CAMDEN GAS WELLS HAZARD RISK ASSESSMENT

Prepared for: AGL Upstream Investments Pty Ltd

Document Number: AGLENE\40-B424

Revision 0

Prepared by: Karin Nilsson

23 February 2018

PO Box 1497
Lane Cove NSW 2066
Telephone: [02] 9427 7851
Email: karin@planager.com.au
www.planager.com.au

Planager
Risk Management Consulting

Camden Gas Wells Hazard Risk Assessment

Acknowledgment

The author would like to thank the teams from NSW EPA and from AGL Upstream Investments Pty Ltd from providing context and for their assistance in preparing this report.

Disclaimer

This report was prepared by Planager Pty Ltd (Planager) as an account of work for AGL Upstream Investments Pty Ltd. The material in it reflects Planager's best judgement in the light of the information available to it at the time of preparation. However, as Planager cannot control the conditions under which this report may be used, Planager and its related corporations will not be responsible for damages of any nature resulting from use of or reliance upon this report. Planager's responsibility for advice given is subject to the terms of engagement with AGL Upstream Investments Pty Ltd.

Rev	Date	Description	Prepared By	Reviewed By	Authorised By
A	24/07/2016	for Comment	Karin Nilsson	Anne Lewis	Karin Nilsson
B	02/02/2017	II for Comment	Karin Nilsson	Anne Lewis	Karin Nilsson
C	20/02/2017	Final for comments	Karin Nilsson	Anne Lewis	Karin Nilsson
D	09/06/2017	Final II for AGL	Karin Nilsson	Anne Lewis	Karin Nilsson
E	08/08/2017	Final for Comments	Karin Nilsson	Anne Lewis	Karin Nilsson
F	30/01/2018	Updates post EPA Comments	Karin Nilsson	Anne Lewis	Karin Nilsson
0	23/02/2018	Final report	Karin Nilsson	Anne Lewis	Karin Nilsson

Planager Risk Management Consulting

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

EXECUTIVE SUMMARY

E1 Introduction and Background

AGL Upstream Investments Pty Limited (AGL) operates the Camden Gas Project (the CGP) in the Macarthur region of New South Wales. The CGP has been safely supplying around five percent of NSW's gas needs since 2001 and is located around 65 kilometres south-west of Sydney.

AGL holds five of the six petroleum production leases in NSW, with the CGP licenced under Petroleum Production Licence PPL1, PPL2, and PPL4, PPL5 and PPL6. These leases are within the Camden, Campbelltown and Wollondilly local government areas.

The project includes 144 gas wells, some of which are suspended or abandoned. A total of 92 wells are in operation at the time of this report. Each gas well is connected to the Rosalind Park Gas Plant (RPGP) through a gathering system consisting of low pressure buried pipework (referred to as *gathering lines*).

A number of hazard and risk analyses have been undertaken throughout the life of the CGP, including those focussing on safety, health and environmental protection. As there was no report that consolidated the results of all these risk assessment, or demonstrated that all risks are managed to acceptable levels, the NSW Environment Protection Authority (NSW EPA) has requested that a ***holistic*** hazard and risk assessment (HRA) be carried out with a focus on the aboveground pipes, vessels and equipment of the CSG wells.

AGL has commissioned Planager Pty Ltd to undertake the HRA and to consolidate the results into this report. Planager is an independent Australian risk engineering consultancy specialising in risk minimisation and inherent safe engineering and management practices for the oil and gas, energy and mining sector.

This HRA has been prepared in accordance with the guidelines for hazard analysis developed by the NSW Department of Planning and Environment (NSW DP&E) in their Hazardous Industry Planning Advisory Paper No 6 (HIPAP6), and the levels of risk have been compared with the available risk criteria in NSW, Australia and Internationally, as appropriate.

E2 Scope and Aim

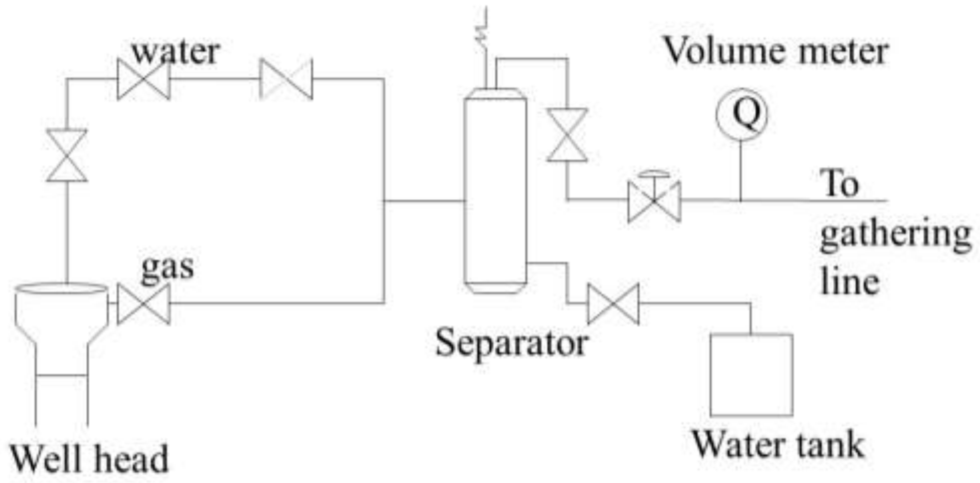
The aim of the HRA is to assess the risk to human safety, health and the environment associated with the above ground portion of the AGL CSG wells within the CGP, and to demonstrate that health, safety and the environment are protected in all circumstances in the vicinity of the above ground portions of the CSG wells.

The NSW EPA established the scope of the HRA as follows:

- Both routine and non-routine operation of the CSG wells must be assessed in order to identify possible emissions from the CSG wells in the form of gas, air, water and noise emissions;
- Emissions from the aboveground well equipment are to be included;
- The HRA is to use a risk focus, with all credible scenarios identified and assessed, and with the probability and consequences documented;
- All types and designs of gas wells in operation, shut-in or suspended must be included.

The general arrangement of a typical gas well is provided in Figure E1 below, showing the scope of the HRA.

Figure E1 – General Arrangement of the CSG Well



E3 Out of Scope

In order to keep the focus of the HRA on the aboveground portions of the gas wells, the upstream (below ground components of the gas well) and downstream plant and equipment (gathering line, gas plant) are excluded from the scope of the HRA. Please note, however, that the potential for an operational upset condition at these upstream and downstream facilities to trigger a hazardous incident at the gas well(s) is included in the scope.

In accordance with the NSW DP&E's guidelines for hazard analysis, construction activities are excluded from the scope of this HRA (and no construction activities are planned for the CGP gas wells), as are project-specific risk and workplace health and safety aspects for people working within the site boundaries. Further, this HRA does not assess any potential for health risks associated with climate change or greenhouse gas emissions.

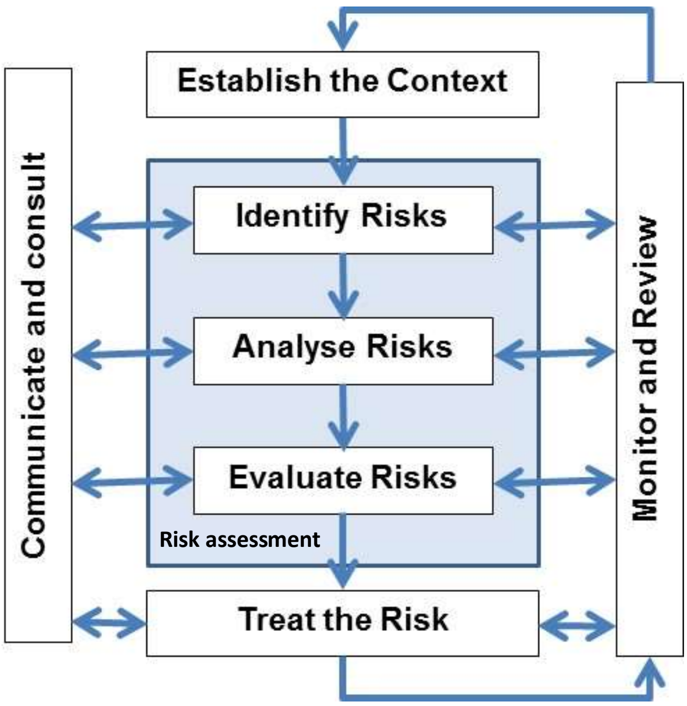
E4 Methodology

The approach for the HRA involves the following steps:

- Establishment of the context and foundation for the HRA;
- Identification of the hazards and risks associated with the gas wells;
- Estimation of the consequences of potentially hazardous incidents;
- Where the consequences may affect human safety, health and/or the environment outside of the site boundaries, estimation of the likelihood with which the incident may occur;
- Estimation of the risk by combining the frequency of occurrence of the hazardous incident with the probability of an undesired consequence to safety, health, and/or the environment; and
- Comparison of the risk with established guidelines and criteria.

This process is outlined in Figure E2 below.

Figure E2 - Risk Assessment Process



From ISO31000-2009 *Risk management*

A combination of qualitative and quantitative risk assessment has been used to determine the risks posed by the aboveground portion of the CSG wells. For each identified hazardous incident an estimate of exposure has been calculated and compared to appropriate NSW, Australia and Internationally safety, health and/or environmental protective guidelines to determine if the wells pose a risk with regard to each of the hazards. For each hazard, if the exposure from the wells is less than the guideline under all circumstances then there is no unacceptable risk. If the exposure from the wells may be larger than the guideline there is potential for unacceptable risk which can be addressed by implementing additional risk control and risk management measures.

E5 Results

The results of the HRA are summarised in Table E1 below.

E6 Conclusion

The review shows that all of the requirements for CSG well integrity and safe management are included in AGL methods for CSG wells that form part of the CGP.

Provided continued successful implementation of the technical controls included in this HRA, the risk to human safety, health or the environment associated with the AGL CSG wells adhere to all International or National criteria identified and specified in this holistic hazard and risk assessment.

It is recommended that AGL regularly conduct a review of this HRA to ensure that the relevant hazards and risks are identified and that the technical controls continue to be successfully implemented.

Table E1 - Results

Risk Dimension	Risk Description	Risk Assessment Outcome	Reference Documents
Safety	1. Leak of gas, ignition, fire and exposure to heat radiation	Acceptable risk Separation distances meet the criteria for land use planning	*Preliminary Hazard Analysis* for Camden Gas Project – 2002 (Planager) *Preliminary Hazard Analysis* for Camden North Expansion Project - 2010 (Planager) *Quantitative Risk Analysis* for Camden CSG wells multiwell pad (assessing risk from up to 6 gas wells within the same well pad) - 2007 (Planager) *Hazardous Industry Planning Advisory Paper No 4 Risk criteria* – 2011 (NSW Department of Planning and Environment) *Locational Guidelines - Development in the Vicinity of Operating Coal Seam Methane Wells* – 2004 (NSW Department of Planning and Environment) *Code of Practice for CSG Well Integrity* – 2012 (NSW Trade & Investment, Resources & Energy)
	2. Release of gas from pressure relief valve, ignition and exposure to heat radiation	Acceptable risk Turbulent and buoyant release ensures Lower Flammable Limit is not reached outside of the boundary and ignition of gas from human activity is therefore not a credible event	

Risk Dimension	Risk Description	Risk Assessment Outcome	Reference Documents
Health	3. Exposure to contaminated air from fugitive emissions from gas wells	Acceptable risk No significant air quality impact from well sites ensures very low risk to human health	*Environmental Health Impact Assessment*, Camden North Expansion Project – 2013 (EnRisks) *Assessment of the impact from opening of pressure relief valve* - 2016 (Planager) *National Environment Protection Measure goals* – 1998 (National Environment Protection Council) Australian Drinking Water Guidelines - 2011 (National Health and Medical Research Council) Fresh and Marine Water Quality Guidelines - 2000 (Australian and NZ Environment and Conservation Council) *Chief Scientist and Engineer Risk report*, CSG extraction in NSW – 2014 (NSW Government)
	4. Exposure to contaminated air from pressure relief valve opening	Acceptable risk Turbulence and buoyancy of the release ensure that gas concentrations do not influence background concentrations in the area	
	5. Health impact from loss of containment of saline water and chemicals	Acceptable risk Distances from wells to water bodies and dilution ensure low levels of pollutants	

Risk Dimension	Risk Description	Risk Assessment Outcome	Reference Documents
Environment	6. Environmental impact from loss of containment of saline water and chemicals	Acceptable risk Distances from wells to water bodies and dilution ensure low levels of pollutants	*Environmental Assessments* for Camden North Expansion Project - 2010/12 (AECOM) *Fugitive Emissions Monitoring Program*, Technical Report -2014 (Pacific Environment Limited) *Groundwater and Surface Water Monitoring Status Report*, Camden Gas Project - 2014-2015 (Parsons Brinckerhoff) Australian Drinking Water Guidelines - 2011 (National Health and Medical Research Council) Fresh and Marine Water Quality Guidelines - 2000 (Australian and NZ Environment and Conservation Council) *Chief Scientist and Engineer Risk report*, CSG extraction in NSW – 2014 (NSW Government)

Risk Dimension	Risk Description	Risk Assessment Outcome	Reference Documents
Noise	7. Noise from opening of a pressure relief valve	Acceptable risk While loud, the maximum peak noise level is not reached; the event is very infrequent and of relatively short duration	Noise assessment from pressure relief valve opening – 2016 (Planager, as part of present HRA) *Noise Management Sub Plan* for Camden Gas Project – 2015 (Wilkinson Murray) *WHS Regulations* - 2011 (NSW Government) *National Hazard Exposure Worker Surveillance, Noise exposure and the provision of noise control measures in Australian workplaces* - 2010 (SafeWork / ASCC) *National Code of Practice for Noise Management and Protection of Hearing at Work* – 2009 (NOHSC)

GLOSSARY

ACGIH	American Conference of Governmental Industrial Hygienists
AGL	AGL Upstream Investments Pty Limited
ALARP	As Low As Reasonably Practicable
AQIA	Air Quality Impact Assessment
AS	Australian Standard
ASCC	Australian Safety and Compensation Council (now known as SafeWork Australia)
ATC	additional technical controls
ATSDR	Agency for Toxic Substances and Disease Registry
CGP	Camden Gas Project
Code (the)	(the) Code of practice for CSG well integrity
CSE	(NSW) Chief Scientist & Engineer
CSG	coal seam gas
dB	decibel (unit for sound measurement / sound levels)
DG	Dangerous Goods
DP&E	Department of Planning and Environment (NSW)
EA	Environmental Assessment
EGBE	ethylene glycol monobutyl ether
EHIA	Environmental Health Impact Assessment
EPA	NSW Environment Protection Authority
EPL	Environment Protection Licence
Hazardous incident	Incidents with potentially hazardous consequences, identified following the methodologies described in the Department of Planning's guidelines for Hazard Analysis (HIPAP6)
HI	Hazard Index
HIPAP	Hazardous Industry Planning Advisory Paper
HRA	hazard and risk assessment
JSA	Job Safety Analysis
LDAR	Leak Detection and Repair

LFL	Lower Flammable Limits
NOHSC	(the Australian) National Occupational Health and Safety Commission
NSW DP&E	NSW Department of Planning and Environment
NSW CSE	NSW Chief Scientist & Engineer
OEHHA	Office of Environmental Health Hazard Assessment
PHD	Potentially Hazardous Development, defined by the Department of Planning (SEPP33)
pmpy	per million per year
Potentially hazardous incident	Incidents with potentially hazardous consequences, identified following the methodologies described in the Department of Planning's guidelines for Hazard Analysis (HIPAP6)
PPL	Petroleum Production Licence
ppm	parts per million by volume
PRV	Pressure Relief Valve
QRA	Quantitative Risk Assessment
RPGP	Rosalind Park Gas Plant
SCA	Sydney Catchment Authority
SCADA	Supervisory control and data acquisition
SEPP33	State Environmental Planning Policy No.33
TC	technical control
TLV	threshold limit value
TNO	the Netherlands Organisation for Applied Scientific Research
TPH	Total petroleum hydrocarbons
TPHWG	Total Petroleum Hydrocarbon Criteria Working Group
UFL	Upper Flammable Limit
WMO	World Meteorological Organization

REPORT

1 INTRODUCTION

1.1 BACKGROUND

AGL Upstream Investments Pty Limited (*AGL*) operates the Camden Gas Project (*the CGP*) in the Macarthur region of New South Wales. The CGP has been safely supplying around five percent of NSW's gas needs since 2001 and is located around 65 kilometres south-west of Sydney.

