

The use of drilling additives during the installation of production wells, and hydraulic fracturing fluids has the potential to result in a short term impact to shallow groundwater if not managed correctly. More specifically, this relates to leaks and spills of these fluids at the ground surface, and subsequent migration into the shallowest aquifer (which is located in the underlying shales).

In addition the temporary storage of produced water (which is formation groundwater from the target coal seams after all drilling and fracture fluids are removed) at the surface has the potential to impact shallow groundwater if not managed correctly such that there is an uncontrolled water spill.

The potential (or likelihood) for such events to occur, however is considered to be very low due to the implementation of the following management/mitigation measures at each well location:

- The well pads are typically constructed within a bund that has the capacity to contain spills (and rainfall) up to 750 kL (AECOM 2010). All activities where fluids are handled (during drilling, hydraulic fracturing and workover activities) are undertaken within the bunded area.
- No chemicals used in drilling, hydraulic fracturing or workovers are stored at the well pad. They are only present during the conduct of these specific site-related activities and hence if a spill occurred personnel are on-site to immediately contain and clean-up any spills that do occur. A spill kit is present at each well pad and a Pollution Incident Response Management Plan (PIRMP) plan is available that addresses measures required to effectively manage and cleanup the spill.
- Produced water is collected in covered storage tanks. Stored water is either reused for subsequent well development or would be disposed of to an appropriately licensed offsite facility (for treatment and recycling). The use of storage tanks minimises the potential for leakage of water into the underlying soil and shallow aquifers.
- The integrity of drill pits and storage tanks will be monitored regularly to minimise the likelihood of leakage into the underlying soil and shallow aquifers.
- Water levels within lined pits or storage tanks will also be monitored to ensure overflow does not occur, thereby reducing the likelihood of produced water contributing to surface runoff.
- Appropriate mitigation and contingency measures will be in place and will be detailed in the Storm Water Management Sub Plan (SWMSP) which will be updated regularly with respect to the Northern Expansion Project.

The potential for spills at the ground surface, during drilling, hydraulic fracturing or workover activities, to occur outside the bund and not be identified or remediated is very low. In addition, the volume of fluid likely to be released would not be sufficient to penetrate into the ground to reach the shallowest (Hawkesbury Sandstone) groundwater aquifer. Many of the chemicals that are used biodegrade, sorb to soil (and are no longer mobile) or dissociate to ions naturally present in the soil. The only mechanism by which a spill may migrate to groundwater is if perched groundwater is present at the location of the spill and migration to deeper groundwater is facilitated by a significant rainfall event. Significant rainfall would also result in significant levels of dilution prior to the spilled water reaching the groundwater and then further dilution within the groundwater. This scenario is

not a continuous release scenario (only occurs once) and hence any such release would be effectively diluted. Hence the mechanism of groundwater contamination relevant to this scenario (a spill outside the bunded area) is not considered to be realistic or complete and it has not been further assessed.

While still considered unlikely to occur, there is the potential for tanks that remain at the well pad for the purpose of collecting production water to have a leak that would not be detected until the tanks were inspected. In the event that the leak was slow, such a leak may not be detected for a period of time. This may result in produced water leaking from the well pad (assuming it leaks outside of the bunding) into the ground surface over a longer period of time, where sufficient volume may leak to result in infiltration to perched groundwater (if present). This scenario has been further evaluated in the following section.

7.4 Further Assessment of Impacts

7.4.1 General

As outlined above, two scenarios have been further evaluated in relation to potential impacts to shallow groundwater:

- Scenario 1: Leaks of produced water stored at well pads; and
- Scenario 2: A hypothetical connection between the target coal seam and shallow beneficial use aquifer.

7.4.2 Scenario 1 – Leaks of Produced Water at Well Pad

This scenario addresses the situation where water tanks stored on the well pad leak (slowly) and produced water migrates to and impacts shallow groundwater.

It is noted that there is no alluvial aquifer present within the Surface and Subsurface Project Area. The water table, representing the most shallow aquifer/water bearing zone (as reported within the Raby site) is approximately 75 m below ground level (PB 2012). Any spills of produced water at the ground surface will not migrate 75 m to this aquifer and hence there are no mechanisms by which the shallow aquifer may be impacted.

However there is the potential for the presence of perched groundwater in some areas of the Surface and Subsurface Project Area (not identified from current investigations) and hence for the purpose of this assessment, a worst-case scenario of a surface spill occurring in the vicinity of local perched groundwater has been considered. The presence of perched groundwater could be assumed to be present approximately 10 m below ground level, within the Wianamatta Group (consistent with observations of water seepage during drilling works to the north-east of the Project Area (PB 2012)). Water quality within the upper weathered clays of the Wianamatta Group is noted to be typically brackish to saline with a very low yield (<0.2 L/s). Hence, while beneficial uses of perched groundwater have been considered, it is considered highly unlikely that any groundwater within such perched groundwater would be a viable source of water for extraction and use for any purpose.

Review of Produced Water Quality

As the nature of the target coal seam is the same, as is the overall geology of the area, produced water quality for the Northern Expansion Project is assumed to be the same as that currently reported from the existing operations. Produced water from existing operations is analysed by AGL to determine whether the water can be re-used or if it needs to be disposed (where it meets the required water quality) as well as to monitor there are no significant changes within the formation water at depth. Available data from these operations has been provided for the purpose of this assessment.

The reported quality of produced water reflects any remaining chemicals that may have been used in the installation, commissioning and maintenance of the CSG well, as well as naturally occurring compounds (including those that may have been made more mobile during drilling and hydraulic fracturing) within the target coal seam aquifer. Parameters relevant to the presence of inorganic and organic chemicals as well as total dissolved solids (indicator for salinity) have been reviewed.

Table 7.2 presents a summary of the range of concentrations (minimum and maximum) reported in produced water from existing operations. While the shallow groundwater is not used as a drinking water source (due to natural elevated salinity and poor yield, refer to **Section 2.5**) the reported concentrations have been initially compared against drinking water guidelines available from the following sources (in order of preference):

- Australian Drinking Water Guidelines (NHMRC 2011);
- WHO Guidelines for Drinking Water Quality (WHO 2011);
- USEPA Regional Screening Levels (RSLs) for residential tap water (USEPA 2012); and
- USEPA Lifetime Health Advisory Goals (current to 2012, considered for chemicals where no drinking water guideline has been established).

Chemicals where the maximum concentration reported in produced water has been further evaluated in relation to potential impacts associated with migration to groundwater are shaded in the **Table 7.2**. The chemicals where the maximum concentration is below the drinking water guideline have not been further assessed as they are already present in the produced water at a concentration that is below the guideline, and need no further consideration of how the concentration may change due to migration to and within the groundwater aquifer prior to extraction and use. It should be emphasised, however, that, like the shallow aquifers in the area, the water bearing zones within the coal seams are not considered drinking water aquifers.

Table 7.2 Preliminary Review of Chemicals Detected in Produced Water (existing operations)

Analyte grouping/Analyte	Units	Range of Concentrations in Produced Water		Drinking Water Guideline			Comments
		Minimum	Maximum	Health Based	Aesthetic	Reference	
Total Dissolved Solids (Calc.)	mg/L	5320	23500	--	600	NHMRC 2011	Salinity of produced water not suitable for drinking water
Sulfate as SO ₄ ²⁻ Turbidimetric	mg/L	1	202	500	250	WHO 2011	
Chloride	mg/L	93	1310	--	250	NHMRC 2011	Common in groundwater and certain catchments (from natural mineral salts)
Metals and Inorganics							
Aluminium	mg/L	<0.01	0.07	16	0.2	USEPA 2012a, NHMRC 2011	NHMRC guideline relevant to aesthetics only
Arsenic	mg/L	<0.001	0.113	0.01	--	NHMRC 2011	
Boron	mg/L	<0.05	0.26	4	--	NHMRC 2011	
Strontium	mg/L	0.151	10.2	9.3	--	USEPA 2012a	
Barium	mg/L	0.448	35.5	2	--	NHMRC 2011	
Beryllium	mg/L	<0.001	<0.001	0.06	--	NHMRC 2011	
Cadmium	mg/L	<0.0001	0.0003	0.002	--	NHMRC 2011	
Cobalt	mg/L	<0.001	0.001	0.0047	--	USEPA 2012a	
Uranium	mg/L	<0.001	0.002	0.017	--	NHMRC 2011	
Chromium	mg/L	<0.005	0.012	0.05	--	NHMRC 2011	Guideline based on chromium VI
Copper	mg/L	<0.001	0.025	2	1	NHMRC 2011	
Manganese	mg/L	<0.001	0.133	0.5	0.1	NHMRC 2011	
Molybdenum	mg/L	<0.001	0.138	0.05	--	NHMRC 2011	
Nickel	mg/L	<0.001	0.024	0.02	--	NHMRC 2011	
Lead	mg/L	<0.001	0.026	0.01	--	NHMRC 2011	
Selenium	mg/L	<0.01	0.01	0.01	--	NHMRC 2011	
Vanadium	mg/L	<0.01	<0.01	0.078	--	USEPA 2012a	
Zinc	mg/L	<0.005	0.074	4.7	3	USEPA 2012a, NHMRC 2011	NHMRC guideline relevant to aesthetics only
Iron	mg/L	<0.05	15.4	11	0.3	USEPA 2012, NHMRC 2011	NHMRC guideline relevant to aesthetics only
Bromine	mg/L	<0.1	5.7	2	--	WHO 2011	Lower value calculated for a young child for bromide
Iodine	mg/L	<0.1	0.8	0.16	0.15	USEPA 2012, NHMRC 2011	NHMRC guideline relevant to aesthetics only
Mercury	mg/L	<0.0001	<0.0001	0.001	--	NHMRC 2011	
Silica	mg/L	<0.1	40.7	--	80	NHMRC 2011	
Fluoride	mg/L	<0.1	3.9	1.5	--	NHMRC 2011	
Ammonia as N	mg/L	<0.01	11.3	30	0.5	USEPA 2012b and NHMRC 2011	Health based value is a lifetime health advisory derived by the USEPA (2012), NHMRC only presents a guideline based on aesthetics
Nitrite as N	mg/L	<0.01	0.42	3	--	NHMRC 2011	
Nitrate as N	mg/L	<0.01	0.19	50	--	NHMRC 2011	
C1 - C4 Hydrocarbon Gases							
Methane	µg/L	290	10500	10000	--	US	US Investigation level for methane in water (flammability/explosive risks, action level at 28000 µg/L). No guidelines are available for the rest of the C1-C4 gases and the hazards are equivalent to those identified for methane, hence this group has been assessed together (sum total) and compared with the methane investigation level
Ethene	µg/L	<10	<10				
Ethane	µg/L	16	16				
Propene	µg/L	<10	<10				
Propane	µg/L	<10	<10				
Butene	µg/L	<10	<10				
Butane	µg/L	<10	<10				

Analyte grouping/Analyte	Units	Range of Concentrations in Produced Water		Drinking Water Guideline			Comments
		Minimum	Maximum	Health Based	Aesthetic	Reference	
Phenolic Compounds							
Phenol	µg/L	1.5	1.5	4500	--	USEPA 2012a	
2-Methylphenol	µg/L	1.5	1.5	720	--	USEPA 2012a	
3- & 4-Methylphenol	µg/L	<2.0	<2.0	1100	--	USEPA 2012a	
2-Nitrophenol	µg/L	<1.0	<1.0	60	--	USEPA 2012b	
2,4-Dimethylphenol	µg/L	<1.0	<1.0	270	--	USEPA 2012a	
2,4-Dichlorophenol	µg/L	<1.0	<1.0	35	--	USEPA 2012a	
2,6-Dichlorophenol	µg/L	<1.0	<1.0	35	--		Guideline for 1,4-dichlorophenol adopted
4-Chloro-3-Methylphenol	µg/L	<1.0	<1.0	35	--		Guideline for 2,4-dichlorophenol adopted
2,4,6-Trichlorophenol	µg/L	<1.0	<1.0	9	--	USEPA 2012a	
2,4,5-Trichlorophenol	µg/L	<1.0	<1.0	890	--	USEPA 2012a	
Pentachlorophenol	µg/L	<2.0	<2.0	10	--	NHMRC 2011	
Polynuclear Aromatic Hydrocarbons							
Naphthalene	µg/L	<1.0	19.2	6.1	--	USEPA 2012a	
Acenaphthylene	µg/L	<1.0	<1.0	400	--		Guideline for acenaphthene adopted
Acenaphthene	µg/L	<1.0	<1.0	400	--	USEPA 2012a	
Fluorene	µg/L	<1.0	12.9	220	--	USEPA 2012a	
Phenanthrene	µg/L	<1.0	18.5	630	--		Guideline for fluoranthene adopted
Anthracene	µg/L	<1.0	<1.0	1300	--	USEPA 2012a	
Fluoranthene	µg/L	<1.0	<1.0	630	--	USEPA 2012a	
Pyrene	µg/L	<1.0	2.4	87	--	USEPA 2012a	
Benz(a)anthracene	µg/L	<1.0	<1.0	0.1	--	TEF	See Note 1
Chrysene	µg/L	<1.0	1	1	--	TEF	See Note 1
Benzo(b)fluoranthene	µg/L	<1.0	1.8	0.1	--	TEF	See Note 1
Benzo(k)fluoranthene	µg/L	<1.0	<1.0	0.1	--	TEF	See Note 1
Benzo(a)pyrene	µg/L	<0.5	1.1	0.01	--	NHMRC 2011	
Indeno(1,2,3-cd)pyrene	µg/L	<1.0	<1.0	0.1	--	TEF	See Note 1
Dibenz(a,h)anthracene	µg/L	<1.0	<1.0	0.01	--	TEF	See Note 1
Benzo(g,h,i)perylene	µg/L	<1.0	1.7	1	--	TEF	See Note 1
BTEX							
Benzene	µg/L	<1	10	1	--	NHMRC 2011	
Toluene	µg/L	<5	16	80	25	NHMRC 2011	
Ethylbenzene	µg/L	<2	5	300	3	NHMRC 2011	
Total Xylenes	µg/L	<4	46	600	20	NHMRC 2011	
Total Petroleum Hydrocarbons							
C6 - C9 Fraction	µg/L	20	80	90 to 15000	--	WHO 2011	
C10 - C14 Fraction	µg/L	60	21700	90 to 300	--	WHO 2011	
C15 - C28 Fraction	µg/L	180	38800	90	--	WHO 2011	
C29 - C36 Fraction	µg/L	130	17200	90	--	WHO 2011	

Note 1: TEF = toxicity equivalent factor adopted to derive the guideline based on the guideline adopted for benzo(a)pyrene. The TEF relates to carcinogenic PAHs and relates the toxicity of individual carcinogenic PAHs to the most well studied PAH, benzo(a)pyrene, using a factor (ranging from 1 to 0.01) as per (CCME 2010).