AGL holds five of the six petroleum production leases in NSW, with the CGP licenced under Petroleum Production Licence PPL1, PPL2, and PPL4, PPL5 and PPL6. These leases are within the Camden, Campbelltown and Wollondilly local government areas.

The project includes 144 gas wells, some of which are suspended or abandoned. A total of 92 wells are in operation at the time of this report. Each gas well is connected to the Rosalind Park Gas Plant (RPGP) through a gathering system consisting of low pressure buried pipework (referred to as gathering lines).

The NSW Environment Protection Authority (*NSW EPA*) has requested that a holistic hazard and risk assessment (*HRA*) be carried out with a focus on the aboveground pipes, vessels and equipment of the CSG wells.

AGL has commissioned Planager Pty Ltd to undertake the HRA and to consolidate the results into this report. Planager is an independent Australian risk engineering consultancy specialising in risk minimisation and inherent safe engineering and management practices for the oil and gas, energy and mining sector.

This HRA has been prepared in accordance with the guidelines for hazard analysis developed by the NSW Department of Planning and Environment (*NSW DP&E*) in their Hazardous Industry Planning Advisory Paper No 6 (HIPAP6, Ref 1), and the levels of risk have been compared with the available risk criteria, as discussed in Section 1.5.

1.2 SCOPE AND AIM OF STUDY

1.2.1 Inside scope

The aim of the HRA is to assess the risk to human safety, health and the environment associated with the above ground portion of the AGL CSG wells within the CGP, and to demonstrate that health, safety and the environment are protected in all circumstances in the vicinity of the above ground portions of the CSG wells.

The HRA uses a risk focus, with all credible scenarios identified and assessed, and with the probability and consequences documented.

The assessment includes the measures that AGL have in place to protect the community and the environment from the operation of the aboveground CSG well equipment.

The HRA takes into account possible CSG, produced water and other liquid emissions from all AGL wells operating at the CGP during routine and non-routine operations, as follows:

- Wells operating under routine conditions and potentially upset operating conditions[1];
- Wells being shut-in or suspended;
- Wells being set up for, and during, workover maintenance activities; and

[1] For example, operating under higher pressures than normal leading to a pressure excursion

- Wells under start-up conditions after having been shut-in for a period of time.

Explanations of these operating conditions are provided in Section 2.3.

The HRA includes triggers for potentially hazardous incidents from:

- a failure at the aboveground equipment at the well itself; and
- an upset condition *upstream* (i.e. belowground components of the well) and *downstream* facilities (i.e. gathering line, gas plant).

1.2.2 Out of scope

In accordance with the NSW DP&E's guidelines for hazard analysis (Ref 1) the construction[2] of the facility under review are excluded from the scope of this HRA, as are project-specific risk[3], and workplace health and safety aspects for people working within the site[4] boundaries.

In order to keep the focus of the HRA on the aboveground portions of the wells, the upstream (below ground components of the well[5]) and downstream plant and equipment (gathering line, gas plant) are excluded from the scope of the HRA. Please note, however, that the potential for an operational upset condition at these upstream and downstream facilities to trigger a hazardous incident at the gas well(s) is included in the scope.

This HRA does not assess any potential for health risks associated with climate change or greenhouse gas emissions.

[2] as relates to the CSG wells, this refers to field exploration/ drilling/ completion of new wells
[3] such as land clearing, road building, traffic
[4] trip, slip, fall, confined space, risk of objects dropping, work at height
[5] potential for subsurface water/gas interconnections are excluded from this HRA

1.3 Context and Foundation for this HRA

1.3.1 National and State legislation, regulations and other instruments

Requirements and obligations on AGL for their operation of the CGP have been imposed by way of:

- direct requirements specified in legislation;
- conditions of the petroleum title, development consent or other form of approval, imposed by legislation;
- conditions of the petroleum title or development consent or other form of approval, at the discretion of the Minister or approving body.

An overview of the NSW legislative and regulatory framework within which CSG industry participants must operate is presented in Table 1 below.

Table 1 – Overview, Legislative and Regulatory Framework for CSG (NSW)

Principal Act	Regulations	Statutory Instruments
NSW		
Petroleum Onshore Act 1991	Petroleum Onshore Reg. 2016	
Mine and Petroleum Site Safety (Cost Recovery) Act 2005 No 116		
Protection of the Environment Operations Act 1997	Protection of the Environment Operations (Clean Air) Reg. 2010	
	Protection of the Environment Operations (General) Reg. 2009	
	Protection of the Environment Operations (Noise Control) Regulation 2008	
	Protection of the Environment Operations (Waste) Reg. 2014	

Principal Act	Regulations	Statutory Instruments
	Protection of the Environment Operations (Underground Petroleum Storage Systems) Regulation 2014	
Environmental Planning and Assessment Act 1979	Environmental Planning and Assessment Reg. 2000	State Environmental Planning Policy (Major Development) 2005 State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007 State Environmental Planning Policy (State & Regional Development) 2011
Water Management Act 2000	Water Management (General) Reg. 2011	Access Licence Dealing Principles Order 2002
Water Act 1912	Water (Part 5—Bore Licences) Reg. 1995	
Wilderness Act 1987		
Environmentally Hazardous Chemicals Act 1985	Environmentally Hazardous Chemicals Reg. 2008	
Heritage Act 1977		
National Parks and Wildlife Act 1974	National Parks and Wildlife Regulation 2009	
Threatened Species Conservation Act 1995	Threatened Species Conservation (Biodiversity Banking) Regulation 2008 Threatened Species Conservation Regulation 2010	
Work Health and Safety Act 2011	Work Health and Safety Regulation 2011	

Principal Act	Regulations	Statutory Instruments
Commonwealth		
Environment Protection and Biodiversity Conservation Act 1999		
National Greenhouse and Energy Reporting Act 2007		National Greenhouse and Energy Reporting (Measurement) Determination 2008

1.3.2 Governmental codes of practice and guidelines

A number of governmental codes of practice and guidelines are relevant for the operation of the CSG wells, as listed below:

A. ***Guidelines for hazard analysis* (Ref 1) and *Risk criteria for land use planning* (Ref 7),** by the NSW DP&E, provide the methodology and criteria for assessing the hazards and risks of Potentially Hazardous Development[6] (PHDs) and for determining whether they are designed, constructed and operated in accordance with due regard to human health and safety and to the biophysical environment. The NSW DP&E use the risk assessment process and criteria to determine the separation distances around PHDs, and the NSW DP&E Locational guidelines (Ref 3, discussed below) was established based on this process and criteria. The adherence to the requirements set by the NSW DP&E in the guidelines for risk assessment and the risk criteria for land use planning is discussed in Section 4 of this HRA.

B. ***Code of practice for CSG well integrity* (*the Code,* Ref 2)**, by the NSW Trade & Investment, Resources & Energy, provides guidance …*to ensure that well*

6 Defined as developments which involve activities which, in the absence of locational, technical or operational controls, may create an off-site risk to people, property or the environment (Ref 7)

operations are carried out safely, without risk to health and without detriment to the environment.

The aim of the Code is to establish a best practice framework which includes mandatory standards for well design and construction, including for:

- design of CSG wells to guarantee the safe and environmentally sound production of gas;
- well monitoring and maintenance; and
- management of produced water from the CSG extraction process.

While it is recognised that the Code was introduced in 2012, the same year AGL drilled their last well in the CGP field, and hence after the design and construction of AGL's last CSG well had been completed, AGL's adherence to the guidelines in the Code was critically reviewed to inform the present HRA. The detailed results are listed in Appendix 1.

C. Locational guidelines **(Ref 3)** by the NSW DP&E, provide guidance for Consent Authorities across NSW to ensure adequate buffers between a development and an existing or future CSG well installation. Separation distances are described in the form of circular areas around the gas wells, centring at the gas well head. The separation distances are determined based on the risk of loss of well integrity with subsequent ignition and fire and harm to human safety. The adherence to the requirements set by the NSW DP&E in the Locational guidelines is discussed in Section 4 of this HRA.

1.3.3 Chief Scientist and Engineer review into CSG activities in NSW

A major independent review into CSG activities in NSW was carried out by the NSW Chief Scientist & Engineer (*the CSE Review)* over a period of 19 months, from February 2013 with the final report published September 2014.

The scope of the CSE Review included establishing risk pathways for both aboveground and belowground facilities, including subsurface water/gas interconnections and interactions. While the belowground facilities and subsurface interconnections are outside the scope of this HRA, the CSE Review still provides a useful platform on which to build the present HRA, in particular, in framing and assessing the risk pathways associated with aboveground well equipment.

The CSE Review examined the potential human health, social and environmental impacts of CSG extraction in NSW. The outcome of the review was published in a number of reports, including:

- *CSE Initial report* (Ref 4), setting the scope, aim and methodology of the review;
- *CSE Risk Report* (Ref 5), detailing the management of human health and environmental risks from CSG activities; and
- *CSE Final report* (Ref 6), summarising the findings of the CSE Review.

The CSE Review built on the expertise of multidisciplinary teams from academia and industry and included input from government and the community. More than 20 background papers by experts on a range of topics backed up the CSE Review. Rigorous community consultation in the form of public submissions, site visits and meetings with local government and community groups and workshops was also conducted to understand the concerns surrounding the CSG topic.

1.4 STUDY METHODOLOGY

The general principles for hazard and risk assessment for land use planning are:

- Avoidance of all avoidable risks;
- Reduction of the risk wherever practicable, even where the likelihood of exposure is low;

- Containment of the effects of significant hazardous incidents within the site boundaries[7] wherever possible; and
- Minimisation of any incremental risk from a development to within established risk criteria and As Low As Reasonably Practicable (ALARP) principles[8].

The approach for hazard and risk analysis in NSW, as defined by the NSW DP&E (Ref 1) involves the following steps:

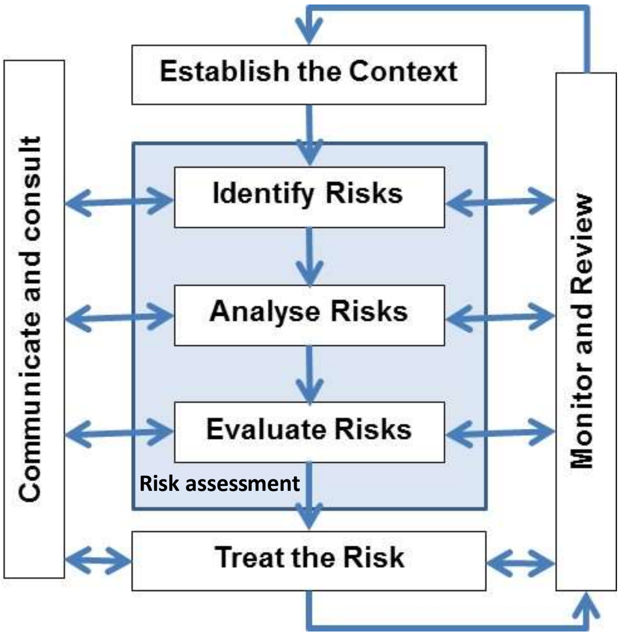
- Establishment of the context and foundation for the risk assessment;
- Identification of the hazards and risks associated with the gas wells;
- Estimation of the consequences of potentially hazardous incidents;
- Where the consequences may affect human safety, health and/or the environment outside of the site boundaries, estimation of the likelihood with which the incident may occur;
- Estimation of the risk by combining the frequency of occurrence of the hazardous incident with the probability of an undesired consequence to health, safety and/or the environment; and
- Comparison of the risk with established guidelines and criteria.

This process is outlined in Figure 1.

7 Site boundaries of the wells sites is defined by the security fence

8 The use of the term *ALARP* (or *As Low As Reasonably Practicable*) by the DP&E in their HIPAP4 is approached in the same manner as the SFAIRP (So Far As Is Reasonably Practicable) criteria defined in the NSW Work Health and Safety (WHS) Regulations-2011

Figure 1 - Risk Assessment Process



From ISO31000-2009 *Risk management*

The characteristics of a hazard are often established by its nature and cannot be easily changed. For example, CSG is a flammable gas, a fact that cannot be changed.

Exposures, on the other hand, depend on:

- The nature of the hazard (the situation in which the hazard arises);
- Exposure mechanism (how people, property and/or the environment might be exposed); and
- Dosage (the quantity, duration and frequency of exposure).

Generally, risk management measures are focused on reducing, changing or removing exposure to a hazard. For example, in the case of CSG, the likelihood of a release of the gas is minimised through a set of formalised protocols, controls and practices; ensuring that any released gas is naturally dispersed through its natural buoyancy and natural ventilation of the area, removal of sources of ignition in the area of a potential flammable cloud, etc.

In this HRA a combination of qualitative and quantitative risk assessment has been used to determine the risks posed by the aboveground portion of the CSG wells. For each identified hazardous incident an estimate of exposure has been calculated and compared to appropriate National or International health and/or safety protective guidelines to determine if the wells pose a risk with regard to each of the hazards. For each hazard, if the exposure from the wells is less than the guideline under all circumstances then there is no unacceptable risk. If the exposure from the wells may be larger than the guideline there is potential for unacceptable risk which can be addressed by implementing additional risk control and risk management measures.

There is a number of risk control/management measures that must be included in gas well design and operation, which are based on operating the wells in terms of best practice, and which are aimed at treating the risk associated with the wells. The inclusion of these measures is discussed in Appendix 1 and is often assumed in the risk calculations.

1.5 Risk Criteria

1.5.1 Criteria for human safety – Heat radiation

Criteria for risks to human safety from potentially hazardous industry are set by the NSW DP&E in their HIPAP4 *Risk criteria for land use planning* (Ref 7), as shown in Table 2 below, and relate to the *Individual fatality risk* (or the risk of death to a person at a particular point). The risk associated with the CSG wells is evaluated against these criteria in Section 4.

Table 2 – Risk Criteria for Human Safety

Risk criteria	Land use			
	Active open space	Business	Residential development	Sensitive development
Per million per year	10 pmpy	5 pmpy	1 pmpy	0.5 pmpy

pmpy = per million per year (equivalent to 10^{-6} times per year)

The risk criteria in Table 2 have been adopted by the NSW DP&E when assessing the safety implications of industrial development proposals and when considering land use proposals in the vicinity of potentially hazardous facilities.

The NSW DP&E have concluded that if a risk from a potentially hazardous installation is below most risks being experienced by the community, then that risk may be tolerated. This is consistent with the basis of other nationally and internationally adopted risk criteria. Table A2.1 in Appendix 2 indicates a range of various risks to which people are exposed as the result of various activities. Further context is provided by Table 3, which shows the Annual risk of death for various United Kingdom age groups based on deaths in 1999. Both tables are sourced from the NSW DP&E's HIPAP4 *Risk criteria for land use planning* (Ref 7).

Table 3 - Annual Risk of Death from All Causes in the UK

Population group	Risk as annual experience (pmpy)	Risk as annual experience per million
Entire population	1 in 97	10,309
Men aged 65-74	1 in 36	27,777
Women aged 65-74	1 in 51	19,607
Men aged 35-44	1 in 637	1,569
Women aged 35-44	1 in 988	1,012
Boys aged 5-14	1 in 6, 907	145
Girls aged 5-14	1 in 8,696	115

1.5.2 Criteria for human health and the environment – Noise exposure

The NSW WHS Regulations 2011 set the requirements for management of noise and noise exposure in NSW (refer Clauses 56 to 59 in the WHS Regulations). The exposure standard for noise, in relation to a person exposed to a noise (in Clause 56) sets the following criteria:

(a) $L_{Aeq,8h}$ of 85 dB(A), or

(b) $L_{C,peak}$ of 140 dB(C) [9]

The Australian Safety and Compensation Council[10] (ASCC) further provides the maximum lengths of time a worker can be exposed to sound without exceeding the occupational environmental noise level exposure[11] (Ref 8). The relationship between sound level and duration of exposure for risk of hearing damage is provided in Table 4.

The risk associated with the CSG wells is evaluated against these noise criteria in Section 6.

Table 4 - The maximum length of time (minutes) a worker can be exposed to sound without exceeding $L_{Aeq,\,8h}$ 85dB(A) and typical sound levels of common occupational noises

Sound level (dB)	Maximum exposure time (minutes)
85	480 (8 hours)
88	240 (4 hours)
91	120 (2 hours)
94	60 (1 hour)
97	30
100	15
103	7.5
106	3.75
109	1.88

Sound level (dB)	Equivalent noise sources
65	Normal conversation
80	Hair dryer
85	Smoke alarm / hand saw
90	Lawn mower
95	Loud crying / hand circular saw
100	Jackhammer at 10m
105	Chainsaw at 1m
110	Siren at 10m

[9] $L_{Aeq,8h}$ means the eight-hour equivalent continuous A-weighted sound pressure level in decibels (dB(A)) and $L_{C,peak}$ means the C-weighted peak sound pressure level in decibels (dB(C)). Both sound pressure levels are referenced to 20 micropascals and determined in accordance with AS/NZS 1269.1:2005 (Occupational noise management—Measurement and assessment of noise immission and exposure).

[10] now known as SafeWork Australia

[11] for an average daily (8 hour equivalent)

Sound level (dB)	Maximum exposure time (minutes)
112	0.94
115	0.47
118	0.23
121	0.12
124	0.06

Sound level (dB)	Equivalent noise sources
115	Sandblasting/rock concert
120	Threshold of pain

Data sourced from the SafeWork *National Hazard Exposure Worker Surveillance, Noise exposure and the provision of noise control measures in Australian workplace*, Ref 8

1.5.3 Criteria for human health and the environment – Contaminated air

Emissions of CSG into the atmosphere from leaking plant and equipment have the potential to contaminate the ambient air.

There are no specific health criteria for methane commonly used in NSW or internationally that are relevant to concentrations that might be expected locally associated with emissions of coal seam gas into the atmosphere (Refs 9, 10). The NSW Health's fact sheet for *CSG and Health in the Camden Gas Project Area* (Ref 11) states that: *Methane is a low toxicity gas which has no impacts on human health at concentrations that commonly occur in the air around us.*

Since 2006, the World Meteorological Organization has published a series of Greenhouse Gas Bulletins[12] that report on observed global levels of greenhouse gases, including methane, in the atmosphere. The most recent bulletin (dated October 2016) reports a globally averaged volumetric concentration of methane of 1.85 ppm in 2015, compared with 1.83 ppm in 2014 and 1.82 ppm in 2013. According to the Fugitive Emissions report (Ref 12), methane levels in urban areas are commonly higher than the global average ranging from 1.8 to 3.0 ppm.

[12] Bulletins are available at http://www.wmo.int/pages/prog/arep/gaw/ghg/ghgbull06_en.html

In the absence of specific health criteria, the risk associated with the CSG wells is evaluated against reported global and urban levels in Section 7.

1.5.4 Criteria for human health and the environment – Liquid contaminants

The approach used in this HRA is to use the risk matrix established in the Environmental Health Impact Assessment EHIA (Ref 13) for exposure to liquid contaminants, as presented in Table 5, with the interpretation of the risk outcomes presented in Table 6.

The risk associated with the CSG wells is evaluated against these criteria in Section 8.

Table 5 - Matrix Adopted to Characterise Environmental Risk Issues

Receptor				Consequence				
				Negligible 1	Low 2	Moderate 3	High 4	Severe 5
Off-Site Human Health Issues (chronic)				No adverse long-term health effects associated with low level environ-mental exposures	Minor transient health effects or odour	Transient effects that may require medical treatment such as respirato-ry effects, more significant irritation	Permanent health effects that require extended medical treatment and/ or permanent disability	Death or significant injury likely to result in death
Off-Site Impacts to Aquatic Ecosystem				Very low potential for adverse effects on aquatic eco-system	Low potential for adverse effects on aquatic eco-system	Moderate potential for adverse effects on aquatic eco-system	High potential for adverse effects on aquatic eco-system	Very high potential for significant adverse effects on aquatic eco-system
Likelihood of Exposure at Receptor	Confirmed use of aquifer or direct discharge to env./ ecosystem	Very likely	5	N	L	M	H	E
	Potential use of aquifer or discharge to local env./ ecosystem	Likely	4	N	L	M	H	E
	Possible use of aquifer, limited management measures in place to prevent surface release (surface liq. release may reach environment)	Possible	3	N	L	M	M	H
	No use of aquifers for any purpose, management measures in place - unlikely liquid releases at ground surface	Unlikely	2	N	L	L	L	L
	Management measures in place to prevent surface liquid releases	Highly unlikely	1	N	N	N	N	N

from the Environmental Health Impact Assessment EHIA (Ref 13)

Table 6 - Risk Outcomes

Risk rank	Description
N	Negligible risk - no adverse impacts
L	Low risk - potential for impacts is very low and potential for impacts to result in adverse effects is low. Risk issues identified can be effectively managed through implementation of appropriate management measures.
M	Medium risk - risk considered to be higher than identified in low risk category, risks should be quantified and management may be required
H	High risk - potential for significant exposures that have the potential to exceed acceptable risk levels for human health or ecological environments
E	Extreme risk - significant health and/or ecological effects may occur

1.5.5 Domino Effects

Domino *effects* are defined by the NSW DP&E in their guidelines for hazard analysis (Ref 1) as an event where one incident may initiate others in nearby plant and equipment.

Domino effects from a fire at a CSG well site to neighbouring structures are assessed in Section 4.

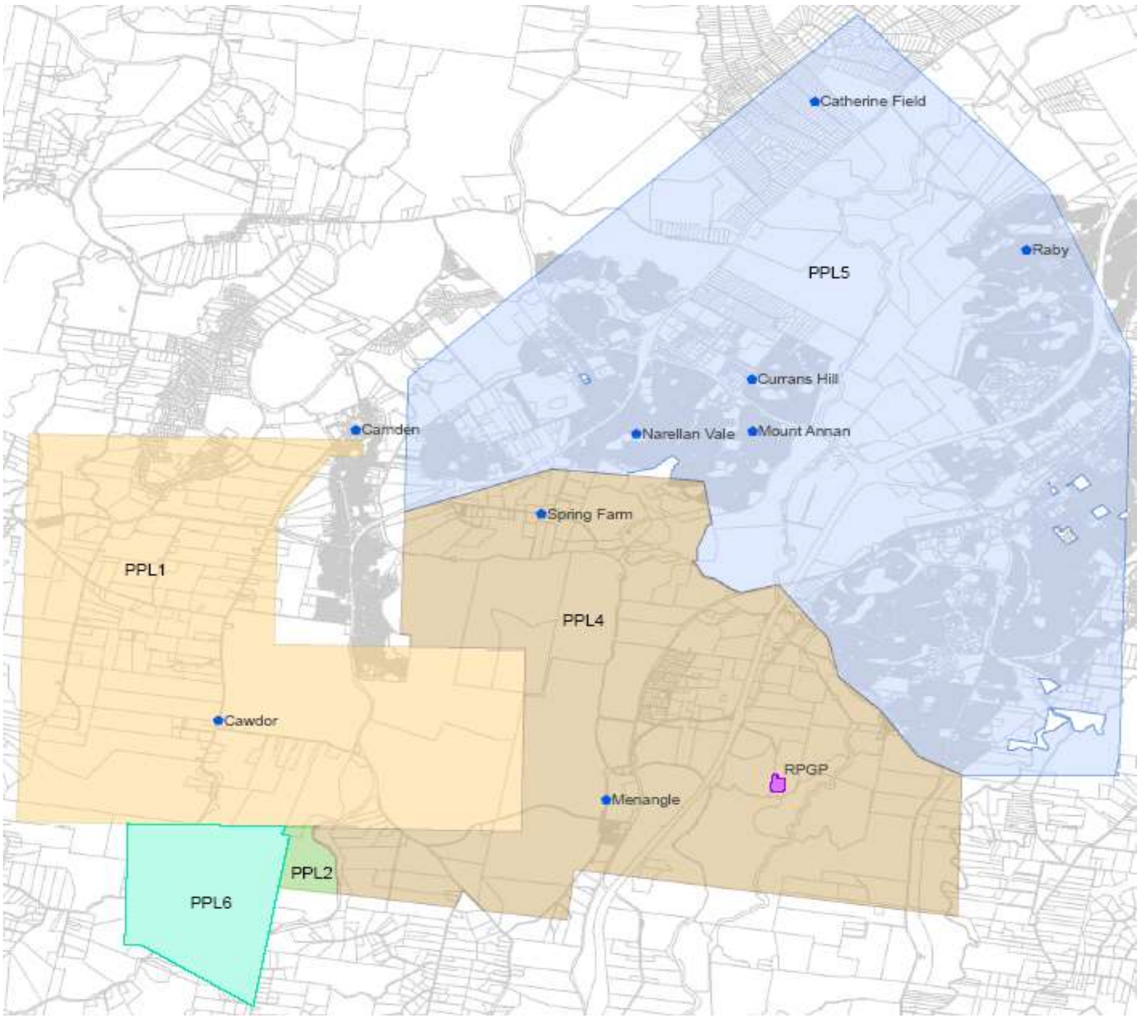
The risk assessment did not identify any other potential domino effects associated with the wells.

2 DESCRIPTION OF THE GAS WELL DEVELOPMENT

2.1 LOCATION OF THE DEVELOPMENT

The location of the CSG well development is shown in Figure 2. Townships and suburbs are shown with a blue dot. A total of 92 wells are in operation in the CGP field at the time of this report.

Figure 2 - Site location

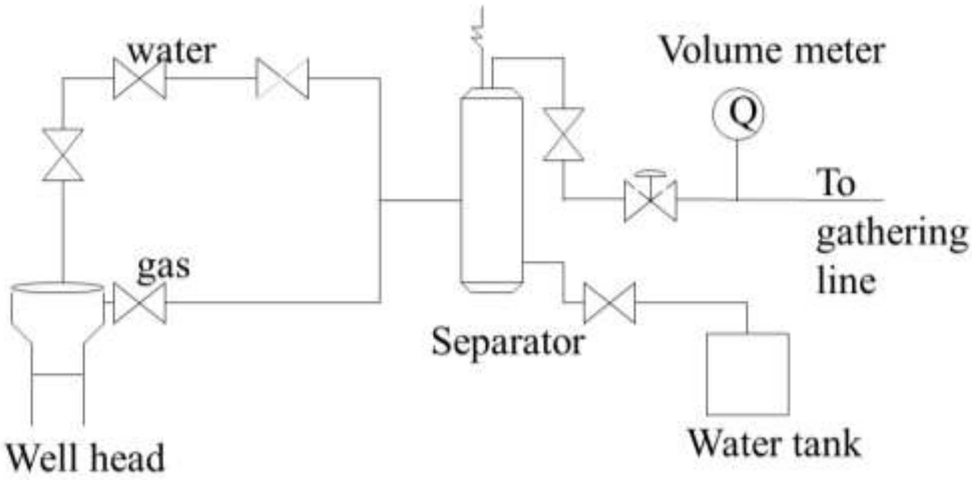


Legend:
PPL = Petroleum Production Licence
PPL1, 2, 4, 5 & 6 are issued to AGL.
PPL3 is not issued to AGL
RPGP = Rosalind Park Gas Plant

2.2 DESCRIPTION OF CSG WELLS

The general arrangement of a CSG well is presented below:

Figure 3 – General Arrangement, CSG Well



The following CSG well above-surface equipment is included in the present HRA:

- *Wellhead* collar which connects the well head casing and tubing to the well head manifold, complete with shut down valve, pressure control and a number of instrumented protective features.
- *Separator* (with pressure relief valve) used to separate water from incoming gas. The separator is typically connected to a water tank to collect the separated water. If the well no longer produces water the water tank is removed.
- *Flow line inlet piping (or meter run)* - connects the well with the gathering line (typically via the separator), complete with pressure control, non-return valve and instrumented protective features.
- Fenced off area and enclosure which acts as a safety and operational barrier between the well and the surrounding land use, and which forms the basis of the site boundaries in this HRA.

Normally, only one CSG well is located within a well site, but a well site can include up to six (6) wells.

2.3 OPERATION

2.3.1 Routine well operation

CSG flows from the well through the above ground flow line inlet piping into underground gathering lines to the gas plant (RPGP).

Produced water from the CGP wells is stored temporarily on site in above ground tanks at each well pad. The water is then collected periodically via truck, and transported to the RPGP. Only one site has an underground storage tank – a hold test is performed annually to confirm tank integrity.

Supervisory control and data acquisition (SCADA) system allows remote monitoring and control of the wells from the control room at the RPGP.

Upset conditions at the well would produce an alarm at the permanently manned RPGP, allowing the operator to investigate and respond, e.g. by shutting down the well operation. Certain conditions would initiate an automatic trip of the well, shutting it in without requiring operator intervention. This includes a bush fire impacting the well, where the shutdown valve would close automatically via burn through of the fusible link, thus automatically closing the valve. The well head and the shutdown valve are rated for fire conditions (to API Spec 6A).

2.3.2 Non routine operation - workover maintenance

Throughout the life of a CSG well at various times, a workover rig is required to access and perform a variety of functions including well maintenance activities, installation and removal of downhole pumps and well decommissioning (plug and abandonment) operations. During workover maintenance operations, small-bore tubing is installed from the workover rig into the production casing to circulate fluid down the tubing to remove debris or sand from the well. Although the frequency of the workover operations is very low (often less than once per well per year) they require appropriate operational and risk management controls to be in place. For the purposes of this HRA, the frequency of workover operations is set as one per year (in line with the NSW DP&E Locational Guidelines, Ref 3).

2.3.3 Shut in conditions

The wells are occasionally isolated, for example during shut down of the RPGP. When isolated, the shutdown valve on the well head piping is closed, allowing pressure in the well head to rise. The well head and shut down valve are rated to fire conditions (API Spec 6A) and have a designed working pressure rating that is in excess of the maximum anticipated surface pressure capable of being produced from the reservoir formation

2.3.4 Start-up conditions

After prolonged shut-in of the wells, the wells would be re-opened, e.g. once the RPGP is re-started, following detailed procedures whereby the wells are opened by the field operator at the well site and the wells are monitored by both the field operator and the operator at the RPGP.

2.3.5 Suspended well

A suspended well is a well on which operations have been discontinued. The usual context is an uncompleted well where operations ceased during drilling, or a well which has reached the end of its productive life, but which has not been plugged, abandoned and rehabilitated. All aboveground well equipment is removed and only the relatively small well head is left protruding from the ground. Enclosure and signposting are still maintained.

2.4 Inspection and Maintenance Activities

General inspection and maintenance activities form part of the ongoing operation of the well, and are designed to maintain the integrity of the equipment and systems. Many of these activities follow the requirements in the Code of practice for well integrity, including:

- Regular visual inspections of the integrity of each well, vegetation management and fencing;

- Regular monitoring of equipment operation, recording of gas flow rates and pressures
- Regular leak testing (leak testing performed at least 6-monthly);
- Regular inspection of the separator, fittings and pressure piping and regular testing of pressure safety valves, as per regulatory requirement in the Code of Practice for CSG well integrity (Ref 2) and the Australian Standard AS3788-2001 *Pressure Equipment In-service Inspection* (Ref 14).

AGL uses a Preventative Maintenance database to manage the inspection and maintenance activities by issuing Work Orders for scheduled activities and for repair activities. Regular internal audits and two three-yearly independent audits (a *Hazard Audit* and a *Compliance Audit,* by NSW DP&E approved auditors) are used to assess the implementation of maintenance requirements.

2.5 Well Site Occupancy

The CSG well sites are un-manned apart from during well site inspections and workover operations and briefly during well start up after prolonged shut-in.

The process conditions are permanently monitored from the RPGP SCADA system.

2.6 Security and Emergency Management

The CSG wells are fully fenced with a locked gate. The fence line defines the boundaries of the well. Security cameras are installed at selected wells. Regular patrols checks fencing and security measures.

A Pollution Incident Response Management Plan (PIRMP) is available, setting out incident notification procedure, actions following incident, communication, training, etc. An Emergency Response Plan and Procedures (including bush fire response flood management) are available for the Camden Gas Project, including for the wells.

Spill kits are kept at the gas well site when chemicals are used.