Based on **Table 7.2**, there are some compounds that are present in produced water at concentrations in excess of the relevant drinking water guideline. These have been further evaluated in relation to the potential concentrations that may be present in groundwater as a result of a prolonged (slow) leakage.

It is noted that there are have been a few detections of low concentrations of benzene, toluene, ethylbenzene and xylene (BTEX) in production water. BTEX is not used for any aspect of the process (drilling, hydraulic fracturing or maintenance), however a review of the nature of the target

coal seam by CSIRO (Volk et al. 2011) has identified the likely presence of low levels of BTEX in the target coal seam aquifer. The small number of low level detections reported from some existing wells is consistent with the presence of BTEX in the target coal seam aquifer.

Migration of Leakage to Shallow Groundwater

A prolonged leakage of water at the ground surface will infiltrate into the ground and eventually reach shallow groundwater (perched groundwater). The worst-case situation is when this occurs and there is no rainfall to dilute the leakage in the ground. This worst-case scenario has been assumed for the purpose of this assessment. In addition it is assumed that the compounds present in produced water remain soluble (i.e. do not sorb to the soil) and do not degrade or dissociate (i.e. remain unchanged).

Produced water will be held at the well pad in large (up to) 75 kL aboveground tanks or smaller 10 kL in-ground or above ground holding tanks. For this assessment it has been assumed that the 10 kL tank leaks its whole volume into the ground over a 1 month period (assumed maximum time between checks). If the leak is from the larger 75 kL tank, a leakage rate of 10 kL per month is considered sufficiently low that it may not be detected quickly. It is noted that once drilling (and hydraulic fracturing) activities are completed and the well is in steady state production, the average volume of water extracted per well typically ranges from ~0 to approximately 62 kL per year. Hence the leakage of 10 kL per month (which is a leakage flow rate of 0.00386 L/s) essentially assumes that all (or greater than) the annual volume of water produced at the well leaks into the ground.

The leakage from the tank is assumed to migrate directly down to perched groundwater (if present at the spill location) where it is assumed to mix with the perched groundwater (where present). Once it reaches the aquifer, the produced water is assumed to further mix within a distance of 50 m (minimum distance assumed from the well pad to a new bore that may be installed for the purpose of extraction and use of groundwater (assuming this is possible within the perched groundwater)), with an average groundwater mixing depth of 2 m and width of 5 m, resulting in a total plume volume for mixing of 500 m³. The perched groundwater is assumed to be present in the Wiannamatta clay/shale materials which has a low yield (groundwater flow rate) of <3 L/s (3 L/s adopted in calculations) and a total porosity of 0.15 (consistent with clay/shale materials). This results in the volume of groundwater within the plume volume being 75 m³ (i.e. 0.15 x 500 m³). The lateral flow rate of groundwater in this plume is 3 L/s.

To calculate a dilution factor from the above the following has been considered:

- For a unit volume of 1 m³ of the groundwater plume, seepage from the ground surface is assumed to be entering the volume (vertically) at a rate of 0.00386 L/s and groundwater is flowing (laterally) through this volume at a rate of 3 L/s. The seepage entering from the ground surface will be diluted in this volume as it simply mixes with the flowing groundwater. This has been calculated on the basis of the flow rates as $3/0.00386 = 777.6$.
- For a groundwater volume (within the plume between the point where the leak may occur and the closest point where groundwater may be extracted) of 75 m³, the total mixing will be $777.6 \times 75 = 58320$.

Based on these assumptions the calculated dilution factor has then been applied to the maximum concentrations of key chemicals identified in production water. The resultant concentration has then

been compared with the adopted drinking water guideline. The ratio of the estimated concentration at the point of extraction to the drinking water guideline has been calculated (termed a Hazard Index, HI). The calculated concentration in water at the point of extraction and the HI are presented in **Table 7.3**.

It is noted that the following calculations do not take into account natural levels of salinity and inorganics that are already present in the aquifer. The calculations are based solely on the additional impact of a prolonged slow leakage of production water.

Table 7.3 Calculated Concentrations and HIs in Extracted Groundwater Following Long-Term Leakage of Production Water from the Well Pad

Key Chemicals Identified in Production Water	Maximum Concentration in Production Fluid (at well pad) (mg/L)	Estimated Concentration in Aquifer at Point of Extraction (mg/L)	Drinking Water Guideline (mg/L)	HI
TDS	23500	0.40	600	0.00067
Arsenic	0.113	0.0000019	0.1	0.000019
Strontium	10.2	0.00017	9.3	0.000019
Barium	35.5	0.00061	2	0.00030
Nickel	0.024	0.00000041	0.02	0.000021
Lead	0.026	0.00000045	0.01	0.000045
Iron	15.4	0.00026	11	0.000024
Bromine	5.7	0.000098	2	0.000049
Iodine	0.8	0.000014	0.16	0.000086
Fluoride	3.9	0.000067	1.5	0.000045
Methane (and other C1-C4 gases)	10516	0.18	10000	0.000018
Naphthalene	0.0192	0.00000033	0.0061	0.000054
Benzo(a)pyrene	0.0011	0.000000019	0.00001	0.0019
Benzo(b)fluoranthene	0.0018	0.000000031	0.0001	0.00031
Benzo(g,h,i)perylene	0.0017	0.000000029	0.001	0.000029
Benzene	0.01	0.00000017	0.001	0.00017
TPH C10-C14	21.7	0.00037	0.09	0.0041
TPH C15-C28	38.8	0.00066	0.09	0.0074
TPH C29-C36	17.2	0.00029	0.09	0.0033

Based on the above table, the HI for all the key chemicals in production water are significantly below a target HI of 1 which would indicate that the concentration present at the point of extraction is lower than the drinking water guideline. The HI remains below 1 even if it is assumed that the whole contents of a 75 kL tank are released over 1 day.

Hence, even under the worst-case (highly unlikely) scenario of an undetected long-term leak of production water, in an area where there is perched groundwater that is of suitable quality and quantity to be extracted and used, impacts to groundwater quality is considered to be negligible.

7.4.3 Scenario 2 – Connection between Coal Seam and Shallow Groundwater

Overview of Issue

For this scenario to occur, there needs to be a connection between the target coal seam and a shallow beneficial aquifer, and subsequent mixing of this water within the aquifer and extraction and use of the water. This scenario is highly improbable for the following reasons:

- The target coal seams are located at a depth of approximately 700 m below ground level.
- Overlying the target coal seam are a number of claystone, sandstone and shale rock layers (refer to photographs in **Figure 7.1** that show these rock types) extending from 700 m depth to between ground surface and 20 m depth (refer to **Table 2.1**). Many of these layers of rock have very few connected pores that can hold water and as a result have a very low permeability (ability of the rock to allow water to flow through it). Some rock layers are more porous and permeable than others (e.g. the sandstone layers are more permeable than the claystone layers), but even those have relatively low permeability for aquifers (refer to **Section 2.5** for the range of permeability values in these rock layers).
- Within the rock layers there may be some horizontal and vertical fractures or cracks. These are narrow fractures within the rock formation, not open gaps in the rock. They are typically filled with grains of weathered rock (such as sand or fine silt). Some examples of these fractures are also shown in **Figure 7.1**.
- The presence of fractures in the rock may provide a more permeable channel that can either hold more water (as there are more pore spaces) and/or enable water to flow through these channels. It is also possible that the fractures may not enhance the flow of water in any way (they can be closed off by the precipitation of minerals, for example). The size of the fractures is small (up to millimetres wide only) and hence the volume of water that may be in these fractures is very small. If the fractures are long or interconnected, these fractures may provide a pathway for the flow of water through rock. In the rock layers between 700 m depth and the ground surface, or 20 m depth, vertical (as well as horizontal) fractures are present however the probability that a series of vertical fractures interconnect through the whole 680 m or 700 m of rock and do enhance water flow is very low (negligible).
- Even if there were some continuous interconnected fractures present for groundwater to migrate from the coal seam to shallow aquifers (the most shallow aquifer in the Project area is at approximately 75 m depth) water would have to migrate against gravity for more than 500m to cause contamination from the coal seam into the shallow aquifer.
- The most shallow regional aquifer in the Project Area is located at approximately 75 m depth within the sandstone or shale rock layers (typically confined as a layer between less permeable, more dense claystone layers). The amount of water that can be extracted from these rock aquifers is very low (with varying levels of groundwater quality) and the water quality (or salinity) of these water aquifers is typically poor. This is why there are few groundwater extraction bores in the Project Area and very limited potential for this shallow groundwater to be used for any beneficial uses (refer to **Section 2.5** for further discussion). In the Subsurface Project area, nine registered bores have been identified that extend to the Hawkesbury Sandstone aquifer, around at 80 to 300 m depth. The use of these bores is not known and given the low permeability of the rock aquifer the volume of water that may be

extracted is expected to be low. The average yield of bores that extend into the Hawkesbury sandstone aquifer is 1.5 L/s.

- The most viable beneficial use aquifer in the greater Camden area is the alluvial aquifer that is present in the top 10 m within more porous alluvial deposits (various soil deposits that have many more pore spaces to hold a much large volume of water). This aquifer is more suitable for extraction (where the average yield is 2.6 L/s and water quality is generally considered to be good) and used for a range of beneficial uses (stock, domestic, irrigation etc). The alluvial aquifers, however, are only present in the vicinity of the Nepean River, outside of the Northern Expansion Project Area. Hence there is no viable beneficial use aquifer located within the Project Area.

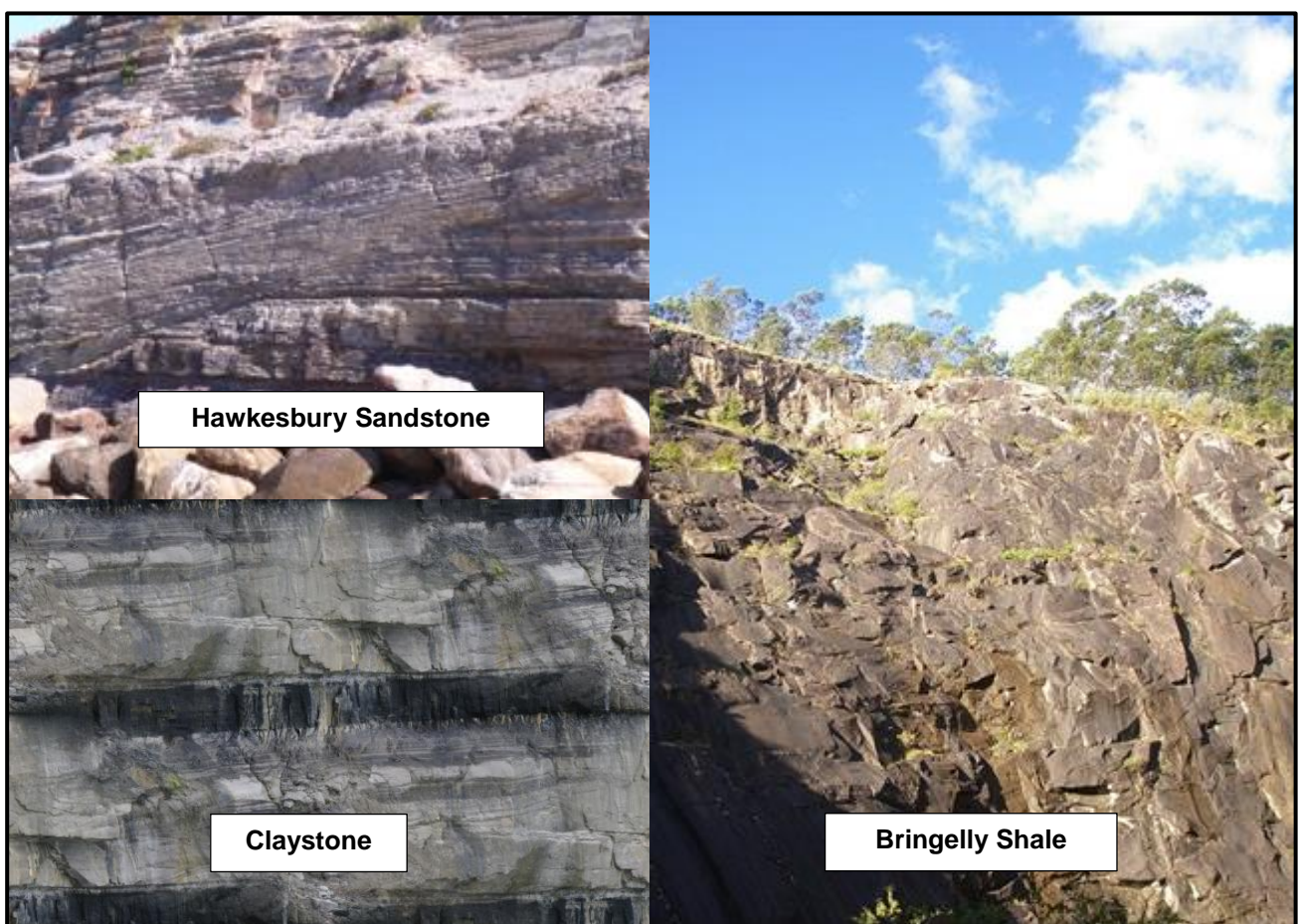


Figure 7.1 Surface photos of examples of rocks found between target coal seam (700 m depth) and ground surface

While there is no potential for water present in the target coal seam to migrate to any beneficial aquifer in the Project Area, for the purpose of this assessment a worst case hypothetical scenario has been considered. This hypothetical scenario is as follows:

- Water present in the target coal seam, following installation of a well, is under considerable natural pressure. The water is present throughout the whole coal seam;
- There is a continuous interconnected series of large volume permeable fractures from 700 m depth to the Hawkesbury sandstone aquifer present between 80 m and 300 m depth, and this aquifer (the Hawkesbury Sandstone) has the potential to be extracted and used for a range of beneficial uses; and
- There is sufficient pressure in the system to push water against gravity from the target coal seam a minimum of 400 m vertically through the fractures to the sandstone aquifer where it vertically mixes with water in the aquifer to the depth where bores are present.

For this scenario, the quality of water in the target coal seam is assumed to be equal to the quality of production water, that comprises water/fluid injected into the well as well as groundwater within the target coal seam. The quality of production water has been reviewed in **Table 7.2** with the concentrations directly compared against drinking water guidelines. There are some compounds that are present in the production water that exceed the drinking water guidelines. These compounds have been further evaluated in relation to the potential for these to migrate to and impact the Hawkesbury sandstone aquifer.

Migration of Water in Coal Seam to Shallow Groundwater

As outlined above this hypothetical scenario involves the migration of groundwater in the coal seam to a shallow beneficial aquifer. It is assumed that the compounds present in produced water that is in the coal seam remain soluble (i.e. do not sorb to the soil) and do not degrade or dissociate (i.e. remain unchanged).

It has been assumed that 200 kL water is injected during drilling activities and 300 kL injected during fracturing activities. For the purpose of this assessment it has been assumed that 100% of this volume of water (i.e. 500 kL) will migrate 400 m through a continuous fracture from the coal seam to the Hawkesbury sandstone aquifer, and this process will occur over a period of 1 month, resulting in a leakage flow rate of 0.19 L/s. This is highly conservative as the vertical flow rate in the strata/rock between the coal seam and Hawkesbury sandstone is very low (resulting in any migration taking many years), assuming there were no restrictions by impermeable confining layers and pressure conditions allowed for this upward vertical movement (which is not the natural case).

The migration of water from the coal seam is assumed to only be vertically up to the Hawkesbury sandstone aquifer where it is assumed to mix vertically and horizontally within the aquifer. The aquifer relevant to mixing is assumed to be 50 m² in area (conservative assumption) by 200 m high (height of aquifer) resulting in a volume of 10000 m³. The sandstone aquifer is assumed to have a low yield (lateral groundwater flow rate) of 1.5 L/s and a total porosity of 0.1 (typical value from the range reported for Sydney sandstone of 0.05 to 0.2, Liu et al 1996). Based on a porosity of 0.1 the total volume of groundwater (i.e. groundwater volume) that can be present between the point of leakage at the coal seam and the groundwater aquifer considered is 1000 m³.

To calculate a dilution factor from the above the following has been considered:

- For a unit volume of 1 m³ of the groundwater plume, seepage from the coal seam is assumed to be entering the volume (vertically) at a rate of 0.19 L/s and groundwater is flowing (laterally) through this volume at a rate of 1.5 L/s. The seepage of water entering from the coal seam will be diluted in this volume as it mixes with the flowing groundwater. This has been calculated simply on the basis of the flow rates, as 1.5/0.19 = 7.8.
- For a groundwater volume (within the plume between the point where the leak may occur and the aquifer of concern) of 12000 m³, the total mixing will be 7.8 x 1000 = 7800.

The calculated dilution factor has then been applied to the maximum concentrations of key chemicals identified in production water. The resultant concentration has then been compared with the adopted drinking water guideline. The ratio of the estimated concentration at the point of extraction to the drinking water guideline has been calculated (termed a Hazard Index, HI). The calculated concentration in water at the point of extraction and the HI are presented in **Table 7.4**.

It is noted that the following calculations do not take into account natural levels of salinity and inorganics that are already present in the aquifer. The calculations are based solely on the additional impact of the hypothetical situation where the total volume of water used in drilling and fracturing migrates to and impacts the more shallow Hawkesbury sandstone aquifer.

Table 7.4 Calculated Concentrations and HIs in Extracted Groundwater Following Hypothetical Migration of Water in Coal Seam to Hawkesbury Sandstone Aquifer

Key Chemicals Identified in Production Water	Maximum Concentration in Production Fluid (in coal seam) (mg/L)	Estimated Concentration in Aquifer at Point of Extraction after hypothetical scenario (mg/L)	Drinking Water Guideline (mg/L)	HI
TDS	23500	3.0	600	0.0050
Arsenic	0.113	0.000015	0.1	0.00015
Strontium	10.2	0.0013	9.3	0.00014
Barium	35.5	0.0046	2	0.0023
Nickel	0.024	0.0000031	0.02	0.00015
Lead	0.026	0.0000033	0.01	0.00033
Iron	15.4	0.0020	11	0.00018
Bromine	5.7	0.00073	2	0.00037
Iodine	0.8	0.00010	0.16	0.00064
Fluoride	3.9	0.00050	1.5	0.00033
Methane (and other C1-C4 gases)	10516	1.4	10000	0.00014
Naphthalene	0.0192	0.0000025	0.0061	0.00040
Benzo(a)pyrene	0.0011	0.00000014	0.00001	0.014
Benzo(b)fluoranthene	0.0018	0.00000023	0.0001	0.0023
Benzo(g,h,i)perylene	0.0017	0.00000022	0.001	0.00022
Benzene	0.01	0.0000013	0.001	0.0013
TPH C10-C14	21.7	0.0028	0.09	0.031
TPH C15-C28	38.8	0.0050	0.09	0.055
TPH C29-C36	17.2	0.0022	0.09	0.025

Based on the above table, the HI for all the key chemicals in production water that may migrate to and be extracted from this aquifer are significantly below a target HI of 1 which would indicate that the concentration present at the point of extraction is lower than drinking water guidelines. The HI remains below 1 even if the porosity of the aquifer is increased from 0.05 to 0.2.

Hence, even under the worst-case hypothetical scenario considered here, impacts to groundwater quality are considered to be negligible as a result of upwards migration of groundwater from the target coal seams to beneficial aquifers.

7.5 Recommendations

It has been found that groundwater aquifers in the Camden area have the following characteristics:

- Groundwater quality in all aquifers and water bearing zones is poor and of limited beneficial use mostly due to salinity;
- Yields are low in all aquifers and do not constitute useful water supply sources;
- Water levels are deep and there is no apparent interaction with the surface environment;
- Groundwater quality in the Hawkesbury Sandstone is very different to the surface water quality in nearby farm dams indicating farm dams are not groundwater fed; and
- No major fractures or faulting appear to be present.

The risks to groundwater from the Project have been estimated to be small. The Project must comply with the relevant requirements of the various regulatory policies that apply including:

- NSW State Groundwater Policy Framework;
- Buried Groundwater Sources Policy; and
- Aquifer Interference Policy.

Compliance with DTIRIS Codes of Practice (DTIRIS 2012a and b) and the requirements within bore licences and the Environment Protection Licence for the Project is also required. These best practice requirements minimise the risk posed to the groundwater in the region.

The risk posed by a surface spillage of produced water to a shallow perched groundwater (if present) has been assessed. Given the presence of bunding at each well, work procedures in place to detect leaks/spills of produced water and spill clean-up, and the lack of viable shallow groundwater aquifers in the Project area (shallow groundwater is only present approximately 75m below ground level) it is considered highly unlikely that any spill of produced water could migrate to or impact any shallow groundwater. Regardless, an unlikely scenario of such a leak occurring and migrating to an unknown shallow aquifer has been assessed, and risks have been calculated to be low and acceptable.

Section 8. Assessment of Impacts – Surface Water

8.1 Introduction

No specific specialist study has been prepared that focuses solely on potential impacts of the Project on surface water quality in the Surface Project Area. Potential impacts to surface water have been presented in Section 9 of the EA (AECOM 2010) and with additional detail presented in the EA Submissions Report (AECOM 2012).

Potential surface water impacts of the Project are limited to the Surface Project Area as activities proposed within the Subsurface Project Area would not result in measurable impacts at the surface. Subsurface drilling activities would take place at some 700 m below ground level with potential impacts expected to be negligible. Potential impacts in relation to groundwater are further discussed in **Section 7**.

In relation to the Surface Project Area, the assessments undertaken have considered the potential for impacts to local creeks, streams and rivers, and shallow groundwater that may discharge into these water features. In addition, as much of the proposed area is rural or semi-rural, potential impacts on dam water quality have been evaluated.

The Surface Project Area is located in south-western Sydney within the Camden and Campbelltown LGA's and covers an area of approximately 3,900 ha. The majority of the Surface Project Area is largely undeveloped and is generally semi-rural in character, with agricultural lands, predominantly used for grazing, scattered between isolated areas of remnant vegetation and land designated for future (residential, commercial and industrial) development. The Surface Project Area is surrounded by residential areas to the north, east and west including Raby, Eaglevale and Leppington respectively. There are also significant areas of both public and private recreation within the area.

The Surface Project Area is located within the Hawkesbury-Nepean and Georges River sub-catchments. The boundary between the Nepean and Georges River catchments generally occurs at the centre of the Surface Project Area. Tributaries of the Georges River generally drain the eastern portion of the Project Areas, whereas tributaries of the Nepean River generally drain the western portion. A number of small tributaries enter the Surface Project Area including Biriwi Creek, Kenny Creek, Bunbury Curran Creek, Cottage Creek, Rileys Creek, Bow Bowing Creek and South Creek. These tributaries are generally located in the headwaters of the catchments and are largely intermittent and ephemeral creeks likely to have limited base flow.

The Upper Canal transects the Subsurface and Surface Project Areas generally north-south and is formed by a system of tunnels and open channels. The Upper Canal is part of the Upper Nepean Scheme and transports water via gravity flow from two small weirs located across the Nepean and Cataract Rivers to Prospect Reservoir, Sydney's main drinking water storage.

Within the Surface Project Area, the canal is generally an open, concrete lined channel which varies between approximately 5-6m in width and 2-3 m in depth. Studies conducted within the area have indicated that surface water is diverted either above or below the Upper Canal where it intersects with drainage lines. An access track is maintained alongside the Upper Canal for the duration of its passage within the Surface Project Area.

The Northern Expansion intends to utilise the existing Upper Canal access corridor for the main spine line of the gas gathering system. The Upper Canal is considered a vital component of Sydney's drinking water supply and therefore warrants careful consideration when designing and implementing mitigation measures to minimise the potential impacts of the Project to surface drainage and surface water quality.

Figure 8.1 illustrates the surface water features present within the Surface Project Area. **Figures 8.2 to 8.4** present more detail in relation to the location of proposed wells, surface water bodies, and residential areas located in the upper, central and lower Surface Project Areas.

8.2 Overview of Specialist Study

The evaluation of potential impacts to surface water has been undertaken on the basis of a qualitative assessment, evaluating the following:

- Potential for the Project to be affected by flood waters (as part of the Surface Project Area is located within the floodplain of tributaries of both the Georges and Nepean Rivers);
- Impacts that may occur during the various phases of the proposed works;
- Potential impacts to and the potential for contamination of drinking water (Upper Canal) and local dams, including the potential for interruption of water supply; and
- Risks associated with proposed infrastructure crossing watercourses in the Surface Project Area.

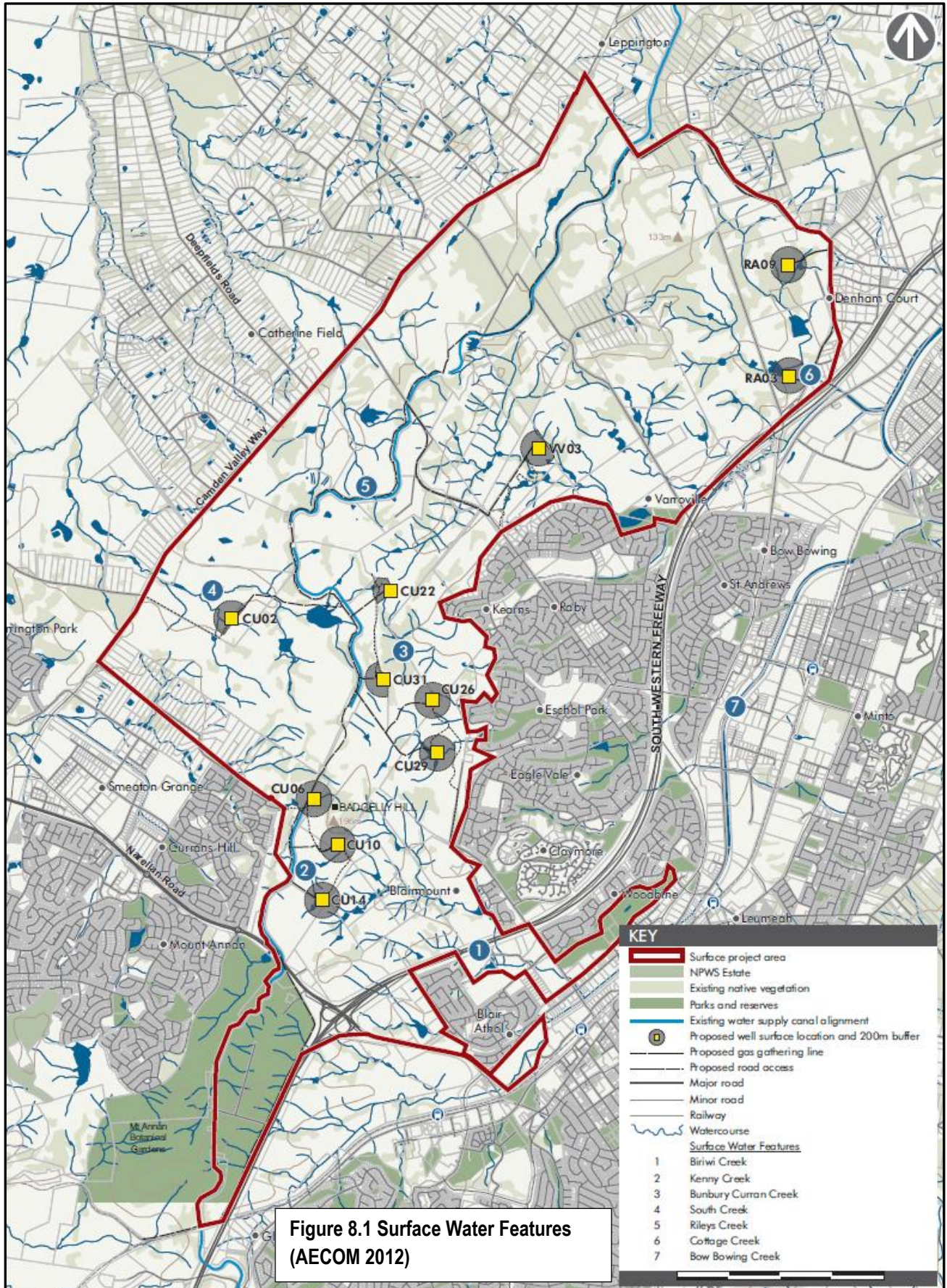


Figure 8.1 Surface Water Features (AECOM 2012)