2.7 STORAGES

There are generally no storages of dangerous goods (DGs) or other chemicals at the wells. If generators are used then some diesel will be stored within the well compound (in the generator fuel tank). Where water is produced at the wells (and removed from the gas stream using the separator) a water storage tank is located at the well site.

During workover activities, DGs and other chemicals may be securely stored at the well site, as discussed in Section 3.1.

3 HAZARD IDENTIFICATION

The hazard identification is based on the following three steps:

- Assessment of hazardous materials involved in the CSG operation and maintenance that may, if control is lost, result in potentially hazardous incident(s). Refer to Section 3.1;
- Review of the key risk pathways and technical controls reported in the technical assessments carried out for the CSG wells (Refs 13 and 19 to 24). Refer to Section 3.2; and
- Review of the above to, as far as possible, identify all hazards and risk incidents which pose a threat to human safety, health and the environment from the CSG wells. Refer to Section 3.3.

3.1 HAZARDOUS MATERIALS

3.1.1 Coal seam gas

Properties: The typical compositions of the CSG extracted in the CGP are summarised in Table 7 (Appendix A in the Environmental Health Impact Assessment – Camden Northern Expansion Project, Ref 13). CSG is predominantly methane (about 95 to 97%), with low levels of carbon dioxide, ethane, propane and with traces of other hydrocarbons. CSG is a buoyant, lighter than air, gas with a specific gravity of 0.6 relative to air (i.e. 60% of the specific gravity of air). On release into the open, CSG tends to rise rapidly to high above the point of release where it disperses to below potentially harmful concentrations.

Table 7 – Analysis of CSG samples from RPGP

	Level		
CSG Component	Sample 1	Sample 2	units
Methane	96.5	97.2	%
Carbon dioxide	3.41	2.72	%

CSG Component	Level Sample 1	Sample 2	units
Ethane	0.133	0.0654	%
Propane	0.00107	0.0103	%
Trace gas analysis			
Ethanol	0.290	0.270	ppm
Acetone	0	0.074	ppm
Aliphatic:			
TPH C5-C6	0.97	0.96	ppm
TPH >C8-C10	7.75	6.29	ppm
TPH >C10-C12	0.75	0.65	ppm
Benzene	<0.02	<0.02	ppm
Toluene	<0.004	<0.003	ppm
Ethylbenzene	<0.006	<0.004	ppm

Note 1: Gas samples taken at the RPGP from gas sourced from the wells

Note 2: Results are those obtained on an air free basis. Only those components that were present in the samples at levels above the limits of detection are shown

Note 3: ppm = parts per million by volume; % = volume/volume percent

Note 4: TPH = Total petroleum hydrocarbons

Flammability: CSG is flammable, and at concentrations between about 5.5% and 14% in air (i.e. between the lower and the upper flammable limits, LFL and UFL) can pose a safety risk to people and property if ignited. Subject to gas pressure, the ignited gas burns as a jet (or torch) fire[13]. If allowed to accumulate, a delayed ignition of CSG could result in an explosion or a flash fire; however, natural

[13] In the same manner as town gas for domestic cooking or heating

ventilation at the gas wells ensures that this risk is negligible. The risk associated with the flammable properties of CSG is assessed in Section 4 and 5.

Noise: A release of CSG from a pressure relief valve (PRV) or from a hole in a pipe or other aboveground plant equipment at the well may be noisy, with noise being a potential human health risk. The risk associated with noise produced from a potential release of CSG is assessed in Section 6.

Contaminated air: Leaking plant and equipment may release CSG into the atmosphere, which may or may not catch fire, depending on the circumstances of the release (e.g. gas concentration, presence of an ignition source). The potential for a non-ignited release of CSG to affect air quality is assessed in Section 5.

Products of combustion: Combustion products produced when CSG is burned are the same as those produced from burning town gas for domestic cooking, i.e. water and carbon dioxide, and there is very little smoke associated with a CSG fire. The heat from the fire would lift the products of combustion into the atmosphere, and any smoke generated would disperse at altitude. The risk to human safety from CSG products of combustion or smoke is negligible.

Gas pressure: In close proximity to well equipment, the pressure of CSG may be hazardous in case of an uncontrolled release and therefore may be a concern to maintenance technicians at the wells. Pressure hazards, while important to people working at a gas well, are extremely unlikely to have implications beyond the immediate location of the release and to pose a threat to human safety outside of the well site fence line. This risk is closely managed at AGL through job safety analysis (JSA) and other risk assessment practices, in accordance with NSW Work Health and Safety Act and Regulation.

Asphyxiation hazard: Due to the buoyancy and pressure of CSG, any release of credible proportions from the wells, in the open, would not present an asphyxiation hazard. With standard confined space entry procedures the risk associated with asphyxiation from CSG is minimal and not discussed further in this HRA.

Odour: CSG is an odourless gas. The CSIRO describes it as a … *colourless, odourless, non-toxic mixture of a number of gases but mostly made up of methane (generally 95-97 per cent pure methane)* (Ref 15). The risk of exposure to offensive odour from CSG wells is negligible.

3.1.2 Liquids used and produced

Materials used in routine operation:

Very few chemicals are held at the well pad during routine operation, and are limited to:

- Greases and lubricating oils used for valve stems and pumps. All greases and oils have low vapour pressure with minimum hazardous vapours evolved from vaporisation or degassing. All greases have food grade rating. The greases are stored in small quantities in cartridges. In the very unlikely event of a release, these materials would be contained within the well site boundaries for clean-up.

- Diesel used in rotating machinery has the potential to cause environmental harm if released. Diesel is stored on site in double skinned tanks which would act as an internal bund in the very unlikely event of a leak from the primary containment and thus a leak would be contained within the well site boundaries.

- Produced water (saline) from gas wells contains trace elements that have a potential to be pollutant. The key compounds found in the produced water include traces of heavy metals (arsenic, nickel, lead etc.), methane gas dissolved in the water, and traces of hydrocarbons (refer Table 8). A comparison against the Australian Drinking Water guideline (Ref 16) is provided for context from a human health perspective. A comparison against the Fresh and Marine Water Quality Guidelines (Ref 17) is provided in Appendix 2, for context from environmental perspective. The produced water is transported off site for treatment in the RPGP. The risk associated with storage of produced water at the well pad is assessed in Section 8.2.

Table 8 – Chemicals Present at the CSG Wells (as Traces in Produced Water)

Activity	Chemical	Concentration in Fluid (at well pad) (mg/L)	Australian drinking water guideline (Ref 16) (mg/L)
Produced Water (where maximum concentrations exceed drinking water guidelines)	Total dissolved solids	23,500	600
	Arsenic	0.113	0.1
	Strontium	10.2	9.3
	Barium	35.5	2
	Nickel	0.024	0.02
	Lead	0.026	0.01
	Iron	15.4	11
	Bromine	5.7	2
	Iodine	0.8	0.16
	Fluoride	3.9	1.5
	Methane	10,516	10,000
	Naphthalene	0.0192	0.0061
	Benzo(a)pyrene	0.0011	0.00001
	Benzo(b)fluoranthene	0.0018	0.0001
	Benzo(g,h,i)perylene	0.0017	0.001
	Benzene	0.01	0.001
	Traces of hydrocarbons (TPH C10-C14; C15-C28; C29-C3)	77.7	0.27

Refer EHIA, Ref 13

Maintenance and workover:

During maintenance and workover, a few more chemicals may at times be required, as presented in Table 9 and discussed below.

Table 9 – Summary of Chemicals Present at the CSG Wells During Workover Activities

Activity	Chemical	Concentration in Fluid (at well pad)	
		Active Constituents Concentrations (Raw)	Typical Concentration Used
Present during workovers	Hydrochloric acid	28-36%	10 – 15% volume (145000mg/L), balance water
	Guar gum	100%	1 - 3 kg per 1000L water
	Xanthum Gum	>60%	2 to 6kg per 1000L water
	Polyglycol	40-100%, balance water	As per recommendations 0.1% by volume to surface of the fluid
	Ethylene glycol monobutyl ether [EGBE]	100%	10-30%
	Calcium Chloride	74-100%, balance water	2-3%, balance water
	Potassium Chloride	99.0-99.5%, balance sodium chloride	10 - 30 kg per 1000L of water
	Sulfamic Acid	99.5-100%, balance water	99.5-100%, balance water
	Amine polymer derivative	Amine polymer derivative 15-40%	0.14%, balance water
	Anionic Surfactant	>60%, balance ethylene glycol monobutyl ether or other non hazardous ingredients	0.25% - 0.5% by volume (up to 2%)

- Ethylene glycol monobutyl ether is a type of soap used to stimulate the wells. The soap is located in 20L, drums. It is a non-Dangerous Goods (Ref 18) with low vapour pressure and no hazardous gases evolved from vaporisation or degassing in case of a liquid release. A spill would be contained within the well site boundaries for ease of clean-up.

- Hydrochloric acid (33%), sulfamic acid and citric acid are used occasionally during workover. Citric acid is a non-Dangerous Goods (non-DG); sulfamic acid and hydrochloric acid are DG Class 8 corrosive liquids, in accordance with the Australian Code for the Transport of Dangerous Goods by Road & Rail (Ref 18). Up to 1,000 litres of hydrochloric acid may be stored at the well pad during workover operation. The dangers associated with the handling of these material are well understood by AGL personnel and measures are in place to prevent, detect and clean-up liquid releases. The storage vessels and pumps would be located inside temporary bunds, allowing a spill to be contained within the well site boundaries for ease of clean-up.
- Salts (calcium chloride, potassium chloride), amine polymer derivative and other (guar gum, xanthum gum), are solid held in bags.
- Portland and blended cement are also used on occasion.

If spilled during handling, these solids would remain within the well site boundaries. These material can be readily and easily cleaned up in accordance with AGL operational requirements. The fact that workover sites are manned during work hours ensures that any spill would be promptly identified and cleaned up. Further, in respect to flood related risks associated with these materials, the AGL ‘Field Production Flood Management Procedure’ states *Where Workover operations are in progress on Flood Group 1-3 wells, the Workover Rig Manager must be instructed to cease operations and secure the well, and then when safe, unsecured equipment (including water tanks) should be removed from site, with first priority to any equipment which could cause potential harm to the environment in the event of a flood (e.g. chemical storage containers or equipment containing fuel/oil)*.

The risk associated with the storage and handling of workover chemicals is presented in Section 8.1.

3.2 KEY RISK PATHWAYS

The approach adopted in this HRA to ensure that all[14] hazards and risks associated with the CSG wells have been identified and can be assessed is as follows:

- Review of potentially hazardous material involved in the CSG well operation (Refer Section 3.1);
- Review of the Code of practice for CSG well integrity (Ref 2);
- Review of the findings in the Chief Scientist and Engineer's (CSE's) review (Refs 4, 5, 6);
- Review of a number of specialised technical risk assessment (Refs 19, 20, 21, 22, 23 and 24).

The risk pathways identified in the CSE's review (Ref 6) are presented in Figure 4 and Figure 5, with the following clarifications:

- Those pathways that are included in the CSE Review and that form part of the scope of this HRA are in solid black line;
- Those pathways that are outside the scope of this HRA are shaded in light grey and
- The additional risk pathways that were identified in this HRA but that were outside of the scope of the CSE Review are noted as dotted lines.

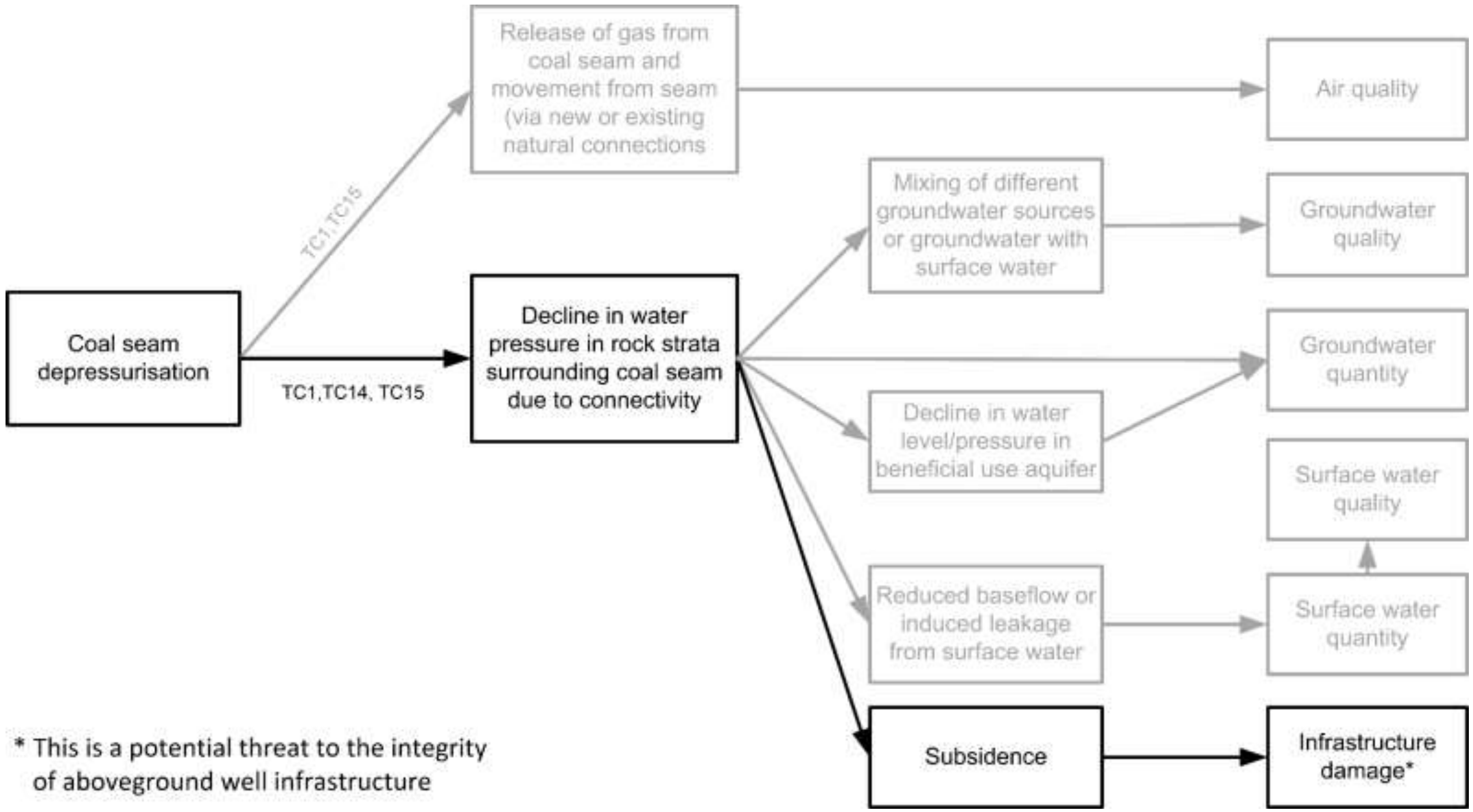
Each risk pathway is associated with one or more controls (technical controls TCs[15] and ATCs[16]), are described in Appendix 1 and summarised in Table 10 and Table 11 above. The TCs and ATCs 1-3 are shown on the pathway figures below, while ATCs 5-9 are overarching risk management measure and are not shown.

[14] As related to a potential threat to human safety, health and the environment.

[15] The TCs are associated with the CSE's *risk pathways* and were defined in the CSE's Review.

[16] The ATCs are associated with the technical assessments and this HRA's *additional risk pathways*. The ATC were defined in the Code for well integrity (Ref 2) and as part of the present HRA.

Figure 4 – Coal Seam Depressurisation, Modified Risk Pathways



Pathways from the CSE Review <u>and</u> part of the scope of this HRA are in solid black line;
Pathways that are outside the scope of this HRA are shaded in light grey.

Figure 5 – Spills and Leaks, Modified Risk Pathways

Pathways from the CSE Review and part of the scope of this HRA are in solid black line. Pathways that are outside the scope of this HRA are shaded in light grey. Additional risk pathways identified in this HRA, but outside of the scope of the CSE Review, are dotted lines.

The risk pathway defined as *CSG is transported through pipelines and processing equipment* (using the definitions in the CSE report) relates to the risk of loss of containment of CSG through a number of different events, as identified in the risk analyses undertaken for the gas wells.