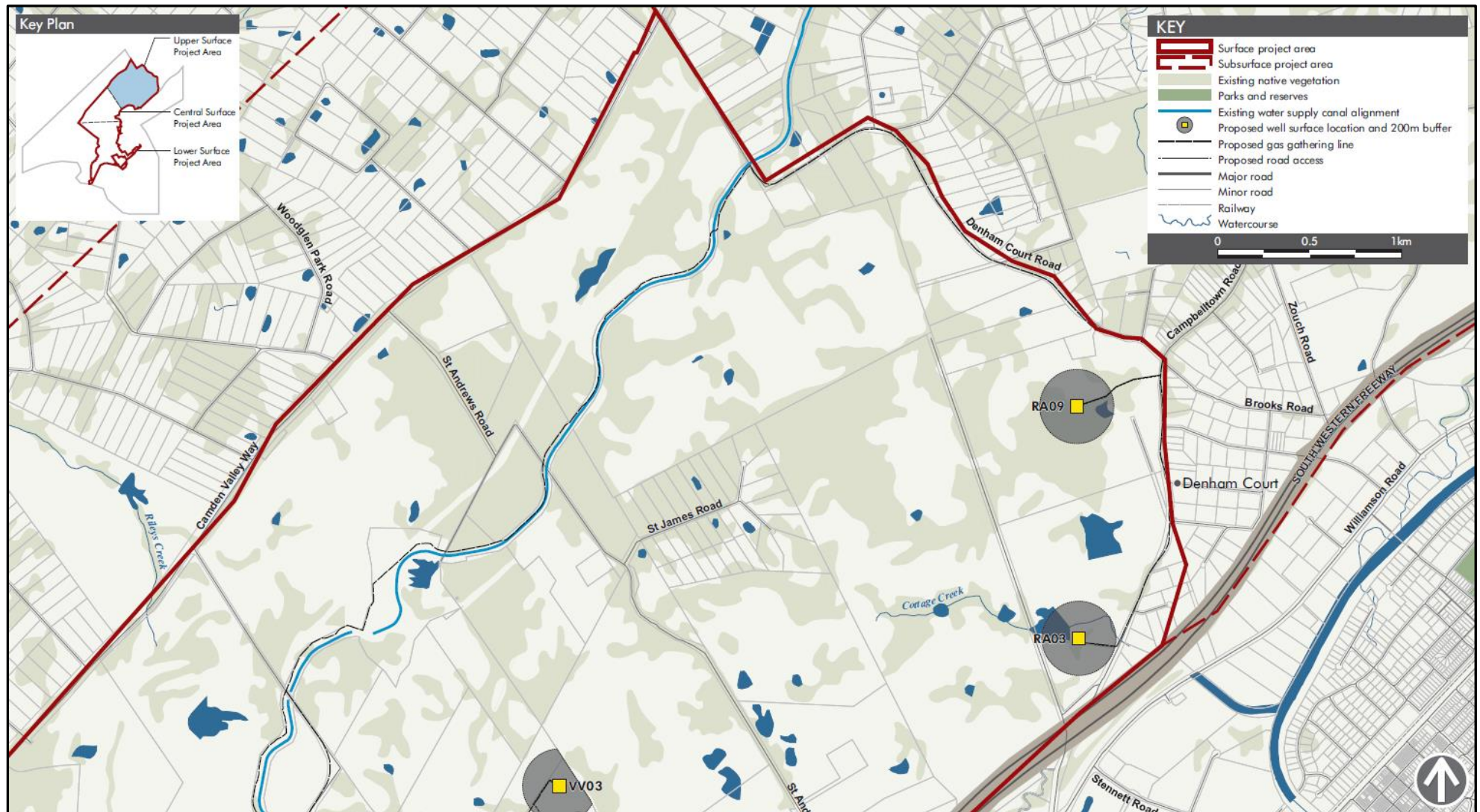


Figure 8.2 Well Locations – Upper Surface Project Area (AECOM 2012)

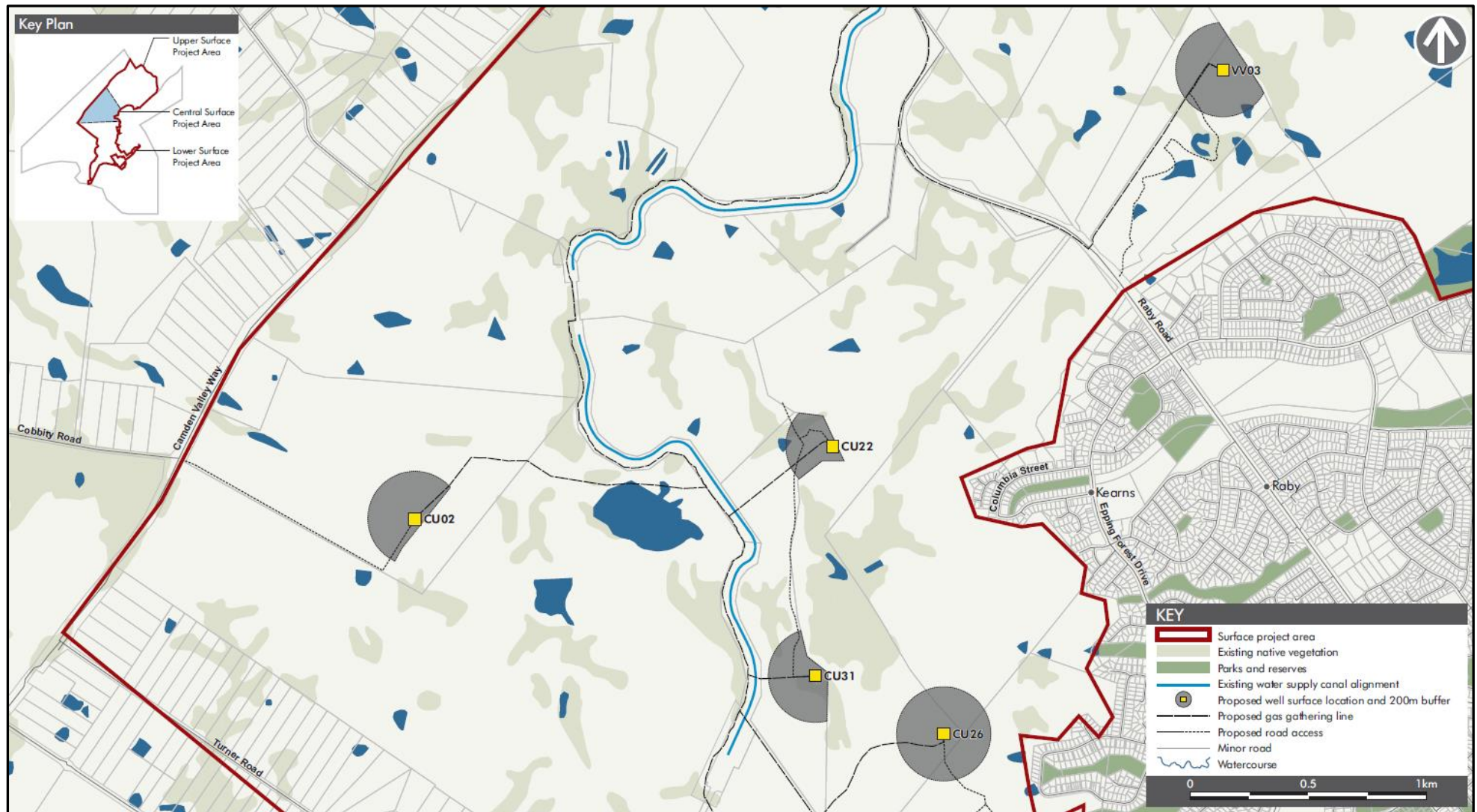
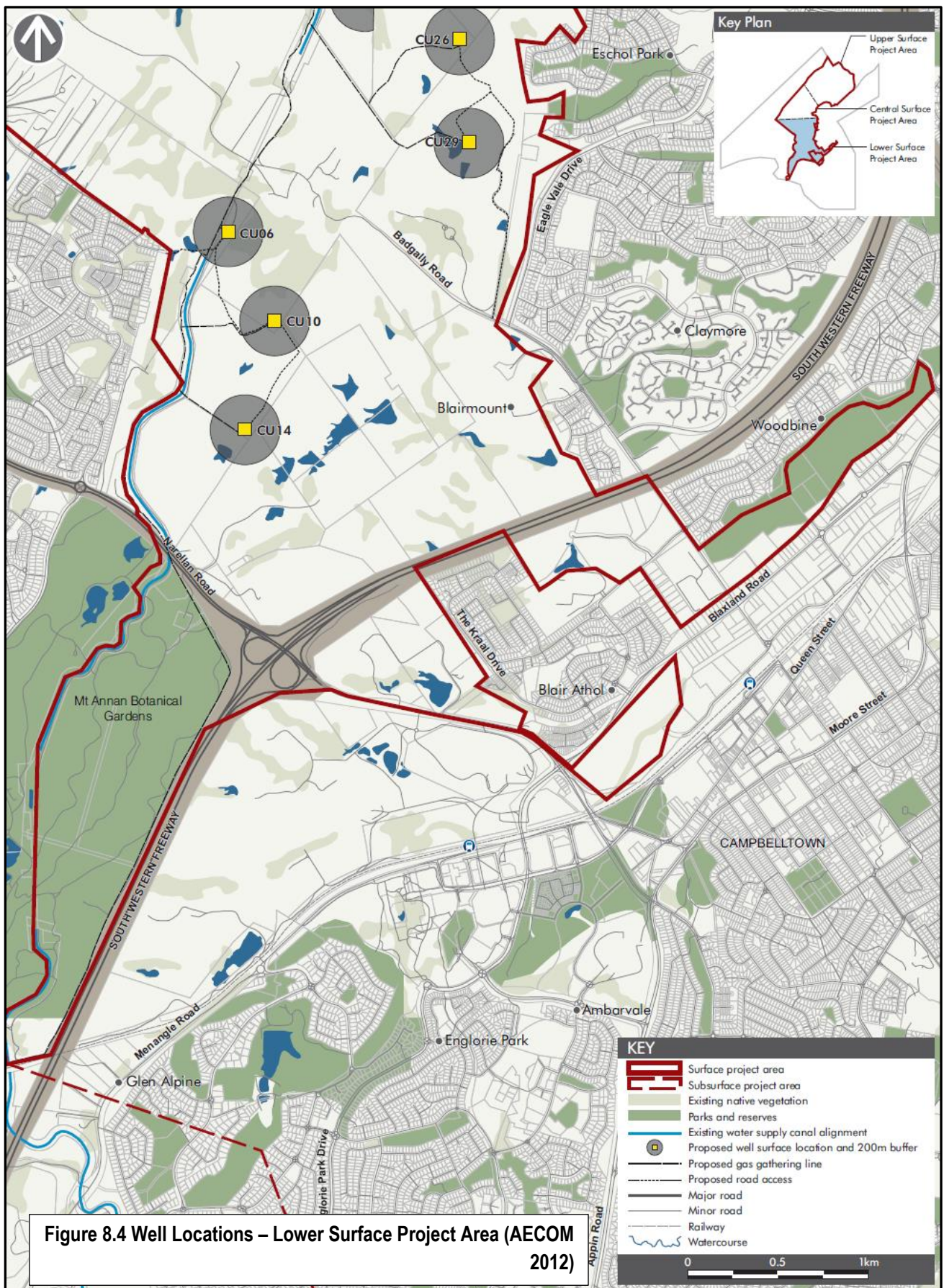


Figure 8.3 Well Locations – Central Surface Project Area (AECOM 2012)



8.3 Potential for Impacts to Community

The following table presents a summary of the potential impacts identified and the outcome of the assessment presented in the EA.

Table 8.1 Summary of Potential Impacts to Surface Water

Development Phase and Potential Impacts Identified	Outcome of the Assessment Presented in the EA
All Phases	
Localised disruptions to the flow of flood water, and/or increased susceptibility to erosion and/or increased surface water runoff (associated with reduced infiltration) during flood events in flood prone areas (Section 9.2 Main Report EA)	Given that there is usually sufficient warning of floods in this area, these impacts can be adequately managed through the implementation of mitigation measures that include safe removal of mobile equipment and design of the wellhead, separator and meter to be able to run while submerged (Section 9.2 Main Report EA)
Construction Phase	
Increased turbidity of surface waters resulting from surface erosion and the transport of sediment laden runoff as a result of earthworks and construction traffic	These impacts can be adequately managed through the implementation of additional mitigation measures (in addition to existing management plans) as outlined in Section 8.5 .
Increased turbidity of surface waters as a result of water and wind erosion of stockpiles, access roads, gas gathering lines and well surface locations and the subsequent deposition of sediment in surface water bodies	
Contamination of surface waters as a result of accidental spillage of fuel from vehicles or equipment, or fluids during drilling or hydraulic fracturing (if required)	
Increased salinity of surface waters resulting from accidental release of saline production water during drilling and well installation	Impacts associated with these operations would be minimised by operational and design measures. Based on review of the assessment and consideration of community concerns this aspect has been considered to be of potential concern and further assessment is presented in Section 8.4 .
Destabilisation of channel bed and banks as a result of construction works associated with the installation of gas gathering lines and associated infrastructure at creek crossings	Construction methods have been identified for different types of watercourses that may need to be crossed. The flora and fauna in each area will be evaluated and all works managed within a Landscape and Rehabilitation Management Sub Plan (LRMSP) and SWMSP.
Potential impacts to and the potential for contamination of drinking water (Upper Canal) and local dams, including the potential for interruption of water supply	Further assessment of these impacts is discussed in Section 8.4 .
Production Phase	
Contamination of surface waters as a result of accidental spillage of fuel from vehicles or equipment	These impacts can be adequately managed through the implementation of additional mitigation measures (in addition to existing management plans) as outlined in Section 8.5 .
Increased turbidity of surface waters resulting from sediment-laden runoff being transported from well surface locations and access roads	
Increased salinity of surface waters resulting from accidental release of produced water from storage tanks or during the transport of saline waters to and from the tanks	
Potential impacts to and the potential for contamination of drinking water (Upper Canal) and local dams, including the potential for interruption of water supply	Further assessment of these impacts is discussed in Section 8.4 .
Post Development	
No additional potential impacts to surface water quality have been identified for the post development phase to those already noted above	
Closure and Final Rehabilitation	
During the closure and rehabilitation phase, potential impacts to surface water quality may result from the release of sediment-laden runoff, resulting in increased turbidity of surface waters. Erosion and sedimentation could potentially occur as a result of stockpiles of soil being disturbed and areas being exposed during the rehabilitation of well surface locations	

As outlined in the above table there are a number of localised activities associated with construction and production that have the potential to result in impacts to surface water if they are not properly managed. These activities and potential impacts are the same as would occur on all construction projects where heavy vehicles are used and there are some earthworks being undertaken. Such activities and potential impacts can be effectively managed through the implementation of mitigation measures. These measures include the prevention of erosion (of sediment) from open surfaces, stockpiled soil and areas where gas lines cross creeks. All vehicles and equipment used in the works are required to be correctly maintained and inspected to effectively manage potential leaks of fuel from these vehicles.