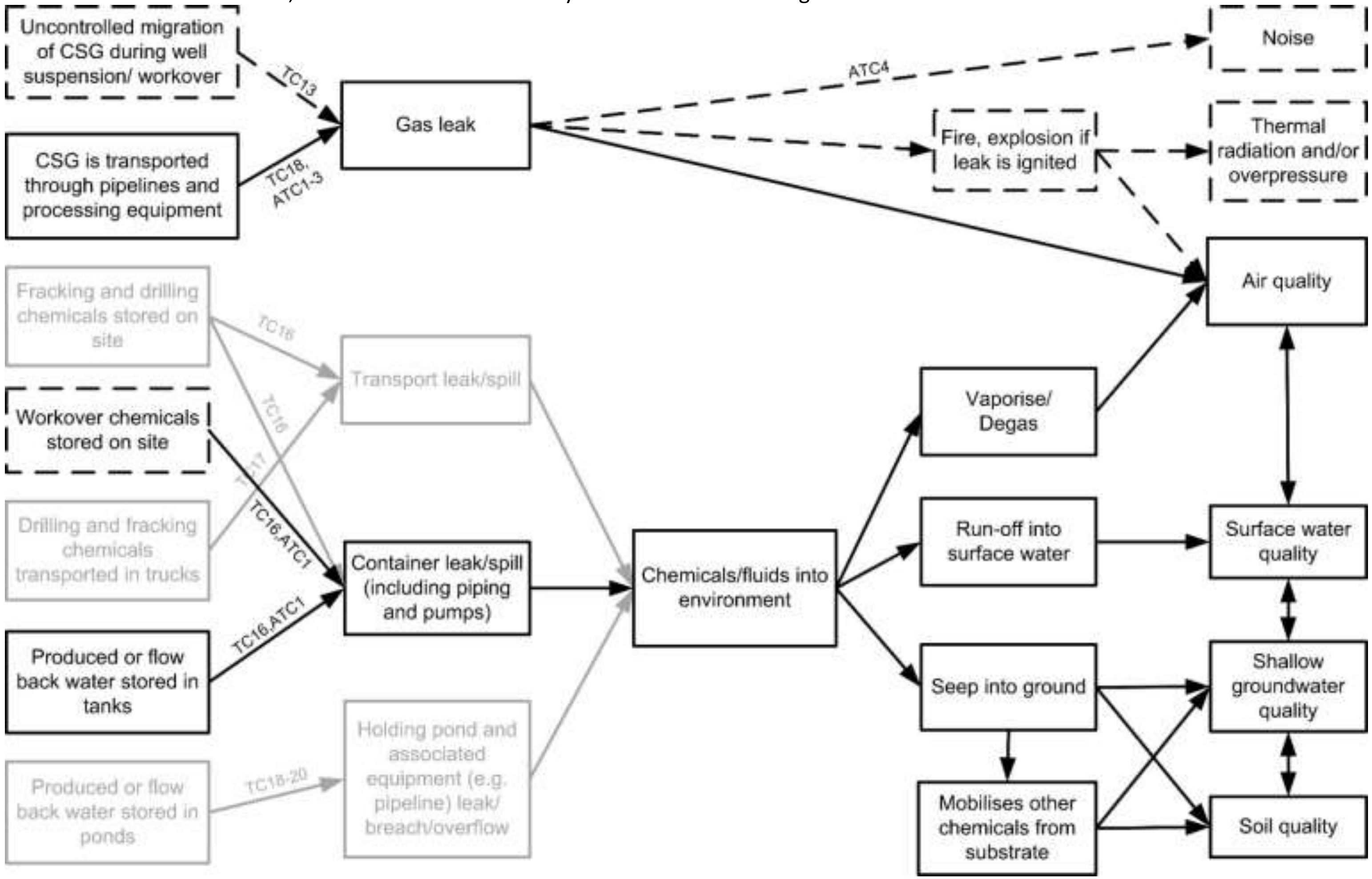


Table 10 – Summary of Technical Controls

Note: The TCs are associated with the CSE's *risk pathways* and were defined in the CSE's Review.

Identifier	Name of Control	Description
TC1	Site selection	This includes both project site selection (e.g. which area of a basin) and activity site selection (e.g. choosing location of well).
TC13	Blowout preventers fitted to well heads	Well heads, blowout prevention and production tree equipment must accord with API and other appropriate standards
TC14	Detailed and robust groundwater models	Use of multiple model realisations combined with local, empirically derived model parameters along with the reporting of upper bound or "worst case" estimates. Modelling should be able to predict pressure, level and quality of groundwater and surface water.
TC15	Depressurisation monitored	Measurements include assessment of pressures, levels and yielded gas levels from the coal seam and potentially connected aquifers and surface waters as well as water quality analysis.
TC16	Suitable tanks	Tanks and other storage vessels should be fit for purpose. This includes design and construction; maintenance, and monitoring. (Refers to both pressure vessels in CSG usage and to atmospheric tanks such as the saline water tanks)
TC18	Suitable pipeline	A. Ongoing monitoring of pressure, flow and physical inspections of integrity should be used to help detect and stop leaks early. B. Pipelines should be fit-for-purpose with respect to the soundness of their design and construction.

Table 11 – Summary of Additional Technical Controls

Note: The ATC were defined in the Code for well integrity (Ref 2) and as part of the present HRA.

Identifier	Name of Control	Description
ATC1	Fencing	Titleholders should construct fencing for well sites for safety and to exclude livestock and wildlife. Titleholders must also abide by any additional measures regarding fences set out in the Access Agreement. The titleholder must ensure that if fencing around the well head is removed during an operation, the fencing is replaced immediately after the operation is completed.
ATC2	Suitable well heads	Well heads should comply with API and other appropriate standards. Wellhead design needs to facilitate installation of Blow Out Preventor Equipment.
ATC3	Well suspension	A well must be made safe in accordance with relevant standards. A suspended well must be sealed in a manner that prevents leakage and facilitates safe recommencement of operations. The site must be made secure to exclude persons and stock. A program must be put in place for regular inspections to check for gas leaks and other health and safety matters with a record kept of all inspections.
ATC4	Suitable noise management	Measures should be in place to minimise the effect of noise on the public.
ATC5	General risk assessment	All significant risk to safety or the environment should be managed through an effective risk management process that includes identification of hazards, assessment of risks, implementation of control measures and monitoring integrity and effectiveness of control measure (including workover programs; hazardous area zoning; audits and inspections; permit to work; preventative maintenance programs).
ATC6	Safety management plan	An operator should have a rigorous, risk based approach to the safety of operations and possess a comprehensive asset integrity regime to minimise risks associated with their operations. The safety management plan must describe the safety standards and safety and maintenance procedures for each stage of well operations and must include identification and assessment of specific risks from ignition sources, or potential ignition sources.

Identifier	Name of Control	Description
ATC7	Incident and emergency response	An operator must have the following management plans to meet various legislative requirements: • Pollution Incident Response Management Plans (PIRMP) • Emergency Response Plan
ATC8	Training	Workers must have the knowledge and skills necessary to perform their work safely and to the highest possible standard. Workover personnel are required to have mandatory minimum qualifications in accordance with the NSW Petroleum Drilling and Well Servicing – Competencies (Guideline)
ATC9	Inherent design	Properties of methane (CSG): methane is lighter than air and therefore rises into the atmosphere, does not pool within low lying areas or confined spaces, reducing the risk of fire or explosion.

3.3 POTENTIAL HAZARDOUS EVENTS AND THEIR CONTROL

3.3.1 Potentially hazardous incidents

From the assessment of all inputs listed, a number of potentially hazardous incidents have been identified for the CSG wells that may cause a threat to human safety, health and the environment. These are presented in Table 12 for a case where all established controls and management systems fail (i.e. worst case).

For each of these potentially hazardous incidents, a Bow Tie diagram has been produced, providing a graphical presentation of the outcome of this assessment. Bow Tie diagrams explain how a hazard can be initiated resulting in a number of possible consequences, and describe the relationships between the hazards, triggers, and control measures (barriers) that are in place.

Table 12 – Potentially Hazardous Events and Outcomes

<table>
<tr><th>Event ID No.</th><th>Potentially Hazardous Incidents</th><th colspan="2">Possible Incident Outcome</th><th>Bow Tie</th></tr>
<tr><td>1.</td><td>CSG release</td><td colspan="2">Failure of well integrity and fire leading to potential human safety risk from heat radiation
Ignition of gas from a Pressure Relief Valve (PRV) leading to potential human safety risk
Generation of noise leading to potential human health risk
Air quality impact from fugitive emissions leading to potential human health risk</td><td>Figure 7 - routine operation
Figure 8 – non-routine operation</td></tr>
<tr><td>2.</td><td>Potentially harmful liquid release</td><td>Vaporisation / degassing of hazardous gases
Runoff into surface water
Seepage into ground
Mobilisation of other chemicals from substrate</td><td>Risk of impact on soil, air and water quality and
- health risk from direct exposure to contaminants or indirect exposure through ingestion of contaminated food or
- environmental risk</td><td>Figure 9</td></tr>
</table>

3.3.2 Introduction to Bow Tie Methodology

A schematic of a typical Bow Tie diagram is presented in Figure 6 below. The hazardous incident forms the centre of each Bow Tie, with the threats (or *triggers*) for hazardous incident listed on the far left of the Bow Tie and the possible consequences (or *outcomes*) listed on the far right.

The controls are then split into those that act as proactive barriers (i.e. minimising the likelihood of a release) and those that act as reactive barriers (i.e. minimising the likelihood of one or more consequence).

Proactive barriers are listed on the left side of the Bow Tie between the relevant threat and the hazardous incident while reactive barriers are listed on the right between the hazardous incident and the relevant consequence.

3.3.3 Bow Ties for the CSG Wells

The Bow Ties associated with the hazardous incidents for the CSG wells are presented in the following figures:

- Figure 7 - CSG release during routine operations
- Figure 8 - CSG release during non-routine operations
- Figure 9 - Potentially harmful liquid release.