There are, however, some scenarios where the potential for impacts to surface water requires further consideration in this assessment and these are addressed in the following section.

8.4 Assessment of Impacts

8.4.1 General

The discussion presented in **Section 8.3** has identified that the potential impacts to surface water quality can be effectively managed through the implementation of current or additional mitigation measures. There are two aspects, however, where additional discussion and assessment is required, which include:

- Potential for accidental releases and contamination of shallow groundwater and surface water from fluids and production water during drilling or production phases of the Projects; and
- Potential for contamination of drinking water (Upper Canal) and local dams.

The potential for contamination of shallow groundwater has been assessed in **Section 7.4.3**. The other aspects, associated with impacts to surface water bodies from leaks and spills at the well pad are assessed further in the following sections.

8.4.2 Storage and Handling of Fluids

In relation to the storage and handling of drilling fluids and production water the following is noted (AECOM 2012):

- All fluids used in drilling (including hydraulic fracturing and production water) are contained within a closed system (i.e. contained in sealed tanks). The individual chemicals used in these fluids are not stored or mixed at any of the locations in the Surface Project Area.
- Each drill pad is constructed with a bund wall that fully encloses the pad and a small lined sump is constructed in one corner of the pad to capture all runoff from the pad. All fluids used or collected during drilling and production are kept within this bunded area.
- The bund wall provides a second barrier of containment in the unlikely event of drill fluid spills on the pad.
- Sediment fencing is also installed around the drill pad as a third line of defence.
- Each drill pad site would be inspected by AGL to ensure compliance with both construction and environmental aspects. A "Daily Shutdown Checklist" has also been developed to ensure maintenance and compliance of the drill site. The checklist, completed each day by the drilling supervisor on site, includes:

- Checks on the drilling mud management, including the closed tank system;
 - Confirmation that erosion and sedimentation controls are in good condition, including if the sump requires pumping out;
 - Inspection of the general housekeeping of the site to ensure all is secure and well maintained; and
 - The completed checklist would then be submitted to AGL daily. An internal site audit/checklist is also randomly conducted by AGL staff to ensure compliance with environmental controls.
- Standard procedures following drilling of the well to the required depth include flushing the well with fresh water to remove additives and to minimise the viscosity of the gels lining the borehole wall.

During drilling, drilling mud generated during these activities is stored in tanks or drill pits prior to reuse or disposal to a licenced facility.

Currently, produced water from the existing CGP wells is stored temporarily on site in enclosed, above ground tanks at each well pad. The water is then collected periodically, and transported to the Rosalind Park Gas Plant. Coal fines and other particulate matter are removed at the Rosalind Park Gas Plant, before the filtered, produced water is transported to a licensed off-site, wastewater facility. At this facility, the produced water is blended with other waste waters from urban Sydney, and recycled for beneficial reuses – namely brick making and other industrial processes.

Produced water from the proposed Project wells will be managed in a similar manner. Produced water would be stored temporarily in enclosed tanks at each well pad. No water generated from hydraulic fracturing would be stored in lined drill pits; all would be stored within enclosed tanks. The tanks used at each well pad include large 75 kL aboveground tanks or smaller 10 kL in-ground holding tanks.

Produced water would then be either reused in other drilling activities, or disposed of to a licensed off-site facility for treatment and recycling for beneficial reuse. 100% of the production water generated will be reused or recycled (consistent with existing operations).

No evaporation ponds or direct discharges to land or water are required. In addition, the Project does not involve the movement of any drilling fluids away from the well pad in any above or belowground pipework.

Fluid Volumes

During hydraulic fracturing activities, the volume of hydraulic fluids pumped into the well is extracted, along with groundwater within the target coal seam. Hence the volume of water extracted from the wells includes the fluids injected as well as groundwater from the target coal seam.

Existing CGP operations hold a licence to extract 30 ML of water per year. It is noted that in 2011, the actual volume of water extracted from all existing wells was much lower, at just less than 4.8 ML. The Northern Expansion Project has requested extension of the existing license by an additional 30 ML. The expected maximum produced water volumes from existing and proposed wells is 35 ML per year for the first year (when more drilling works are undertaken and when groundwater flow from the target seam is highest) which decreases to 4 ML per year after year 8.

These water volumes are low reflecting the low yield of groundwater in the target coal seam (i.e. there is very little groundwater present in the tightly packed coal seam).

The volume of water required for drilling at each well depends on the drilling type/process required at each location. For most drilling activities the volume of water required will be up to 200 kL. At most, this whole volume of drilling fluids may be stored at each well at any one time.

The volume of fluid required for hydraulic fracturing activities is in the order of 250 to 500 kL (depending on the fracture design and geological properties at each location) per well.

The whole volume held at the well pad during drilling and hydraulic fracturing will not be held in one storage container, rather it will be held within a range of tanks up to 75 kL and . Hence it is not reasonable to assume that 100% of the volume of drilling fluids or hydraulic fracturing fluids will be accidentally released at one time. At most, the whole contents of one of the larger storage containers, 75 kL, may be accidentally spilled.

Where drill pits are present, the water level in these lined pits will not exceed 80% capacity at any one time to account for any additional runoff from rainfall (AECOM 2010).

Once drilling (and hydraulic fracturing) activities are completed and the well is in steady state production the average volume of water extracted per well (as production water) ranges from ~to 0 to approximately 62 kL per year. For the purpose of this assessment it is assumed that 62 kL is stored at any one well pad and this whole volume leaks.

In relation to workover chemicals, the volumes of the products that may be temporarily stored and used at each well pad is very small, ranging from 1 L to 100 L.

8.4.3 Hazards Associated with Drilling and Hydraulic Fracturing Fluids and Production Water

Fluids are used in the drilling, hydraulic fracturing and maintenance of gas wells. These fluids largely comprise water, however a range of chemicals may also be used. The hazards associated with these chemicals have been assessed in chemical risk assessments (included in **Appendices C, D and E**) where a qualitative assessment of the potential for exposure and risk was conducted.

Appendices C to E outline the chemicals (and chemical composition) used, during drilling, hydraulic fracturing and workover (maintenance) activities, and presents an evaluation in relation to potential hazards to human health and the environment). The evaluations undertaken include the identification of trigger values relevant to drinking water (based on published drinking water guidelines or a value derived using the methodology outlined in the Australian Drinking Water Guidelines (NHMRC 2011)) and protection of freshwater environments (based on published guidelines or a trigger value obtained from available studies). These trigger values provide a basis for evaluating the likely hazard of these chemicals. The potential for there to be a risk to human health, however, depends on the potential for exposure, and if exposure occurs, the level of such an exposure. It is noted that not all the chemicals used during drilling, hydraulic fracturing and workover activities have drinking water guidelines as they are common compounds present in a range of food products. Review of these compounds by key organisations such as the WHO has not identified any adverse effects associated with the consumption of these compounds (present in food at higher levels than would be present in fluids used in CSG operations).

In relation to production water, data from existing operations has been reviewed against drinking water guidelines in **Section 7.4.2** and **Table 7.2**. Chemicals present in production water that exceed the current drinking water guidelines have been further considered in this assessment.

Table 8.2 presents a summary of the chemicals used in the proposed activities and the trigger values (i.e. drinking water guidelines) adopted for the assessment of potential risks to human health.

Table 8.2 Summary of Chemicals and Trigger Values (Drinking Water)

Process/Key Chemicals	Drinking Water Guideline (mg/L)
Drilling Fluid/Mud	
Sodium carbonate	NA - Based on pH
Xantham gum	NA
Starch	NA
Tetrakis(hydroxymethyl)phosphonium sulfate	0.126
Benzoalkonium chloride	0.1
Potassium chloride	6.4
Cellulose fibre	NA
Barite sulfate	2 (soluble species, note barite sulfate is insoluble in water)
Hydraulic Fracturing	
Citric acid	15
Hydrochloric acid	NA - Based on pH
Guar gum	NA
Hemicellulose enzyme concentrate	NA
Acetic acid	NA
Sodium hypochlorite	5
Sodium hydroxide	NA - Based on pH
Monoethanolamine borate	4 (boron)
Choline chloride	12250
Workover	
Hydrochloric acid	NA - Based on pH
Guar gum	NA
Xanthum Gum	NA
Polyglycol	NA
Ethylene glycol monobutyl ether [EGBE]	0.8
Calcium Chloride	NA
Potassium Chloride	6.4
Sulfamic Acid	NA - Based on pH
Amine polymer derivative	NA
Produced Water (where maximum concentrations exceed drinking water guidelines)	
TDS (total dissolved solids)	600
Arsenic	0.1
Strontium	9.3
Barium	2
Nickel	0.02
Lead	0.01
Iron	11
Bromine	2
Iodine	0.16
Fluoride	1.5
Methane (and other C1-C1 gases)	10 000
Naphthalene	0.0061
Benzo(a)pyrene	0.00001
Benzo(b)fluoranthene	0.0001
Benzo(g,h,i)perylene	0.001
Benzene	0.001
TPH C10-C14	0.09
TPH C15-C28	0.09
TPH C29-C36	0.09

Note: NA = not applicable – for most entries there is not guideline value as it is a compound that is acceptable in food without restriction.

8.4.4 Potential Exposure Pathways

An exposure pathway occurs when there is a mechanism by which chemicals are released into the environment and there is a way in which someone (or an aquatic/terrestrial species) may come into direct (via ingestion or dermal contact) or indirect (via inhalation of volatiles or ingestion of chemicals accumulated into produce) contact with these chemicals. When assessing potential risks there must be a pathway of exposure and it is the concentration of the chemical at the point of exposure that is of importance.

Based on the methods for the storage and use of fluids (and chemicals) for drilling, hydraulic fracturing and maintenance as outlined in **Section 8.4.2**, there are few mechanisms by which these fluids may migrate from the well and discharge to an environment where exposure may occur. These mechanisms are associated with leaks and spills at the ground surface.

The assessment of potential exposures in the Surface Project Area has considered the following:

- Creeks located close to the well locations (where these fluids may be used) are mostly ephemeral and hence surface water is generally very low flowing or not present except during periods of sufficient rainfall. The closest distance between a creek bed and a well is >100m (where not uphill, refer to AECOM 2012 and **Section 3.2**), hence any spill of water at the well would either need to be of sufficient volume that it flowed across the ground surface and into the creek and downstream into a local dam or portion of the creek where surface water is present or occur during periods of rainfall when rainwater flows across the ground and within the creek are present.
- Local dams are present on rural properties located in the Surface Project Area, with the closest dam located approximately 100 m (where not uphill) from any proposed well. Water from these dams is not used for drinking water as a reticulated water supply (from Sydney Water) is provided to this area. Dam water however is used for stock watering and some irrigation.
- An open gravity water concrete lined supply canal, part of the Upper Canal system, runs through the middle of the Surface Project Area. The Upper Canal is a system of canals, aqueducts and tunnels that transfers up to 680 ML/day of water from Metropolitan dams to Prospect Reservoir and the Prospect Water Treatment Plant, that supplies drinking water to Sydney. It is operated by Sydney Catchment Authority and remains an important component of Sydney's bulk water supply. Well CU06 is proposed to be developed within 170 m of an open portion of the canal and while it is highly unlikely that any spills at the ground surface will be of sufficient volume to migrate this distance to discharge into the canal, the potential for this to occur has been further evaluated.
- Groundwater dependant ecosystems (GDEs) are aquatic ecosystems and surface water features that are dependent on the discharge of shallow groundwater for the maintenance of the aquatic system. In these areas spills of chemicals at the ground surface has the potential to result in impacts to shallow groundwater that feeds these ecosystems. As outlined in **Section 2.5** there are no GDEs associated with any of the deep sedimentary rock groundwater systems. It is highly probably that the Cumberland Shale Woodland is a GDE, however it is dependent on very shallow localised perched groundwater that is not close to or connected with the proposed well locations. Hence even if any surface spills impacted on

the most shallow groundwater aquifer, these aquifers are not interconnected with any GDEs and hence there would be no exposure to aquatic species.

- In areas located closer to where the wells are proposed, hydrogeological investigations have been undertaken by Parsons Brinckerhoff (PB 2012) to determine the interconnectivity between shallow groundwater aquifers and local dam water quality. Groundwater samples were collected from aquifers located in the upper Hawkesbury sandstone (150 to 300 m below ground level). Groundwater could not be sampled from the Ashfield shale (most shallow aquifer, 84 m below ground level) as there was not enough groundwater available to sample. Dam water quality was also tested from existing dams on farms close to the location of the groundwater wells. Water levels in the underlying aquifer were too deep to interact with any surface water feature. The groundwater quality in the Hawkesbury sandstone was found to be very different to the dam water quality supporting the conclusion that in these areas dams on farms are not fed by groundwater.
- The dams are primarily recharged via rainfall and surface water runoff. Hence the assessment presented in this report has focused on potential exposures that may occur via surface water runoff to the local dams.

Based on the above, in the event of a leak or spill of fluids at the ground surface that occurs outside the bund wall (constructed at each well to capture any such spills), then there is the potential for the following contamination to occur:

- Runoff to and discharge into local farm dams where water may be used for stock watering and irrigation (where exposures to livestock [via ingestion] and local residents [via ingestion and dermal contact with irrigation water and inhalation of aerosols during irrigation] may occur); and
- Runoff and discharge to the Upper Canal which carries water that feeds into Prospect Reservoir, part of Sydney's domestic water supply.

The potential for these exposures to be of significance will depend on the concentration of chemicals in the water at the point of exposure (i.e. in drinking water or dam water). Any chemicals spilled at the ground surface, at the well location, will be subject to dilution (and likely degradation) as they migrate in water from the spill location into the water body evaluated.