Figure 6 - Typical Bow Tie Diagram

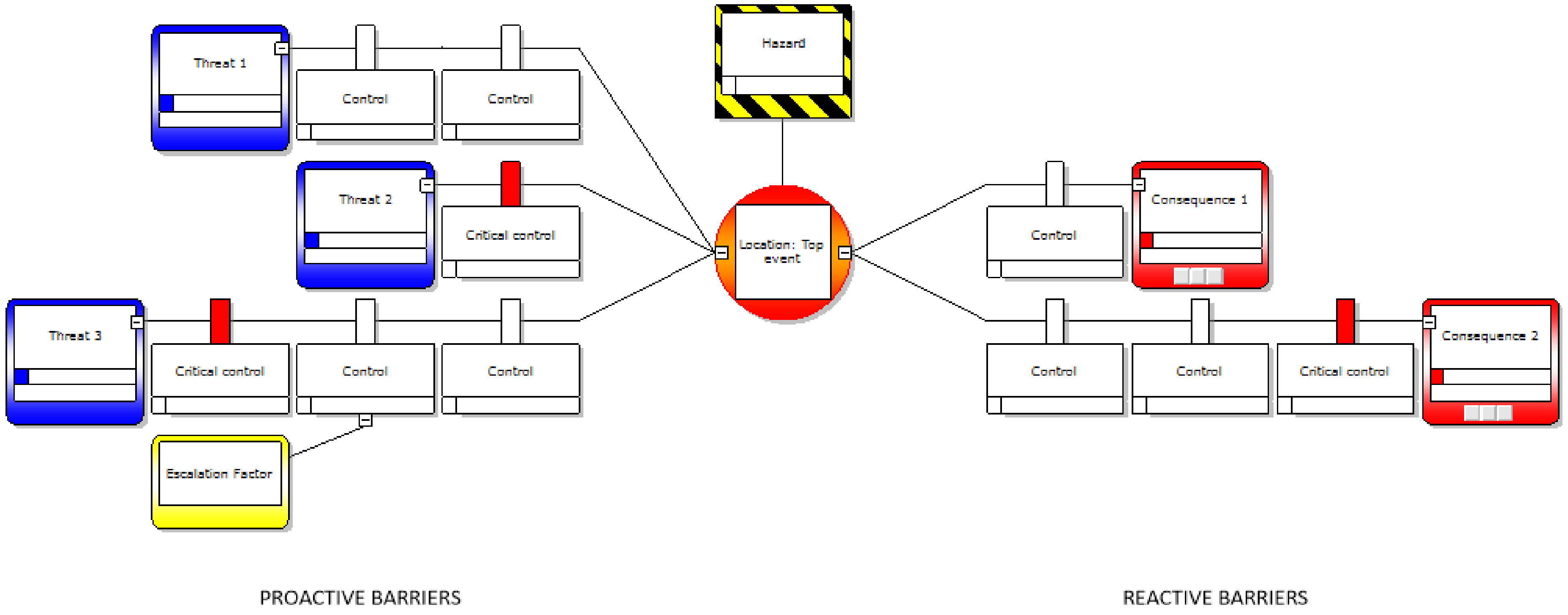


Figure 7 - CSG release during routine operations

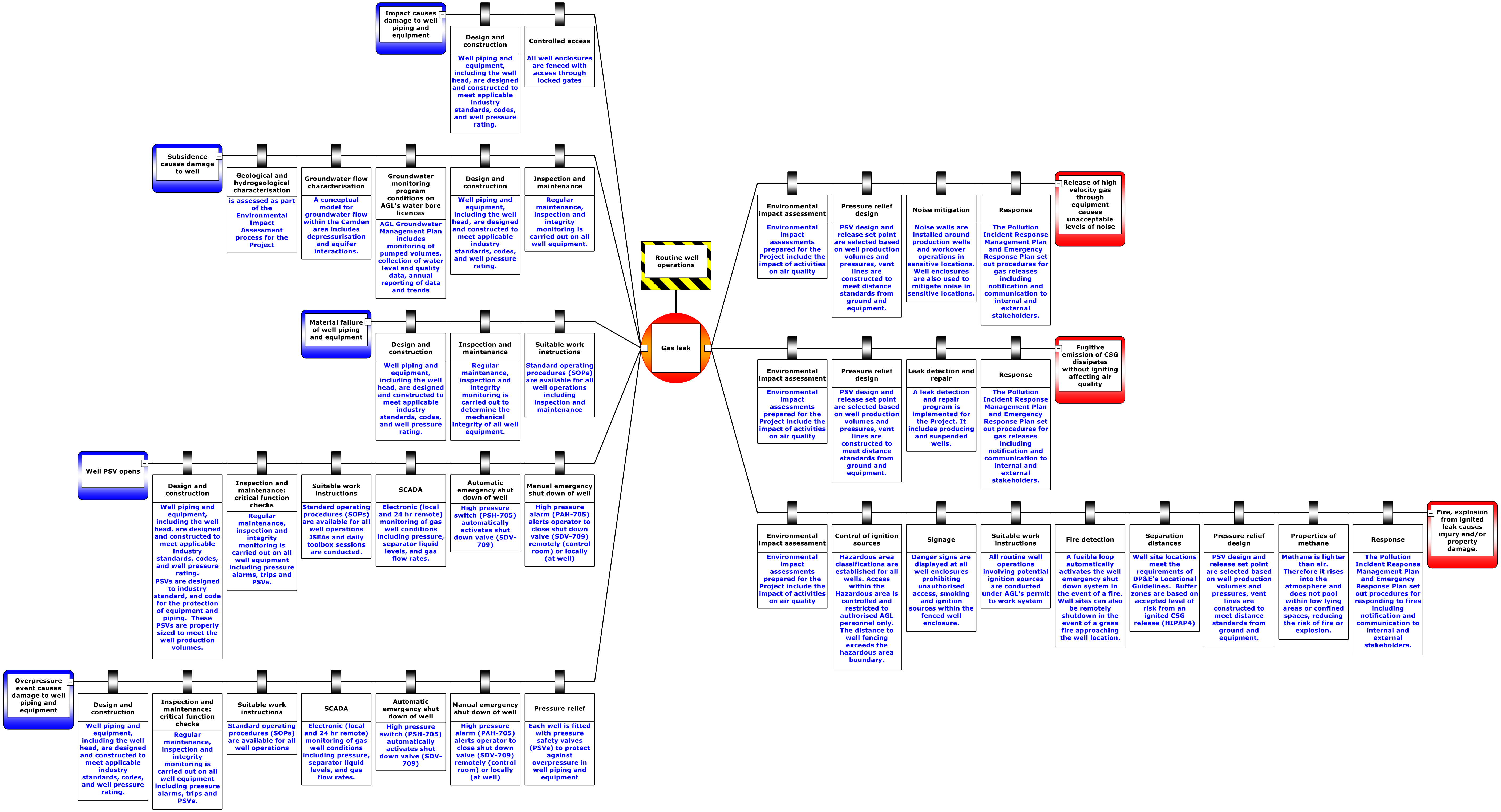
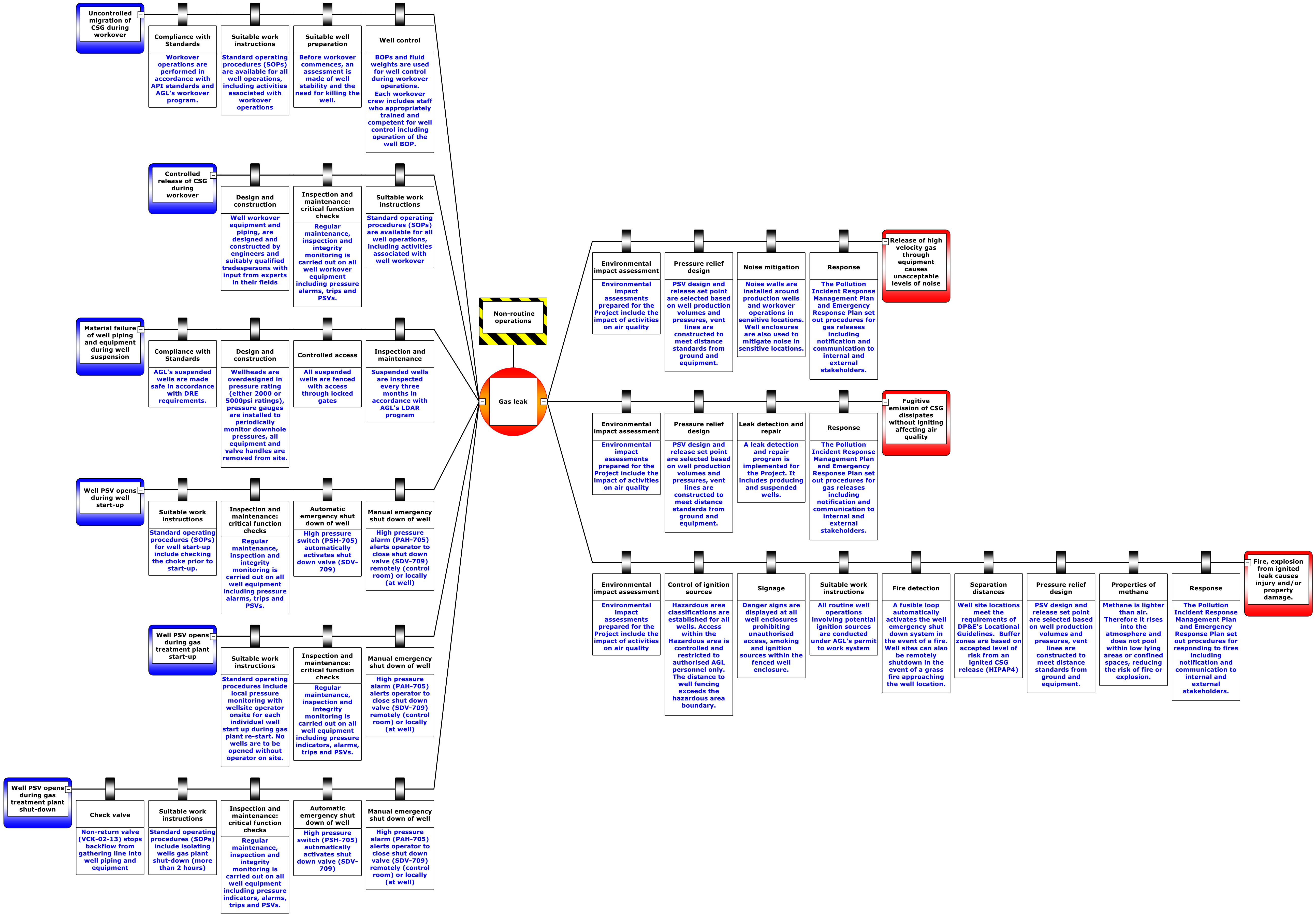
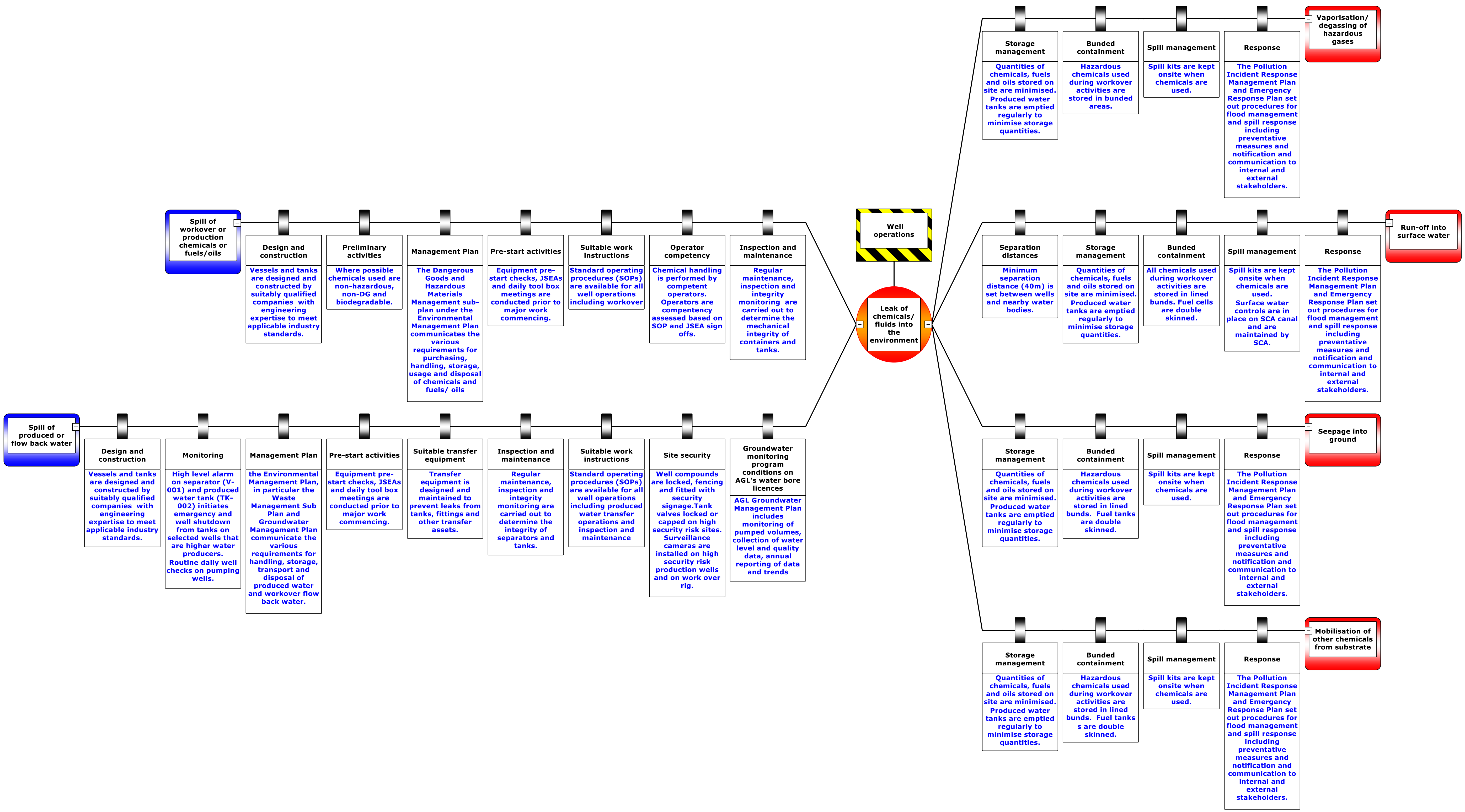


Figure 8 - CSG release during non-routine operations



Planager
Risk Management Consulting

Figure 9 - Potentially harmful liquid release



4 RISK ASSESSMENT – FIRE FROM FAILURE OF WELL INTEGRITY

A failure of well integrity may result in a release of CSG into the atmosphere. This would have the potential to cause a human safety risk if there was ignition, which resulted in a fire incident with associated heat radiation, and there was exposure to the heat radiation. The factors involved are:

- Failure of pipes or equipment must occur causing a release of CSG. There are several possible causes of failure, with the main ones being corrosion and damage to the equipment by external agencies, e.g. impact; or failure to manage pressure excursions (e.g. through failure of sensors, high pressure switches and pressure safety valves; or cement bonding degrading and gas pressure not contained within the well casing);

- The released material must come into contact with a source of ignition. In some cases this may be heat or sparks generated by mechanical damage while in others, the possible ignition source could include non-flame proof equipment, vehicles, or naked flames;

- Depending on the release conditions, including the mass of material involved and how rapidly it is ignited, the results may be a localised fire (for example a so called jet fire) or a flash fire if there was any potential for the gas to accumulate;

- Finally, for there to be a risk to human safety, people must be present within the harmful range (consequence distance) of the fire or explosion for exposure to occur. How close the people are will determine whether any injuries or fatalities result.

A Quantitative Risk Assessment (QRA) was prepared by Planager (November 2002, Ref 22) on behalf of Sydney Gas Operations P/L, the original developers of the CGP, as part of the Environmental Impact Statement process for the Camden Gas Project. The aim of the QRA was to assess the risk of loss of well integrity in order to determine the required separation distances of the gas wells from a range of neighbouring land uses to ensure that the risk from the wells is minimal and in line with acceptable risk criteria (Ref 7).

The focus of the risk assessment was the potential for a CSG release to ignite and cause a fire which could lead to human safety risk from exposure to heat radiation. The risk of domino effects was also assessed.

The Planager 2002 QRA preceded the 2004 NSW DP&E's *Locational guidelines* (Ref 3) and the buffers developed by Planager for the CSG wells were very similar to those later developed by the NSW DP&E (though Planager's buffers were somewhat larger - more conservative - accounting for the early stage in the CSG activities in NSW and the conservative assumptions typically made in such early assessments).

Two additional QRAs were later carried out for the CGP, also by Planager; this time on behalf of AGL who took over operation of the CGP in February 2006.

- The first (September 2007) assessed the risk of up to six CSG wells at one surface location (Ref 23), aiming at determining the additional risk from the CSG wells due to the potential for domino effects between adjacent wells.
- The second (July 2010) covered the proposed Camden North development (Ref 24) and updated the earlier QRAs with the latest well design and technology.

Each Planager QRA was conducted in accordance with the NSW DP&E guidelines for hazard analysis (Ref 1) and the risk was compared with NSW DP&E risk criteria for land use planning (Ref 7).

4.1 Consequence Assessment

The consequences from an ignited CSG release are determined using the calculation methods defined in the internationally recognised *Yellow Book* (Ref 25) by TNO (the Netherlands Organisation for Applied Scientific Research), with leak rates and duration, effect and impact of the fire event determined in accordance with established practices, as discussed below.

4.1.1 Leak rates

For CSG releases, leak rates from a hole in process equipment or piping is calculated as a function of the pressure drop over the hole using the method as applies to the condition known as *critical* or *choked flow*, when the internal pressure is more than double atmospheric pressure (approximately). The equations for choked flow from the TNO Yellow Book (Ref 25) are used to calculate the leak rates, with the initial leak rates shown in Table 13.

Table 13 – Leak Rates

Release rate (kg/s)	Hole-size			
	Small leak (3mm)	Intermediate leak (13 mm)	Major leak (25 mm)	Massive leak (full bore)
Upstream of the variable choke (pressure regulator)	0.005 kg/s	0.10 kg/s	0.35 kg/s	7.5 kg/s
Downstream of the variable choke (pressure regulator)	0.002 kg/s	0.02 kg/s	0.13 kg/s	0.7 kg/s

The results predict that the decrease in leak rate for a large release, e.g. a full bore rupture of a connecting pipe, would be dramatic with a drop to less than half of the initial leak rate within seconds. However, the risk assessment conservatively assumes that leak rates would remain constant until isolation can be made, refer discussion below.

4.1.2 Duration

The duration of a release will depend on the system(s) available to identify and isolate the source of the release from a remote location (RPGP); the nature of the release; the training, procedures and management, and ability to access the well if remote isolation was hindered for some reason. The approach used in the risk assessments is as follows:

- Small leaks are likely to be identified by personnel during routine patrols or by the operator in the control room through indication on the control panel. The duration of a small CSG release is set as 60 minutes, at which time a *steady-state* dispersion has been established. From a risk assessment point of view, the results obtained are independent of duration once a steady state has been reached.
- Large CSG releases are likely to initiate an automatic trip at the gas well, which would initiate the automatic closure of the well isolation valve, stopping the release without human intervention. A signal (alarm) would be sent to the RPGP control room operator prompting investigation. The duration of such a release scenario is limited to the time it takes for the trip valves to shut and for the inventory between closed valves to be released. The instruments and equipment associated with the automatic isolation of the wells are under a *Critical Function Testing* program whereby they are tested every two months (increased to monthly for some wells).
- In the unlikely event where the trip fails to initiate valve closure, the duration of the release has been set to 60 minutes, at which time a *steady-state* dispersion has been established (again, there is no change, from a risk assessment point of view, once this steady state has been achieved).

4.1.3 Radiation effects - The *Point Source* method

Radiation effects are evaluated using the point source method, which assumes that a fire is a point source of heat, located at the centre of the flame, and radiating a proportion of the heat of combustion. The radiation intensity at any distance is then determined according to the inverse square law, making allowance for the attenuating effect of atmospheric water vapour over significant distances (e.g. 100 metres or more).

$$I = \frac{Qf\tau}{4\Pi r^2}$$

With the rate of energy release, Q, given by:

$$Q = \dot{m} H_C$$

With:

I	= radiation intensity at target (kW/m^2)
Q	= rate of energy release (kW)
f	= fraction radiated (-)
τ	= atmospheric transmissivity (-)
r	= distance to target (m)
$\dot{m}$	= rate of combustion of fuel (kg/sec)
H_C	= heat of combustion

4.1.4 Impact assessment

The above techniques allow the level of radiation resulting from fires to be determined at any distance from the source. The effect or impact of heat radiation on people is shown in Table 14, with those relating to the NSW DP&E risk criteria (in Ref 7) shaded.

Table 14 - Effects of Heat Radiation

Radiant Heat Level (kW/m2)	Physical Effect (exact effect depends on exposure duration)
1.2	Received from the sun at noon in summer
2.1	Minimum to cause pain after 1 minute
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds' exposure
12.6	Significant chance of fatality for extended exposure High chance of injury
23	Likely fatality for extended exposure and chance of fatality for instantaneous (short) exposure
35	Significant chance of fatality for people exposed instantaneously

Heat radiation levels as low as $12.6kW/m^2$ are assumed to have a significant probability (30%) of causing fatality in the case of a jet flame scenario. A heat radiation of $23kW/m^2$ is assumed to cause fatality in 95% of all fires.

4.2 LIKELIHOOD ANALYSIS

The consequence distances of some incident scenarios extend beyond the CSG well compound (as defined by the security fence line). However, after the likelihood of occurrence has been taken into account, they may not contribute significantly to the cumulative individual risk associated with the wells.

The following factors are considered when determining the likelihood of the failure scenarios:

- The basic failure rate of each type of failure combined with the overall failure rate applicable to each release scenario (taking into account piping lengths and equipment configurations);
- The probability of failure of protective systems; and
- The probability of ignition of the released gas, i.e. that a jet fire occurs.

4.3 RISK ASSESSMENT AND COMPARISON WITH RISK CRITERIA

The risk for each incident outcome is estimated according to:

Risk = Consequence x Frequency

The risk associated with the CSG wells is assessed using quantitative risk assessment (QRA) where the total risk is obtained by adding together the results from the risk calculations for each incident, i.e. the total risk is the sum of the risk calculated for each individual release scenario.

The results of the risk analysis are presented in the form of *Individual fatality risk*, i.e. the likelihood (or frequency) of fatality to notional individuals at locations around a CSG well, as a result of any of the postulated release scenarios.

The units for individual risk are likelihood per million per year (pmpy, equivalent to 10^{-6} times per year)).

Separation distances for various types of land use can be derived by setting the separation distance equal to the radius of the relevant fatality risk contour, taking into account sensitivity issues, as shown in Table 15 below, for up to six (6) wells in each well-compound (Ref 24).

Table 15 – Minimum Distance to Satisfy Land use Criteria, CSG Wells

Minimum Distance (metres) – up to 6-wells in each compound			
Active open space (risk criterion: 10 pmpy)	Business (risk criterion: 5 pmpy)	Residential development (risk criterion: 1 pmpy)	Sensitive development (risk criterion: 0.5 pmpy)
10 metres	10 metres	15 metres	20 metres

Note 1: pmpy = per million per year (equivalent to 10^{-6} per year)

Note 2: Data relevant for Established operation

Note 3: These minimum distances were developed by the Department of Planning and Environment to satisfy their land use risk criteria. In practice, larger separation distances apply to provide adequate space for workover activities.

Note 4: The minimum distances have conservatively been rounded up to the nearest 5, i.e. a calculated distance of 11, 12, 13, 14 or 15 metres would all be listed as of minimum distance to safety criteria of 15 metres.

Note 5: The risk levels refer to those established by the NSW DP&E in their landuse safety criteria document HIPAP4 (Ref 7). This is discussed in Section 1.5.1 and Appendix 2, Section A2.1.

These distances can be lowered somewhat for single well compounds, in which case the separation distances calculated in the NSW DP&E *Locational guidelines* (Ref 3) can be used.

Provided these minimum buffers are maintained between the wells and the various land uses, the risk to human safety can be regarded as acceptable and well within the criteria for land use planning.

The separation distances between any of the gas wells forming part of the CGP to residential land use is 30 metres and exceeds 50 metres to the nearest residential dwelling. There are no sensitive developments in the vicinity of the gas wells, and the separation distances to the nearest sensitive development exceeds 30 metres[17]. The separation distances to any active open space exceed those listed in Table 15. The separation distances to any business use exceed those listed in Table 15 assuming this excludes business use of the landholders. With such separation distances between the CSG wells and neighbouring land use, the risk to human safety from a fire at a CSG well is acceptable and well within the criteria for land use planning.

As discussed in Section 3.1.1, products of combustion from a fire of CSG are water vapour and carbon dioxide. There is very little smoke associated with a CSG fire. The heat from the fire would lift the products of combustion and any smoke generated would disperse at altitude. The risk to human health and the environment from CSG products of combustion or smoke is negligible.

[17] The distance between gas well SL02 and the boundary of the Broughton Anglican School exceeds 30 metres. The distance to the closest school building exceeds 200 metres.

5 Risk Assessment – Ignition of Gas Released from an Open Pressure Relief Valve

The primary purpose of a pressure relief valve (PRVs) is to protect life, property and environment in the case of excess pressure from vessels or equipment. Excess pressure may be caused by a failure to manage failed pressure sensors and/or high pressure switches.

PRVs are standard protective equipment in most industrial applications where oil or gas are produced, transported and/or handled. They are designed, installed, maintained and tested in accordance with stringent Australian and International Standards. These Standards specify various requirements for PRVs, including in terms of the minimum height above ground level to ensure that the risk to human safety from the opening of the PRV is minimal and well within ALARP principles.

At the request of AGL, Planager has modelled the concentration profile of the CSG released from an opened PRV to verify that the CSG issuing from the opened PRV would indeed disperse at height and that no flammable gas concentrations would descend to locations where an ignition source may be present.

The aim of the assessment is to determine the potential safety risk to people in the case of a release of CSG through a PRV, e.g. from smoking or driving near a well at the time when the PRV opened.

5.1 Consequence Assessment

The consequences from a CSG release from a PRV are determined using the calculation methods defined in the internationally recognised *Yellow Book* by TNO (Ref 25), with leak rates and duration, effect and impact of the release event determined in accordance with established practices, as discussed below.

5.1.1 Leak rates

The release from the PRV would occur vertically at a minimum height of 3 metres above ground level, corresponding to the minimum height set in the Australian Standard for PRVs (adherence to this minimum height requirement has been verified by AGL for their wells as part of this HRA process).

The consequence modelling was undertaken using the TNO consequence modelling software program Effects (version 8.0). The TNO tools are internationally recognised by industry and government authorities. The consequence models used within Effects are well known and are fully documented in the TNO Yellow Book (Ref 25).

The modelling shows that the CSG cloud would be released at pressure, forming a jet from the point of release at the PRV, with the CGS exiting with a high momentum and rising vertically upon release.

Outflow rates were predicted to be up to 0.26 kg/s (or 260,000 gram/second).

5.1.2 Duration

Overpressure at the CSG well would initiate one or both of two separate pressure monitoring devices which would sound an alarm at the RPGP if the pressure of the well exceeds normal operating pressure.

The pressure monitoring devices and their associated high pressure alarm are tested every month for the critical wells (i.e. those that are capable of producing sufficient pressure to open the PRV –10 to 15 of the 92 wells in operation at the time of the HRA). The test is done every two months for less critical wells.

The sounding of a high pressure alarm would allow the RPGP operator to investigate the source of the overpressure and, if necessary, shut down the well remotely – this is expected to only take a few minutes, from identification of the condition to closure of the well and depressurisation of the closed in well equipment.

If the shutdown was to fail, or if it was not done quickly enough, the PRVs would open. The PRV would normally only stay open for a couple of seconds to relieve the excess pressure and then automatically reseat as the pressure reduced to below the set-point.

In the event that the reseating mechanism on the PRV was to fail, the AGL operator can shut in the well remotely from the RPGP – in normal circumstances, this should only take a few minutes.

The expected maximum (worst case) duration of a PRV opening, as per AGL estimation, is 20 to 25 minutes. At this time the steady-state has been established, with the concentrations of gas remaining unchanged should the time duration increase further.

As a very conservative approach, this HRA used one hour as the maximum duration of the PRV release for the worst case situation with all controls failing.

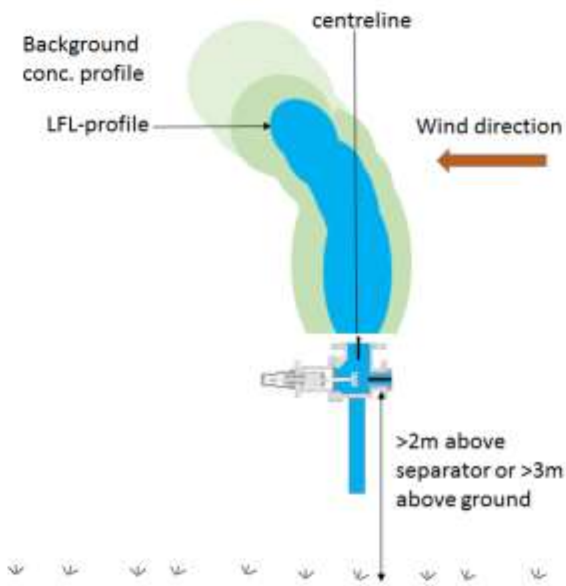
5.1.3 Impact assessment

Modelling results show that influence of strong winds may displace the gas from the centreline, but at no point would the dispersing cloud reach LFL concentration anywhere near the ground.

Figure 10 below provides a graphical representation of the methane concentration in the CSG cloud that would be released into the atmosphere following an opening of a PRV.

The LFL cloud is represented by the blue profile and the light green profile represents the background concentration.

Figure 10 – Methane Concentration Profile for PRV Release



The blue cloud represents the gas at concentrations at or above the LFL concentration (of 5.5% in air). Below this level, the concentration of flammable gas in air is too low for ignition to occur.

The green cloud represents the gas at a concentration below the LFL but above the background concentration of methane (of 1.8ppm, Ref 12). At or below this concentration, the amount of CSG released into the atmosphere is insignificant with respect to the ambient concentration of methane.

5.2 Likelihood Analysis

Approximately 10 to 15 of the 92 wells under operation at the time of this HRA are capable of generating the pressures required to open the PRV.

Under current operating conditions and based on previous estimations completed by Planager, taking into account the management measures in place at the gas wells[18], a release of CSG would be expected to occur approximately every fifty (50) years through a relieving PRV on one of the 92 wells in operation at the time of this HRA. The likelihood of it occurring at one specific well (i.e. the

[18] Including failures of pressure sensors and/or high pressure switches

likelihood of a specific well PRV opening) is less than 2×10^{-4} times per year (or less than 1 in 4,600 years).

5.3 Risk Assessment

The flammable gas concentrations of CSG are below the lower flammable limit (LFL) outside of the well compound (defined by the security fence line) and do not descend below the height of the PRV (minimum 3 metres above ground level) at any location past the opening of the PRV.

The gas concentration does not pose a hazard to human safety, and ignition of the CSG from a PRV opening from human activity outside of the well site boundaries is not a credible event.

6 Risk Assessment – Generation of Noise from CSG Release

Low level background noise and noise during planned activities such as workovers have been assessed in previous EAs and managed through Conditions of Consent requirements. The Conditions of Consent for the CSG wells forming part of the CGP, as cited in the Camden Noise management sub-plan (Ref 27), specify noise limits from selected operating wells to any residential receiver of:

- 35 to 49dBA (15 min period)
- 45dBA (1 min period, night)

depending on the time of day and Conditions of Consent pertaining to the gas field.

At the CGP, noise monitoring is undertaken within a week of production starting at a well; after three months of operation, and then if the well status changes. If operational noise monitoring data exceed criteria, mitigation measures are implemented and further monitoring carried out until the criteria is met (Camden Noise management sub-plan, Ref 27).

The results of noise monitoring are reported as part of the Annual Environmental Performance Report which is made publically available on the AGL Camden Gas project website. The human health impact from low level background noise and noise during planned activities at the wells is considered adequate and not assessed further in this HRA.

Non routine events at the gas wells can generate higher noise levels, and noise from an opening of a pressure relief valve (PRV) have been estimated as a representative non routine incident. The risk of human health impact associated with the noise of a PRV release is assessed below.

6.1 Consequence Assessment

6.1.1 Noise level

The noise levels generated have been calculated using the method described in American Petroleum Institute Standard for *Pressure-relieving and Depressuring Systems* API-521 (Ref 26).

The specifications and operating conditions of the PRVs in place at the CGP wells, and used in these calculations, are given in Table 16.

Table 16 – PRV Specifications and Operating Conditions

PRV type	Mercer 9100 D orifice
Outlet diameter (mm)	25.4
Gas	methane
Relieving pressure (kPa absolute)	601.3
Outlet pressure (kPa absolute)[19]	101.3
Volumetric outflow rate (SCFM / m^3/s)	312 / 0.147
Mass outflow rate (kg/s)	0.10

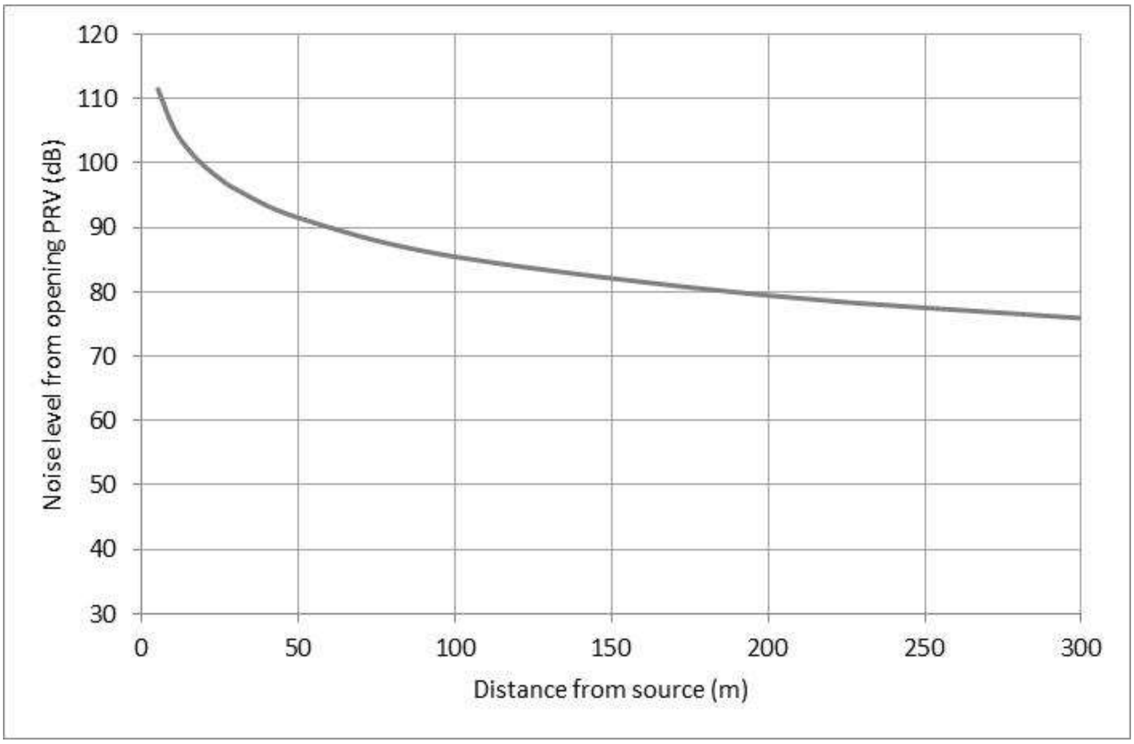
The noise level as function of distance is shown in Figure 11 below.

The results indicate that the noise associated with the opening of a PRV is significant even at a distance of 300 metres. Since residential receivers are located within this distance, the estimated noise levels exceed the limits specified in the Camden Noise Management Sub-plan (Ref 27).

19 The outlet pressure is assumed to be equal to atmospheric pressure.

In the unlikely event of a release from a PRV at one of the wells, the noise level at the nearest resident (located at 55 metres from a CSG well) is calculated to be approximately 90dB.

Figure 11 – Noise Created by an Opening PRV



It should be noted that the calculated noise levels are conservative as no allowance has been made for back pressure in calculating the pressure ratio used in the estimation process. Further, the calculations ignore the effect of any noise mitigation measures such as sound barriers or insulation, nor do they give credit for any molecular noise absorption effects.

6.1.2 Duration

As discussed in Section 5.1.2, the expected duration of a PRV opening is only a few seconds (possibly a few minutes if the automatic reseat fails and time is required to allow for remotely activated PRV closure by the RPGP operator). The maximum duration of a PRV opening, as per AGL estimation, is 20 to 25 minutes. The conservative assumption in this HRA is a maximum of 1 hour.

6.2 LIKELIHOOD ANALYSIS

Approximately 10 to 15 of the 92 wells under operation at the time of this HRA are capable of generating the pressures required to open the PRV.

Under current operating conditions and based on previous estimations completed by Planager (taking into account the management measures in place at the gas wells), a release of CSG would be expected to occur approximately every fifty (50) years through a relieving PRV on either one of the 92 wells in operation at the time of this HRA. The likelihood of a PRV opening, even for a very short duration of a few seconds, at one specific well is 2×10^{-4} times per year per well (or 1 in 4,600 years per well).

The likelihood that the PRV stays open for the maximum duration of 1 hour assumed in this HRA (Refer Section 6.1.2) is much lower than the 2×10^{-4} times per year, by several orders of magnitude.

6.3 RISK ASSESSMENT

The (Australian) National Occupational Health and Safety Commission (NOHSC), in their National Code of Practice for Noise Management and Protection of Hearing at Work, provide the decibel levels of a number of common sounds (Ref 28). This information is supplemented from the Safe Work Australia guidance on noise (Ref 29). The distance from the PRV to these sound levels are presented in Table 17.

Table 17 – Distance from PRV to Decibel Levels of Common Sounds

Decibel levels of common sounds			Decibel level reached at distance from PRV
	30m from a jet aircraft	140	Level not reached
	Threshold of pain	130	Level not reached
		120	Level not reached
		110	5 metres
	Chainsaw	105	10 metres
	Lawn mower	100	20 metres
		90	55 metres - distance to the nearest residential dwelling[20]
	Kerbside of busy road	80	200 metres
	Conversational speech	70	
		60	
		50	
	Quiet bedroom at night	40	Simplifications in assumptions render calculations invalid for longer distances from the PRV
		30	
		20	
	Background in TV studio	10	
	Threshold of hearing	0	

[20] Noise level at the nearest resident from a CSG well (which is 55 metres) is added for the purpose of this HRA

The maximum length of time (minutes per day) a worker can be exposed to sound without exceeding the occupational environmental noise level criteria for an average daily (8 hour equivalent) dose, as established in Ref 8 by The Australian Safety and Compensation Council[21] (ASCC), was used to characterise the risks associated with the noise from the opening of a PRV. These criteria are discussed in Section 1.5.2.