8.4.5 Quantification of Potential Exposure and Risk

A simple, worst-case scenario has been evaluated in this assessment. This scenario has assumed that the whole volume of either drilling fluids, hydraulic fracturing fluids or workover chemicals (prior to use which is when the concentrations are greatest) are stored in the largest container at the well location (75 kL for drilling and hydraulic fracturing fluids and 62 kL for produced water) is spilled on the ground surface where:

1. The spill directly enters a farm dam; or
2. The spill directly enters the Upper Canal.

The exposures that may occur as a result of these events include:

- Ingestion via drinking water; and
- Ingestion and dermal contact with water used for the purpose of irrigation.

None of the chemicals used in drilling, hydraulic fracturing or workover activities are volatile and hence the inhalation pathway is considered to be incomplete.

As discussed in the above sections, chemicals (present in a range of products) may be present at the ground surface, at the well pad, in drilling muds, hydraulic fracturing fluids, workover chemicals/fluids and in produced water.

The concentrations of these chemicals at the well pad will not be the same as the concentration that may occur in a farm dam, the Upper Canal or in shallow groundwater in the event of an accidental spill or leak that is not managed within the well pad area. The exposure concentration will be lower as the water/fluid has to migrate from the well pad into these water bodies, during which time the fluid will soak into the ground surface and concentrations will be diluted (with rainwater and/or water within the dam or canal), sorbed to soil (and will never reach the water body) and degraded/dissociated (to non-toxic compounds).

It is noted that the drilling mud used has a high viscosity; hence it will not rapidly flow across the ground surface if spilled. The runoff is expected to be sufficiently slow that it can be readily contained and cleaned up. These fluids would not be used where no personnel are present. Hence the potential for these fluids to be accidentally spilled and runoff to any surface water body (and not be identified and cleaned-up in accordance with the appropriate spill response clean-up procedure) is negligible. Regardless, this worst-case assessment has considered potential spills of drilling fluids, assuming that they occur during periods of rainfall where they may be more mobile and migrate off the well pad (assuming it leaks from the bunded area).

The assessment of potential impacts to surface water bodies has conservatively assumed the following:

- A full 75 kL storage container of drilling mud or hydraulic fracturing fluid (prior to use in the well) or 62 kL of production water (a full year of produced water assumed stored at the well) accidentally splits open and leaks into the bunded area. The spill is not immediately cleaned-up.
- The bunding fails and 100% of the contents leaked are released from the bunded area.
- The bund failure and leak is not immediately detected and cleaned-up.
- The leaked fluid from the bunded area migrates to the closest surface water body (where the minimum distance (not up-hill) from a proposed well pad to a receiving water body is 100 m, refer to **Table 3.2**). During migration of the leaked fluid, it is assumed that none of the chemicals present are sorbed to the soil, degrade or dissociate (to non-toxic compounds). Given the distance from the well pad to the receiving environment, and the nature of these chemicals, it is likely that most will not reach the water body due to these processes.
- For the purpose of this assessment it has been assumed that 10% of the spilled fluids at the well pad reach the surface water body at the one time.
- Once in the surface water body it is assumed that the chemicals do not sorb to suspended particulates, degrade or dissociate which would reduce their availability to organisms or be taken up by people.
- If the chemicals enter the Upper Canal, it is assumed that the treatment system at the Prospect Water Treatment Plant fails and all of the chemicals in the Upper Canal enter the drinking water supply.

Based on the above assumptions, this assessment has considered the potential for chemicals present in drilling and hydraulic fracturing fluids and production water spilled at the well pad to be diluted in the receiving water body.

It is noted that in relation to workover chemicals used at the well pad, the volumes of the products used is very small, ranging from 1 L to 100 L. Even in the unlikely event that a container of one of these products was spilled in the bunded area, and leaked from the bunded area, there would be insufficient volume of fluid to be able to migrate 100 m or more to the closest receiving surface water body. Hence the pathway for these chemicals to migrate to and impact on surface water bodies is not considered to be complete and these chemicals have not been further assessed.

Capacities of Receiving Bodies

Farm Dams

For this scenario, where an accidental spill occurs at the well pad, outside the bunded area, no dilution has been assumed from rainwater or during runoff from the well pad to the local dam. In addition, 10% of the volume of water/fluid spilled is assumed to reach the dam and remains soluble in water. The closest dams to the proposed wells range in size, however for the purpose of this assessment a “standard field-farm pond” size/depth of 1 hectare and 0.15m deep has been considered. This is the dimensions of a farm pond that is considered by APVMA (EPHC 2009) when evaluating potential impacts of the use of various pesticides in the community.

This results in a dam with a water capacity of 1500 m³, or 1500 kL.

Upper Canal

Water from the Upper Canal feeds into Sydney’s drinking water supply. Water from the Upper Nepean dams is transferred to Prospect Water Filtration Plant via the Upper Canal, which is an open conduit for much of its 64 km length. Water that is treated at the Prospect Water Filtration Plant and enters Sydney’s drinking water supply is derived from 3 different sources:

- Warragamba Dam;
- Upper Canal; and
- Prospect Reservoir.

The dilution of any contamination that enters the Upper Canal into the drinking water supply (at the Filtration Plant) will depend on the ratio of water derived from these 3 sources. The worst-case scenario occurs when no water is sourced from Warragamba Dam, but all the water entering the treatment plant is sourced only from Upper Canal and Prospect Reservoir. This will result in the lowest level of dilution at the Filtration Plant that supplies the drinking water.

For the purpose of the worst-case assessment presented here, it has been assumed that when the spill at the well pad occurs, only water from the Upper Canal is being treated at the Prospect Water Filtration Plant and that the treatment system has failed and water from the Upper Canal enters the Drinking Water supply unchanged (i.e. untreated). The flow rate of water in the Upper Canal varies, and is typically around 250 ML/day, with an upper capacity of 700 ML/day. Where drinking water is only sourced from the Upper Canal, a flow rate closer to 700 ML/day is expected (to meet demands of Sydney’s water supply).

Again as a conservative (and more unrealistic) assumption, the more typical flow rate of 250 ML/day has been assumed in these calculations.

The spill event has been assumed to occur on one day only, where water/fluids from the well pad are spilled outside the bunded area, that no dilution occurs between the well pad and discharge into the Upper Canal, 10% of the volume of water/fluid spilled reaches the Upper Canal, and all the chemicals remain soluble in water.

Based on these assumptions the volume of water that may be affected over a 1 day period in the Upper Canal is 10 420 kL. It is noted that water from other sources are mixed with water from the Upper Canal at the Prospect Water Treatment Plant to ensure that the volume of water required to meet Sydney's domestic requirements are met. Hence it is expected that the water volume considered in this assessment will be further diluted prior to entry into the drinking water supply.

Calculated Concentrations in Surface Water

Based on the assumptions presented above a dilution factor has been calculated using the following equation:

$$C_{SW} = C_F \times \frac{V_F}{V_{SW}}$$

Where:

- C_{sw} = concentration of chemical in surface water body (mg/L)
- V_{sw} = volume of surface water body (1500000 L for farm dam and 10442000 for Upper Canal) (L)
- C_F = concentration in the fluid (mg/L)
- V_F = volume of fluid that has leaked (L) (based on the assumption that 10% of the total volume of fluid reaches the water bodies, i.e. 10% of 75000 L = 7500 L for drilling and hydraulic fracturing fluids and 10% of 62000 L = 6200 L for produced water)

The above has been used in conjunction with the maximum concentrations of chemicals presented in drilling and hydraulic fracturing fluids (prior to use in the well when concentrations are highest) and the key chemicals identified in production water. The resultant concentration has then been compared with the adopted drinking water guideline. The ratio of the estimated concentration at the point of extraction to the drinking water guideline has been calculated (termed a Hazard Index, HI). The calculated concentration in surface water and the HI is presented in **Table 8.3**.

It is noted that the following calculations do not take into account natural levels of salinity or other inorganics and organics that are present in surface water as a result of runoff from surrounding urban and rural areas. The calculations are based solely on the accidental release scenario only.

Table 8.3 Calculated Concentrations and HIs in Surface Water Following Accidental Release of Fluids from the Well Pad

Process/Key Chemicals	Drinking Water Guideline (mg/L)	Concentration in Fluid (at well pad) (mg/L)	Concentration in Receiving Body (mg/L)		HI	
			Farm Dam	Upper Canal	Farm Dam	Upper Canal
Drilling						
Sodium carbonate	Based on pH	450	2.3	0.32	--	--
Xanthan gum	NA	3000	15	2.2	--	--
Starch	NA	5	0.025	0.0036	--	--
Tetrakis(hydroxymethyl)phosphonium sulfate	0.126	100	0.50	0.072	4	0.6
Benzoalkonium chloride	0.1	75	0.38	0.054	4	0.5
Potassium chloride	6.4	NA			--	--
Cellulose fibre	NA	NA*			--	--
Barite sulfate	2 (soluble species)	NA*			--	--
Hydraulic Fracturing						
Citric acid	15	6600	33	4.8	2	0.3
Hydrochloric acid	Based on pH	145000	725	104	--	--
Guar gum	NA	2400	12	1.7	--	--
Hemicellulose enzyme concentrate	NA	5	0.025	0.0036	--	--
Acetic acid	NA	320	1.6	0.23	--	--
Sodium hypochlorite	5	180	0.90	0.13	0.2	0.03
Sodium hydroxide	Based on pH	90	0.45	0.065	--	--
Monoethanolamine borate	4	1200	6.0	0.86	1	0.2
Choline chloride	12250	1640	8.2	1.2	0.0007	0.0001
Produced Water (where maximum concentrations exceed drinking water guidelines)						
TDS (total dissolved solids)	600	23500	97	14	0.2	0.02
Arsenic	0.1	0.113	0.00047	0.000067	0.005	0.0007
Strontium	9.3	10.2	0.042	0.0061	0.005	0.0007
Barium	2	35.5	0.15	0.021	0.07	0.01
Nickel	0.02	0.024	0.00010	0.000014	0.005	0.0007
Lead	0.01	0.026	0.00011	0.000015	0.01	0.002
Iron	11	15.4	0.064	0.009	0.006	0.0008
Bromine	2	5.7	0.024	0.0034	0.01	0.002
Iodine	0.16	0.8	0.0033	0.00048	0.02	0.003
Fluoride	1.5	3.9	0.016	0.0023	0.01	0.002
Methane (and other C1-C1 gases)	10000	10516	43	6.3	0.004	0.0006
Naphthalene	0.0061	0.0192	0.000079	0.000011	0.01	0.002
Benzo(a)pyrene	0.00001	0.0011	0.0000045	0.0000065	0.5	0.07
Benzo(b)fluoranthene	0.0001	0.0018	0.0000074	0.0000011	0.07	0.01
Benzo(g,h,i)perylene	0.001	0.0017	0.0000070	0.0000010	0.007	0.001
Benzene	0.001	0.01	0.000041	0.0000060	0.04	0.006
TPH C10-C14	0.09	21.7	0.09	0.013	1	0.1
TPH C15-C28	0.09	38.8	0.16	0.023	2	0.3
TPH C29-C36	0.09	17.2	0.071	0.010	0.8	0.1

Review of the calculations presented above indicates the following:

- The calculations presented are based on a highly unlikely scenario of contamination, and the calculations have adopted very conservative assumptions.
- In relation to the potential for accidental releases impacting on the drinking water supply provided via Upper Canal, the calculated HI for all the chemicals evaluated is less than 1. This means that under the unlikely scenario evaluated, potential concentrations of chemicals that may be derived from operations at the well pad in the drinking water supply are below the available drinking water guidelines.
- In relation to the potential for accidental releases impacting on surface water quality within local farm dams, the calculated HI is less than 1 for most of the chemicals assessed with the exception of chemicals used in drilling mud, hydraulic fracturing and TPH (C15-C28) that

may be present in produced water, where the HI ranges from 1 to 4. While these HI's are higher than the target of 1, no health impacts are expected on the basis of the following:

- The assessment presented is based on water from the dam being used as a drinking water supply and long-term exposures (i.e. drinking this quality of water every day for a lifetime). This is not the case as dam water is not used for this purpose and the contamination scenario is short-term only;
- Dam water is used for stock watering and irrigation where the level of exposure differs from drinking water. Stock watering guidelines (where available) and irrigation water (short-term trigger levels) (ANZECC/ARMCANZ 2000) are higher than drinking water guidelines, with stock and crops/plants noted to be tolerant of short-term fluctuations in concentrations (as would be the case in this scenario);
- The chemicals evaluated are not bioaccumulative and will have no long-term impact if they are present in surface water for a short period of time;
- As noted in **Section 8.4.5**, the viscosity of drilling fluids means that if spilled they will not flow over the ground surface and enter a water body. The only way these chemicals could reach the farm dam is during a rainfall event where additional significant levels of dilution would occur, resulting in much lower concentrations than considered in this assessment; and
- Chemicals in hydraulic fracturing where the HI exceeds 1 are chemicals that rapidly degrade and dissociate in the environment and hence would not be expected to reach the surface water body or remain in surface water long enough for any exposure to occur.

On the basis of the above, for the highly unlikely event that drilling mud, hydraulic fracturing fluids or production water is accidentally released at the well pad and can migrate to a surface water body, no adverse impacts on drinking water or dam water quality have been identified.

It is noted that the proposed operations involve significant levels of management and levels of protection to ensure that fluids used during drilling and hydraulic fracturing, and water produced from the wells do not migrate off the well pad.

Wells and other infrastructure associated with the existing CGP are located in areas with similar land use and proximity to surface water bodies. No impacts to surface water processes including drainage and water quality as a result of the construction and operation of wells and infrastructure associated with the CGP in these areas has been identified.

8.5 Recommendations

The potential to impact on surface waters from the activities that make up the Project has been evaluated. Worst case scenarios to evaluate the potential for impacts on farm dams and on the Upper Canal have been evaluated. Even in conservative situations where a large quantity of water escapes from the bunded area around a well pad, the risk of damage to human health is low and acceptable.

The Environmental Management Plan (EMP) for the Project contains several sub plans which address the environmental objectives for managing the potential impacts of the CGP on surface waters. The Soil and Water Management Sub-Plan (SWMSP) includes procedures to be implemented during construction and operation of the Project designed to:

- Prevent soil erosion, exposure and contamination;
- Minimise negative impacts on surface water resources;
- Maintain current surface drainage patterns and surface water quality;
- Ensure there is no long-term erosion as a result of the works; and
- Monitor and manage soil erosion and water flows until the area has stabilised.

More specific best practice measures that will be part of the EMP specifically to minimise potential surface water impacts as a result of the proposed works include:

- Construction of silt fences and other erosion control measures that would be implemented to minimise surface erosion.
- A water management system, including water gathering lines where necessary, will be employed to enable collection, management and appropriate reuse of water produced as a result of the drilling, fracture stimulation and production operations including the storage of saline production water in storage tanks.
- Infrastructure will be inspected and audited following a flood event to ensure that all elements are operating effectively, and necessary rehabilitation works are carried out immediately.
- Gas wells will be located at a minimum distance of 100 m from creeks or other water bodies (not located uphill from the well).
- Appropriate crossing locations will be selected on dry creek beds for the installation of gathering lines and the area rehabilitated suitably following any earthworks.
- Under-boring would be used for the installation of gas gathering lines where permanent water flows occur and for crossings of watercourses in the vicinity of the Mount Annan Botanic Gardens.
- Rehabilitation of areas where earthworks have taken place to a surface profile similar to the original profile, particularly where gathering lines have been installed by either trenching or under-boring. Rehabilitation works would be in accordance with AGL's established and proven LRMSPP as detailed in the existing EMP.
- Saline water produced from the wells will be stored either in lined drill pits or water storage tanks (majority). Bunding will be in place around lined pits to reduce the potential for saline waters contained within the pits to be liberated during a flood. The water level and quality of water stored within the lined drill pits will be monitored regularly to ensure sufficient space is available for rainfall contribution and to ensure that the quality of the water is acceptable for proposed future uses.

Section 9. Assessment of Impacts – Hazards

9.1 Introduction

A preliminary hazard analysis was undertaken for the Project by Planager Pty Ltd in-line with the Director-Generals requirements. This assessment is detailed in Appendix D of the EA and summarised in Section 10 of the Main Report. The conclusions of the assessment were rechecked in regard to the revised well locations in the Submissions Report in Section 5.8.2.

9.2 Overview of Specialist Study

NSW Planning provides guidance – SEPP 33 (Hazardous and Offensive Development) and associated guidelines – to define when a proposed industrial facility poses a major hazard to the community. This Project does not meet the definitions provided in regulatory guidance so is not classified as a potentially hazardous industry. It does not meet the definition in the SEPP because no Dangerous Goods will be stored at the site in excess of the amounts listed in the SEPP and the well sites are located with careful consideration of residential and other sensitive land uses. Chemicals will be brought on site for short periods during construction and during well workover and shut down and the CSG will be immediately gathered from each well and taken to the Rosalind Park Gas Plant.

Despite there being no requirement to undertake further assessment of the potential for acute hazards from the Project a preliminary hazard analysis (PHA) was undertaken as part of the EA process in line with the analysis required for hazardous facilities. The preliminary hazard analysis was undertaken according to the methods outlined in regulatory guidance from NSW Planning.

The analysis looked at both the well locations and the gas gathering system. The analysis involved a number of steps – hazard identification, quantitative consequence and effect analysis, quantitative frequency analysis, and quantitative risk analysis. Generally, acute hazards can arise from the Project through failure of equipment or due to damage to equipment from external causes (e.g. pipe breakage due to accidental excavation of buried pipeline during another development) or from human error.

The CSG is the potentially hazardous material relevant to this Project. It is a buoyant, flammable gas which will tend to disperse rapidly at altitude. On release in an enclosed area an explosion or flash fire is possible if an ignition source is present. It is an asphyxiant gas but due to its buoyancy is unlikely to cause such a hazard in open areas.

The PHA looked at all the relevant potential leaks and failures (including well workovers) that could occur that would lead to a release of coal seam methane gas. International statistics are available about how often pipes, valves, pressure vessels or other equipment used for the Project have been known to fail and these failure rates were used in the PHA. Consideration was given to both fire and explosion risk. For an acute risk to occur for this Project some equipment failure must occur, it must go unnoticed for long enough to release sufficient quantities of CSG, there must be an ignition source and people must be present sufficiently close to be affected by a fire or an explosion.

9.3 Well Workovers

Well workovers occur when a well needs maintenance. It involves running small bore tubing from the workover rig into the production casing inside the established well. A high pressure pump is then used to circulate water down the tubing into the well to remove debris and sand from the well. These activities are not required often but may occur 1-2 times in the first year and then once in 2 to 5 years.

Failures can occur during this process. Leaks in the equipment can result in small releases of CSG. A blowout preventer is fitted to the well head to minimise the chances of such failures occurring. Strict adherence to safe working procedures also minimise the potential for such failures. Oxygen detectors and strict procedures to purge the system of oxygen prior to restarting the well also assist in minimising the potential for explosions should a gas leak occur.

9.4 Potential for Impacts to Community

Hazardous industry are sites where one or more chemicals that are classified as Dangerous Goods are stored in sufficient quantity that if an accident were to occur or if some of the control measures were to fail, it would create a situation that could cause concern to the community and have the potential to cause significant injury. This Project does not meet the hazardous industry definitions but some stakeholders might expect that it would.

CSG is handled at the well pads that will be established for this Project but it is not stored at these locations. For an acute risk to occur for this Project some equipment failure must occur, it must go unnoticed for long enough to release sufficient quantities of CSG, there must be an ignition source and people must be present sufficiently close to be affected by a fire or an explosion.

Should such a fire or explosion occur the potential off-site impacts would be damage to buildings due to fire or overpressure or injury to people.

Most of the activities currently undertaken in the area that may be affected by this Project are residential type activities, however schools and other sensitive locations are also present. In the northeast of the Project area the Foti Fireworks factory is located.

9.5 Assessment of Impacts

The PHA has found that the potential for acute hazards does not extend more than between 10 and 20 m from the well heads (which is actually within the fenced off area which will remain after the wells are installed – i.e. on-site) and the pipelines that make up the gas gathering system. At these distances the potential risks of fatality or injury are well below criteria provided by NSW Planning. The closest residence to a well pad is currently approximately 500-700 m away. There are no wells close to the Foti Fireworks factory. The closest well is VV03 and it is at least 2 km to the south/southeast.

Any future residence would be >20 m from a production well and therefore outside the hazardous zone as defined by the PHA.

9.6 Recommendations

This Project does not meet the definitions of potentially hazardous industry in SEPP 33. The PHA confirms this conclusion as it shows the potential for acute risks due to a large release of CSG is well below the criteria set by NSW Planning.

It is still appropriate to include best practice equipment and procedures for use at the site to ensure the risks are even lower than those estimated in this PHA. In fact, it is required that a range of engineering emergency shutdown equipment are included in the construction of the wells.

A range of additional measures that will be included in the Project include:

- Security arrangements at the wells to prevent unauthorised access. This includes at a minimum locked equipment (or removing the movable part of the equipment as for valve) and secured confined spaces (i.e. fencing to Australian standards).
- Operational and emergency planning for the well sites taking into account the possibility of a bush / shrub fire.
- Control of vegetation in the vicinity of the facilities to be included in the safety and operations management plan for the well sites and gathering system.
- Additional monitoring of the area should the flare operate in high or extreme fire conditions.
- A comprehensive safety management system (SMS) will be implemented, including appropriate internal and external audits carried out to assure that the SMS is functioning properly and that it is appropriate to the hazards of the facilities. Detailed specialist audits of engineering and safety issues will be carried out at least once every four years.
- Ensuring the Hazardous Area zone (as defined in the Australian Standard for electrical zoning in potentially flammable areas) of the well compound does not extend beyond perimeter fence. Fenced-off area at least exceeds the hazardous zone.
- Bollards or other physical protection in high risk areas will be installed to protect the installation against damage from vehicles or other moving machinery.

Section 10. Assessment of Impacts – Subsidence

10.1 Introduction

A report on the potential for CSG extraction to result in subsidence at the surface was prepared by Mine Subsidence Engineering Consultants Pty Ltd and included as Appendix K of the EA.

10.2 Overview of Specialist Study

Surface subsidence can occur if one of the following situations exist:

- Large voids are created in the strata by a mining or extractive activity, leading to subsequent collapse, consolidation and subsidence of the overlying strata;
- Large voids are created in the strata by a mining or extractive activity, leading to failure of remnant pillars left between excavated areas resulting in subsidence of the overlying strata; or
- Unconsolidated beds of strata are present, which can subsequently be consolidated by the weight of the overburden, following the removal of interstitial fluids.

The specialist study looked at whether any of these situations could exist as a result of this Project given the proposed activities to be undertaken and the methods to be used.

10.3 Potential for Impacts to Community

Subsidence is where the surface of the ground collapses due to compaction or consolidation of the geological materials beneath. It is a natural process in some areas but is also associated with mining and extractive industries or significant levels of groundwater extraction (UNSW 2013). The collapse can be a few millimetres through to metres

If significant subsidence occurs it can damage structures on the surface including houses, commercial buildings, roads and other infrastructure.

10.4 Assessment of Impacts

The wells that will be drilled as part of this Project are up to 180 mm in diameter (i.e. 0.18 m). In each well pad location up to 6 wells will be drilled. The subterranean spacing of the wells will generally be at least 350 m. Each well once drilled will be cased and sealed to facilitate collection of the CSG and to prevent any hydraulic linkages through the different levels.

The coal seam will be dewatered as part of the process to recover the CSG but coal seams are usually confined aquifers. Consequently, extracting the water from the wells is unlikely to have much of an effect on the surrounding aquifers above and below the seam being extracted.

The process for extracting CSG in the Camden area does not result in the creation of large voids underground which could collapse. Also, the seam containing the coal measures is not unconsolidated material and, in fact, is usually hard and well consolidated rock.

The conditions that could result in subsidence at the surface are, therefore, not present for this Project. It is, therefore, considered that the potential for subsidence, as a result of this project, is negligible.



10.5 Recommendations

No control measures need to be included in the Project to minimise the potential for surface subsidence given the current design of the wells and how they will be created.



Section 11. Summary of EHIA

The results of the EHIA are summarised in **Table 11.1**.

Table 11.1 Summary of EHIA Outcomes and Mitigation Measures

Health Aspect/Issue Evaluated	Potential Impact to Local Community Identified in EHIA	Potential Health Impacts Identified and Outcome of Assessment	Types of measures that could be implemented to enhance positive impacts or mitigate negative impacts
Noise	Potential impacts of noise addressed in EA	<p>If noise impacts are not effectively managed they can result in sleep disturbance, annoyance, children’s school performance and cardiovascular health. The specialist study has adopted noise goals for the Project that have been developed in line with regulatory guidance which is aimed at being protective of health in an urban environment.</p> <p>Noise impacts at the closest residents have been modelled at each proposed well location, including consideration of the worst-case event (night time with a temperature inversion). During operations it is estimated that noise from the Project will meet the relevant Project specific goals at all the existing houses around all the wells. This outcome is based on the incorporation of noise barriers at some locations to ensure that noise levels meet the project objectives. Noise during construction of all the wells is expected to be a bit higher than noise during operations. At some of the wells temporary noise barriers will be required to be installed to shield residences. There is potential for elevated noise in this area if planned residential developments proceed. If the developments go ahead a few additional noise control measures installed at the wells are estimated to minimise noise at these new houses.</p>	The noise assessment assumed that a number of noise management measures will be instigated as part of the Project. This will ensure noise emissions from all aspects of the work will be acceptable (i.e. meet the regulatory guidance).
Vibration	Potential impacts addressed in the EA	Vibration impacts assessed in accordance with regulatory guidance that includes the assessment of impacts on human comfort and damage to structures (heritage listed Upper Canal or residential homes). No impacts were identified during construction or operation of the proposed Project. Predicted levels of vibration are well below the regulatory criteria.	The only mitigation measure identified was the management and measurement of vibration impacts while working close to the Upper Canal (relevant to the assessment of structural impacts during the proposed works).
Subsidence	Potential impacts assessed in the EA	If significant subsidence was possible due to the activities undertaken as part of this Project, then impacts could include minor to significant damage to structures at the surface. However, no control measures need to be included in the Project to minimise the potential for surface subsidence given the current design of the wells.	No impacts are expected.
Local air quality	Potential impacts associated with construction (from dust and diesel vehicles)	Impacts from dust generation and oxides of nitrogen (from construction and vehicle emissions) have been assessed in accordance with NSW EPA guidance where National air quality goals are available that are based on the protection of public health.	No impacts are expected to occur during construction provided effective dust mitigation measures are implemented as outlined in the EA. These dust mitigation measures have been shown to be effective on many sites in the control of emissions during construction activities.
	Potential impacts during operations (including fugitive emissions of CSG)	<p>Potential fugitive emissions of methane and other major and minor compounds detected in gas (from existing operations) have been qualitatively and quantitatively assessed. The potential for hazards and health impacts associated with fugitive losses on the closest residential areas are low and essentially negligible.</p> <p>Impacts associated with the operation of generators at the well pads (during operations) have been evaluated on the basis of a conservative screening level approach and all concentrations are below air quality goals that are protective of public health, hence impacts are considered to be negligible.</p>	Fugitive emissions from current operations have been measured at the well heads (to test for leaks) and found to be minimal (lower than the level of leakage from the existing gas distribution system). No additional measures, other than ongoing leak testing and the completion of a fugitive emissions monitoring program, have been recommended. All data collected is required to be reviewed in line with appropriate industry standards where trigger levels for methane levels are available.

Health Aspect/Issue Evaluated	Potential Impact to Local Community Identified in EHIA	Potential Health Impacts Identified and Outcome of Assessment	Types of measures that could be implemented to enhance positive impacts or mitigate negative impacts
Groundwater quality (of beneficial use aquifers)	Potential impacts of well installation and operation on shallow beneficial use aquifers evaluated. Beneficial uses of the shallow aquifers include irrigation and stock watering. Existing groundwater not suitable for drinking water.	<p>Assessment of the local geology, in particular the characteristics of the rock strata between the target coal seam at 700m depth and the shallow aquifers with some beneficial uses (10-300m depth) and the well construction methodology (and required testing to demonstrate well installation meets the required standard) has indicated that there is no mechanism for any cross-contamination of aquifers during well installation. In addition there is no mechanism by which fluids used in drilling, hydraulic fracturing or workovers can migrate from the target coal seam to the shallow beneficial use aquifers.</p> <p>The potential for leaks of drilling fluids, hydraulic fracturing fluids or production water to be able to migrate to an impact on groundwater quality within the most shallow aquifer (located 75 m below ground level) is negligible, i.e. there is no mechanism by which these leaks can reach the shallow groundwater. Regardless the assessment considered impacts in the unlikely event that this occurred. All chemical concentrations were calculated to be low and below drinking water guidelines.</p> <p>The only mechanism of potential shallow groundwater contamination identified is where there may be perched groundwater present at the well site (none have been identified) and there is a slow leak of production water at the well pad, which may not be detected and repaired, leaks outside of the well pad bunding, may migrate over a long period of time to the perched groundwater, and the aquifer is of sufficient quality and volume (yield) to be extracted and used. Other fluids used in drilling, hydraulic fracturing and workover activities are only present when being used (i.e. not stored at the location) and hence there is no potential for undetected leaks. The potential for production water to leak and migrate to perched groundwater has been quantitatively assessed and all concentrations of chemicals (naturally present in the coal seam aquifer or from chemicals used in drilling, hydraulic fracturing or workovers) predicted to be present in the most shallow aquifer (at the closest point of extraction) are within relevant drinking water guidelines. Hence no health impacts are predicted from this worst-case leakage scenario.</p>	<p>No additional management measures have been identified, over and above those adopted in current operations, however the following aspects are noted to be of particular importance:</p> <ul style="list-style-type: none"> • The installation and testing of CSG wells in accordance with the required specification. • Ensuring spill detection and clean-up procedures are effectively communicated and implemented. • The regular checking of well pad bund integrity. • The regular checking and testing for leaks of stored production water at each well pad.
Surface water quality	Potential impacts on surface water quality, in particular the quality of water in farm dams and the drinking water supply within the Upper canal.	<p>Due to the operations proposed, the risk mitigation and management measures implemented, no mechanism of long-term impacts to any surface water body has been identified.</p> <p>The only impacts that may occur, under an unlikely worst-case scenario, is where the largest storage tank containing drilling mud, hydraulic fracturing fluid or production water splits at the well pad, is not cleaned up, the well pad bunding fails, the bund failure is not identified and repaired/cleaned-up, spilled fluids flow across the ground surface and discharge (10% of the spilled volume) to a farm dam or the Upper Canal with no sorption to soil, degradation or dissociation to other non-toxic compounds. This scenario has been quantitatively evaluated and no impacts have been identified that would affect drinking water quality supplied via the Upper Canal, or stock water/irrigation water quality supplied by farm dams.</p>	<p>No additional management measures have been identified, over and above those adopted in current operations, however the following aspects are noted to be of particular importance:</p> <ul style="list-style-type: none"> • Ensuring spill detection and clean-up procedures are effectively communicated and implemented. • The regular checking of well pad bund integrity. • The regular checking and testing for leaks of stored production water at each well pad.
Hazardous materials management	Potential impacts assessed in the EA	Assessment of hazards (explosive/flammable risks) has been undertaken in accordance with regulatory guidance. The assessment did not identify any acute hazards that would impact on any current or proposed residential or commercial property adjacent to the proposed wells.	A range of operational and security management measures are recommended at each well location to ensure risks are lower than assessed in the EA.

Section 12. Conclusions

AGL currently operates the Camden Gas Project (CGP) for the extraction of CSG from the Illawarra Coal Measures, within the Southern Coalfields of the Sydney Basin. The CGP includes 144 existing CSG wells (of which 105 are currently in operation), access roads, a high pressure supply pipeline, underground gas gathering lines (GGLs) and the Rosalind Park Gas Plant (RPGP). AGL currently proposes to expand its operations to the north of existing CGP infrastructure, including development of additional gas wells and associated field infrastructure (refer to **Figure 1.2**). The Northern Expansion Project would tie in to the existing CGP network (also shown on **Figure 1.2**). The primary objective of the Northern Expansion Project is to continue gas production from the Illawarra Coal Measures to supply the NSW energy market.

An Environmental Health Impact Assessment (EHIA) has been undertaken to address concerns raised by NSW Health and the local community in relation to the health impacts of the proposed expansion Project.

The assessment has considered potential for adverse health effects in the community associated with environmental impacts that may be associated with the proposed Project. The assessment has not considered ecological, political, economic or social aspects of the Project. In addition the assessment has addressed the potential for adverse health impacts associated with the Northern Expansion Project only, based on site-specific and project-specific information. Hence the assessment has not addressed other CSG projects that may operate in other parts of Australia or the United States, unless data has been collected that is directly relevant to the Northern Expansion Project.

The potential for risks to health from the Project in terms of noise, air quality, vibration, groundwater, surface water, acute hazards and subsidence has been reviewed in this EHIA. Many aspects of the Project are required to comply with a range of best practice regulatory policies or codes of practice. Also the AGL Environmental Management Plan commits AGL to undertake the works in accordance with other best practice requirements. The assessment does assume that these best practice requirements are incorporated into the Project (**Table 11.1**).

The risks posed have been found to be low and acceptable for all aspects of the Project.

Section 13. References

Specialist/Technical Reports

AECOM, 2010. AGL Camden Gas Project – Northern Expansion Environmental Assessment (Oct 2010).

AECOM, 2012. AGL Camden Gas Project – Northern Expansion Submissions Report (Oct 2012).

Broadstock, B., 2011. Impact of groundwater pumping on stacked water sources, NSW Office of Water, Sydney.

Herbert, C. and Helby, R., 1980. A guide to the Sydney Basin, Bulletin 26, Geological Survey of New South Wales, Department of Mineral Resources, Sydney.

Jewell, 2001. Assessment of groundwater impacts of coal-bed methane development, Chris Jewell and Associates, Cawdor, NSW.

KBR, 2008, Upper Nepean (Kangaloon) Borefield Environmental Assessment. Report for Sydney Catchment Authority, Kellogg Brown and Root Pty Ltd.

Merrick, N., 2009. Bulli Seam Operations Groundwater Assessment: A hydrogeological assessment in support of the Bulli Seam Operations Environmental Assessment. Unpublished report for Illawarra Coal Holdings Pty Ltd by Heritage Computing, July, 2009.

Parsons Brinckerhoff (PB), 2012. Update on the Phase 2 Groundwater Program – Denham Court Road, Denham Court. Unpublished report for AGL Energy Ltd, August 2012.

PB, 2008, Leonay – Emu Plains pilot testing program: Hydrogeological analysis of drilling and testing programs. Report for Sydney Catchment Authority, Parsons Brinckerhoff.

PB, 2011a, Phase 1 Groundwater Assessment and Conceptual Hydrogeological Model – Northern Expansion of Camden Gas Project. Unpublished report for AGL Energy Ltd. Parsons Brinckerhoff. Available online at www.agl.com.au/camden

PB, 2011b. Unpublished schematic stratigraphic diagram of Camden North prepared for AGL. Parsons Brinckerhoff.

Planager, 2010. Preliminary Hazard Analysis for AGL Energy Limited's Camden Gas Project: Expansion at Camden, NSW. Report prepared for AECOM, 30 July 2010.

SCA, 2005a. Metropolitan Water Plan- priority groundwater investigations for contingency drought relief – Area 2: Upper Nepean Catchment. Report no. 05- GL31A/2. Sydney Catchment Authority.

SCA, 2005b. Metropolitan Water Plan- priority groundwater investigations for contingency drought relief – Area 3: Upper Canal (Appin). Report no.05-GL31A/3. Sydney Catchment Authority.

Other references

ANZECC/ARMCANZ, 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

ATSDR, 1994. Toxicological Profile for Acetone. Agency for Toxic Substances & Disease Registry, available from <http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=5&tid=1>



Australian Bureau of Statistics, 2003. Socio-Economic Indexes for Areas: Australia 2001. Commonwealth of Australia. Canberra, Information Paper 2039.0.

Australian Bureau of Statistics, 2011. Selected characteristics retrieved from QuickStats, TableBuilder and DataPacks. www.abs.gov.au. Accessed September 2012 and November 2012.

Australian Bureau of Statistics, 2012. Census 2011. Available at: <http://www.abs.gov.au/websitedbs/censushome.nsf/home/Census?opendocument#from-banner=GT>

Australian Standard AS4645.3-2008. Gas Distribution Network Management. Available at: <http://infostore.saiglobal.com/store/Details.aspx?ProductID=1089795>

CCME, 2010. *Canadian Soil Quality Guidelines, Carcinogenic and Other Polycyclic Aromatic Hydrocarbons (PAHs) (Environmental and Human Health Effects), Scientific Criteria Document (revised)*, Quebec.

Day, S., Connell, L., Etheridge, D., Norgate, T., Sherwood, N., 2012 Fugitive greenhouse gas emissions from coal seam gas production in Australia. CSIRO, Australia.

DECCW, 2011. *Road Noise Policy*. Department of Environment Climate Change and Water NSW, Sydney.

DEEDI, 2011. Coal seam gas well head safety program. Final Report. Qld Department of Employment, Economic Development and Innovation.

DTIRIS, 2012a. Code of Practice for Coal Seam Gas. Fracture Stimulation Activities. NSW Department of Trade and Investment, Regional Infrastructure and Services. Available at: <http://www.resources.nsw.gov.au/community-information/coal-seam-gas/cop>

DTIRIS, 2012b. Code of Practice for Coal Seam Gas. Well Integrity. NSW Department of Trade and Investment, Regional Infrastructure and Services. Available at: <http://www.resources.nsw.gov.au/community-information/coal-seam-gas/cop>

enHealth, 2001. Health Impact Assessment Guidelines. Published by the Environmental Health Committee (enHealth), which is a subcommittee of the Australian Health Protection Committee (AHPC).

enHealth, 2004. Environmental Health Council of Australia's guidance - The health effects of environmental noise – other than hearing loss.

enHealth, 2012. 'Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards', Commonwealth of Australia.

EPHC, 2009. *Environmental Risk Assessment Guidance Manual for Agricultural and Veterinary Chemicals*, Environment Protection and Heritage Council.

Harris, P., Harris-Roxas, B., Harris, E. & Kemp, L., 2007. Health Impact Assessment: A Practical Guide, Centre for Health Equity Training, Research and Evaluation (CHETRE). Part of the UNSW Research Centre for Primary Health Care and Equity. University of New South Wales, Sydney.

HSDB (n.d.). *Hazardous Substances Data Bank*. Retrieved 2013, from Toxnet, Toxicology Data Network, National Library of Medicine: <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB>

Jeffrey, R.G., 2011. Assessment of hydraulic fracture height growth potential for treatments in Illawarra Coal Measures. CSIRO.



Liu K., Boulton P., Painter S. and Paterson L., 1996. Outcrop analog for sandy braided stream reservoirs; permeability patterns in the Triassic Hawkesbury Sandstone, Sydney Basin, Australia. AAPG Bulletin December 1996 v. 80 no. 12 p. 1850-1866.

NEPC, 1999. *Schedule B(4), Guideline on Health Risk Assessment Methodology*, National Environment Protection Council.

NEPC, 2010. *Draft National Environment Protection Measure, Guideline on Ecological Risk Assessment*, National Environment Protection Council.

NHMRC, 2011. *Australian Drinking Water Guidelines, National Water Quality Management Strategy*, Canberra: National Health and Medical Research Council and Natural Resource Management Ministerial Council, Commonwealth of Australia.

NSW EPA, 2000. *NSW Industrial Noise Policy*. Environment Protection Authority, Sydney.

NSW Health, 2007. *Groundwater use in urban areas. Factsheet*, available from:
http://www0.health.nsw.gov.au/factsheets/environmental/groundwater_urban.html

NSW Health, 2008a. *The Health of the People of New South Wales, Summary Report*. NSW Health, Report of the Chief Health Officer.

NSW Health, 2008b. *New South Wales Population Health Survey, 2005-2006 Report on child health*. NSW Health Centre for Epidemiology and Research.

NSW Health, 2010. *The Health of the People of New South Wales, Summary Report*. NSW Health, Report of the Chief Health Officer.

OEHHA, 1999. *Potential Health Risks of Ethanol in Gasoline*. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, available from
<http://oehha.ca.gov/air/pdf/etohR3.pdf>

OSM, 2001. *Technical measures for the investigation and mitigation of fugitive methane hazards in areas of coal mining*. Office of Surface Mining Reclamation and Enforcement, Department of the Interior, USA.

Saddler, 2012. *Review of literature on international best practice for estimating greenhouse gas emissions from coal seam gas production*, pitt&sherry.

Serov, P. Kunginis, L., Williams, J.P., 2012. *Risk assessment guidelines for groundwater dependent ecosystems*, NSW Department of Primary Industries, Office of Water, Sydney.

SIMTARS, 2010. *Gas Monitoring at Tara Gas Field for Safety and Health Division*, Department of Employment, Economic Development and Innovation, Queensland. Available at
[http://mines.industry.qld.gov.au/assets/petroleum-pdf/gas_monitoring_at_tara_gas_field_\(final\).pdf](http://mines.industry.qld.gov.au/assets/petroleum-pdf/gas_monitoring_at_tara_gas_field_(final).pdf)

SWSLHN, 2012. *South Western Sydney Local Health District, Community Health Profile*. South Western Sydney Local Health Network.

TPHCWG, 1999. *Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 4, Development of Fraction Specific Reference Doses (RfDs) and Reference Concentrations (RfCs) for Total Petroleum Hydrocarbons (TPH)*, 1997-1999.

UK HPA, 2010. *Methane, General Information Fact Sheet*. UK Health Protection Agency.



UNSW, 2013. Subsidence in groundwater basins, Article. Connected Waters Initiative, University of New South Wales. Available at: <https://www.connectedwaters.unsw.edu.au/resources/articles/subsidence.html>

USEPA, IRIS. Data and information available from the Integrated Risk Information System, an online database, available at <http://www.epa.gov/iris/>

USEPA, SCREEN3 Screening Level Dispersion Model, available from http://www.epa.gov/scram001/dispersion_screening.htm

USEPA, 1995. AP-42 Compilation of Air Pollutant Emission Factors, available from <http://www.epa.gov/ttnchie1/ap42/>

USEPA, 2012a. 'Regional Screening Levels for Chemical Contaminants at Superfund Sites', [online], Available at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm

USEPA, 2012b. 2012 Edition of the Drinking Water Standards and Health Advisories. EPA 822-S-12-001. Office of Water, US Environmental Protection Agency. Available at: <http://water.epa.gov/action/advisories/drinking/upload/dwstandards2012.pdf>

Volk, H., Pinetown, K., Johnston, C. and McLean, W. 2011. A desktop study of the occurrence of Total Petroleum Hydrocarbon (TPH) and partially water soluble organic compounds in Permian coals and associated coal seam groundwater. CSIRO.

WHO, 2000. Guidelines on Community Noise. World health Organisation, <http://www.who.int/docstore/peh/noise/guidelines2.html>

WHO, 2011. Guidelines for Drinking-Water Quality, Fourth edition. International Programme on Chemical Safety, ISBN 978 92 4 154815 1 (NLM Classification WA 675). Available at: http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/index.html