The results of the analysis are as follows:

- The noise level at the nearest resident to any of the wells (located at approximately 55 metres[20] from the closest well) is 90dB(A)[22].
- This noise level is similar to that up close to a lawn mower (refer Table 17, sourcing information from Ref 29).
- Such noise level would result in a loss of amenity to residents close to the well. With the likelihood of occurrence (determined in Section 6.2 above) being 2×10^{-4} times per year (or 1 in 4,600 years), this likelihood is much lower than what would generally be acceptable for exposure to this level of noise, and the risk of loss of amenity from a PRV opening is extremely low.
- The assessment of the risk of hearing damage from this level of noise shows:
    - The maximum exposure time at 90dB(A) would be 120 minutes (two hours) per day, without a risk of hearing damage (Ref 8). This corresponds to twice the worst case (Planager assumed) duration of a PRV release and is four times the maximum duration estimated by AGL. According to the criterion, a person can be exposed to this noise level every day for a maximum duration of two hours without a risk of hearing damage.

[21] now known as SafeWork Australia

[22] without taking into account any attenuation from going inside the building

- The maximum peak noise level (of 140dB(C)) at any time during the day is not reached in the case of an opened PRV.

The maximum exposure to the sound levels at the nearest resident is shown in Table 18, alongside the typical sound levels of common noise sources.

Table 18 - Maximum length of time (minutes) of sound exposure at nearest resident without exceeding sound criteria

Sound level (dB)	Maximum exposure time (minutes)	Equivalent noise sources
90	120 (2 hours)	Lawn mower

Data sourced from the SafeWork *National Hazard Exposure Worker Surveillance, Noise exposure and the provision of noise control measures in Australian workplace*, Ref 8

The conservative assumption in this HRA for the duration of a PRV opening and emitting this level of sound is a maximum of 1 hour, or half the maximum time of exposure of 2 hours.

The likelihood of the PRV opening at one specific well and emitting this sound level, even for a few seconds, is 2×10^{-4} times per year (or 1 in 4,600 years), or much less than the accepted maximum daily exposure of two (2) hours in the table above.

The likelihood that the PRV stays open for a full hour (Planager worst case scenario) is much lower than this (by several orders of magnitude, say 2×10^{-6} times per year, or 1 in 460,000 years).

Hence, the risk of hearing damage at the nearest resident from PRV opening is extremely low and well within the acceptable range.

These quantitative results do not take into account the following mitigation methods used by AGL to protect the public from unnecessary noise from their activities:

- A site selection process that avoids sensitive receptors where possible;

- Restricted hours of operation of non routine operations (e.g. workovers);
- Noise walls installed around selected well sites;
- Noise level logging, onsite and at nearby receivers, to monitor compliance with noise criteria and to determine areas where more mitigation measures may be required; and
- Community consultation during the EA phase of projects.

Further, as per the methodology specified by the NSW DP&E in their HIPAP 6 (Ref 1), the results do not take into account the ability of people to take evasive actions, e.g. by walking inside.

Taking such mitigation methods into account, the risk of hearing damage and loss of amenity due to noise from PRV opening would be even lower.

7 RISK ASSESSMENT – EXPOSURE TO CONTAMINATED AIR

Non-ignited gas releases are commonly referred to as *fugitive emissions,* defined as ..*unintended gas or vapour emissions from leaks or other faults in pressurised equipment during industrial processes, resulting in air pollution and potential economic loss* (Ref 4).

Fugitive emissions from the CSG wells can arise from emissions from leaks in pipes, valves or fittings and from vented emissions from PRV or openings during maintenance. Methane and carbon dioxide make up over 99.9% of the CSG in the CGP field, with the remainder being low levels of ethane, propane and with traces of other hydrocarbons (refer Section 3.1.1).

7.1 CONSEQUENCE ASSESSMENT

AGL have conducted a number of studies and monitoring programs to determine the consequences and potential impact of fugitive emissions from CSG operations.

A number of the assessments are predictive in nature and prepared in conjunction with proposals to increase production for the CGP, (e.g. during the planning phase for the Camden Northern Expansion Project*,* in the *Environment Assessment* (EA, Ref 9); in the subsequent Submissions Report (Ref 10); and in the *Environmental Health Impact Assessment* (EHIA, Ref 13)), while other assessment have been prepared using actual data from the CGP, as in the AGL *Fugitive Methane Emissions Monitoring Program* (Ref 12).

The aim of the assessments has been to assess the potential for adverse environmental and health impacts associated with the CSG well operation.

The most in-depth of the predictive assessments were conducted for the Northern Expansion Project (which was subsequently abandoned). With the assessments being based on information which was, in large part, either sourced directly from experience at the CGP or pertinent also to the operations at the

CGP, much of the findings in these reports are relevant also for the present HRA. Only such information that is applicable to this HRA is discussed in this report. In particular, the following assessments are relevant for this HRA:

1. *Screening assessment for fugitive emissions of CSG* (Ref 13) for a defined release of CSG during routine operation of the wells, discussed in Section 7.1.1;
2. *Fugitive emissions monitoring*, using actual data from the CGP (Ref 12), discussed in Section 7.1.2;
3. *Gas released from an open pressure relief valve*, discussed in Section 7.1.3.

The results from these assessments are discussed below.

7.1.1 Screening assessment

An Air Quality Impact Assessment (AQIA) was carried out by PAE Holmes and the results were reported in the EA for that for the Northern Expansion Project (Ref 9). The aim of the AQIA was to determine the impact on health and the environment from venting of CSG during well commissioning and operation.

Fugitive emissions of major and minor compounds detected in the CSG (listed in Table 7 above) were qualitatively and quantitatively assessed and a CSG emission rate was predicted, issuing from ground level sources at the well.

Based on the assessment in the EHIA (Ref 13), the fugitive emission from the average well at the CGP was determined as equivalent to 0.02 grams per second[23], and the concentrations of CSG in air from this emission rate were estimated in the EHIA at two locations:

- close to the well – defined as at 5m from the well; and
- at the closest residential receptor – 55 m downwind of the well[24].

[23] Refer page 45 in the EHIA (Ref 13)

[24] The closest residential dwelling to any well is located at 55 metres from the well

The predicted worst case downwind gas concentrations are listed in Table 19. While these calculations were determined for the Northern Expansion Project they are directly relevant for the CGP as they are based on the same gas composition[25] and the same atmospheric (wind-weather)[26] data and a very similar topography.

Table 19 – Predicted Worst-Case Downwind Air Concentration of Pollutants from Fugitive CSG Emission (Routine Operation - 0.02 gram/second)

Component	Predicted Worst Case Concentration (in Air)		Screening Level Guideline used in Ref 13
	At well head (5m)	At closest resident (50m)	
Methane	0.003% (30ppm)	0.0002% (2ppm)	0.5% health - in buildings 5% fire risk
Carbon dioxide	0.00004%	0.000003%	0.5% health - in buildings
Ethane	<44µg/m^3	<3.3µg/m^3	TLV = 1,230,000µg/m^3 (ACGIH). No public health guideline available
Propane	<2.2µg/m^3	<0.17µg/m^3	TLV = 1,800,000µg/m^3 (ACGIH). No public health guideline available.
Ethanol	0.0066µg/m^3	0.00050µg/m^3	100,000µg/m3 based on chronic public health guideline from OEHHA
Acetone	0.0018µg/m^3	0.00013µg/m^3	30,000µg/m^3 based on chronic public health guideline from ATSDR
Aliphatic			
TPH C5-C6	0.022µg/m^3	0.0017µg/m^3	18,400µg/m^3 based on chronic public health guideline from TPHCWG
TPH >C8-C10	0.18µg/m^3	0.013µg/m^3	1,000µg/m^3 based on chronic public health guideline from TPHCWG
TPH >C10-C12	0.015µg/m^3	0.0012µg/m^3	

Benzene, toluene and ethylbenzene not included as gas sample results did not show any traces of these compounds

[25] Gas composition is that from the CGP, as sourced from the Human Health risk assessment

[26] Sourced by PAE Holmes from Camden Airport Automatic Weather Station (Bureau of Meteorology, 2010)

The concentrations of all CSG components during normal operation of a CSG well are well below all screening level guidelines both at the well and at the nearest resident.

The predicted impact on human health and the environment from a common, small, fugitive emissions gas release is therefore well within the acceptable range as per the findings in the EHIA (Ref 13).

7.1.2 Fugitive emissions monitoring

In 2013, Pacific Environment Limited, on behalf of AGL, undertook a fugitive emissions monitoring program throughout the CGP (Ref 12). The aim of the program was to determine if fugitive methane emissions from the operations were influencing ambient methane concentrations in the vicinity of the CGP.

It is used in this HRA to confirm the results from the predictive screening assessment (discussed in Section 7.1.1 above).

Methane levels were measured at 20 locations within the CGP and at five background locations chosen in conjunction with the community. Measurement locations within the CGP area ranged in distance from 100 metres to 1,100 metres from the nearest well site while the background measurement sites were located between 2.0 km and 7.6 km from the nearest gas well site. One measurement site was located within a kilometre of the RPGP.

Over the 12 week monitoring program the average methane concentration was 2.1 ppm with no significant differences observed between the sites within the project area and those chosen as background locations. This value is just above the global average of 1.8 ppm (WMO, 2013) and in-line with methane concentrations measured in urban areas (commonly ranging between 1.8 ppm and 3.0 ppm). The measured value is also comparable with the predicted value at the closest resident of 2 ppm (see Table 19).

Review of the data does not indicate significant fugitive methane emissions were present during the monitoring period.

Further, at the methane concentration measured in the area, none of the CSG components listed in Table 7 (in Section 3.1.1) would exceed the screening level guideline targets in Table 19.

7.1.3 Gas released from an open pressure relief valve

At the request of AGL, Planager has modelled the concentration profile of the CSG released from an opened PRV to assess the potential for exposure to contaminated air from such a release.

The consequence assessment was modelled using the calculation methods defined in the internationally recognised *Yellow Book* by TNO (Ref 25), with leak rates and duration, effect and impact of the release event determined in accordance with established practices, as discussed in Section 5.1, including the minimum height above ground of the release of 3 metres, corresponding to the minimum height set in the Australian Standard for PRVs, and the very conservative (Planager) estimate of the duration of the release from the PRV of one hour. As per the calculations discussed in Section 5.1.1, outflow rates were predicted to be up to 0.26 kg/s (or 260,000 gram/second).

Modelling shows that concentrations at ground level are lower than the 1.8 ppm at all points, with 1.8 ppm representing the background concentration of methane, Ref 12, refer discussion in Section 1.5.3 (risk criteria). At or below this concentration, the amount of CSG released into the atmosphere is insignificant with respect to the ambient concentration of methane.

Figure 10 in Section 5.1.3 provides a graphical representation of the methane concentration in the CSG cloud that would be released into the atmosphere following an opening of a PRV.

7.2 LIKELIHOOD ANALYSIS

AGL conducts an ongoing Leak Detection and Repair (LDAR) program as part of their CSG well monitoring and as part of AGL's Environment Protection Licence for the CGP (EPL 12003). The program includes leak testing of field equipment (at and around the well heads and associated above ground facilities and infrastructure and gas gathering lines) and the gas plant (valves, vessels, instrumentation, piping and compressors). Leaks are measured directly at the source and are classified as:

Table 20 – Leak Classification and Repair Timeframe

Classification	Methane concentration	Repair timeframe
Minor	0.1%- <1% (1,000-10,000ppm)	Within 14 days
Major	1% - <5% (10,000-50,000ppm)	Within 5 days
Significant	>5% (>50,000ppm)	Within 1 day

At just a metre or so away from the source of the leak, the concentration is significantly reduced to below these concentrations.

The results obtained for the gas wells for the last three reporting periods (Ref 30) are shown in Table 21. Two *significant* leaks were detected in 2013 and again in 2014. No significant leaks were detected in 2015. One significant leak was detected in 2016. All of the leaks were repaired within the timeframe (as specified in AGL's Environment Protection Licence). In 2016, AGL installed 12 volt air compressors at all production well sites. These air compressors supply instrument air, replacing gas from the wells as the previous source of instrument air. Through this initiative, the number of leaks from AGL's gas wells has notably decreased.

Table 21 – Results from AGL's LDAR program for the CGP

Reporting period	May – Dec 2013[27]	Dec 2013 – Dec 2014	Dec 2014 – Dec 2015	Dec 2015 –Dec 2016
Number of components checked	4,465	10,875	14,049	13,760
Number of minor leaks detected	3	4	19	7
Number of major leaks detected	4	5	10	2

[27] Results from audit carried out by the NSW EPA between September and December 2013

Reporting period	May – Dec 2013[27]	Dec 2013 – Dec 2014	Dec 2014 – Dec 2015	Dec 2015 –Dec 2016
Number of significant leaks detected	2 (max concentration 5.02%)	2 (max concentration 5.3%)	0	1

7.3 Risk Assessment and Comparison with Risk Criteria

The concentrations of all CSG components during normal operation of the wells are well below all screening level guidelines for fugitive emissions. The methane concentration at ground level from a PRV release corresponds to the background concentration in the area.

The CGP well sites have no significant air quality impacts as the emissions from the development contribute only a small fraction to the regional air quality which remains below the National Environment Protection Measure goals.

It then follows that the risk to human health from impact on air quality from the CSG wells which form part of the CGP is low and well within the acceptable range.

8 RISK ASSESSMENT - POTENTIALLY HARMFUL LIQUID RELEASE

As detailed in Section 3.1.2, a number of liquids are stored and handled at the CSG wells during operation and maintenance activities, including workovers. These include:

- Diesel, greases, oils for rotating machinery (pumps and generators on some of the wells) and valves.
- Produced water (i.e. the water extracted in the well), with volumes ranking between 0 to approximately 62kL per year. For the purpose of this assessment it is assumed that 62kL is stored at any one well pad and this whole volume leaks.
- Workover chemicals in their concentrated form, with volumes of the products that may be temporarily stored and used at each well pad ranging from 1L to 100L, with the occasional storage of up to 1,000L during acid wash. These may be diluted at the well pad to volumes up to 24m^3 to lower concentrations.

The risk associated with potentially harmful liquids held at the CSG wells during routine and non routine operation (e.g. workover operations) were assessed in the EHIA (Ref 13) using the risk matrix and risk acceptance criteria provided in Section 1.5.4.

8.1 RELEASE OF MATERIALS USED IN NON ROUTINE WORKOVER OPERATION

8.1.1 Consequence Assessment

The consequences for all potentially pollutant chemicals to be used in non routine operation such as well workover activities (refer Section 3.1.2) were assessed against the risk matrix in Section 1.5.4 (from the EHIA, Ref 13) to provide a *hazard ranking* for workover activities. The results are summarised in Table 22 below.

Table 22 – Hazard Ranking for Chemicals used in Well Workover Activities

Chemical	Hazard Ranking	
	Chronic Health Impacts	Ecological Impacts
Hydrochloric acid	Low	Moderate
Guar gum	Negligible	Negligible
Xanthum gum	Negligible	Negligible
Polyglycol	Negligible	Negligible
Ethylene glycol monobutyl ether (EGBE)	Low to Moderate	Negligible to Low
Calcium Chloride	Negligible	Negligible to Low
Potassium Chloride	Negligible	Negligible
Sulfamic acid	Negligible	Moderate
Amine polymer derivative	Low	Moderate

These results show that most of the chemicals utilised in well workover activities are associated with either *Negligible* to *Low* hazards to human health and/or the environment, with the following definitions:

- *Negligible hazard level*:
    - Off-Site Human Health Issues (chronic) - *No adverse long-term health effects associated with low level environmental exposures;*
    - Off-Site Impacts to Aquatic Ecosystem - *Very low potential for adverse effects on aquatic ecosystem; and*
- *Low hazard level*:
    - Off-Site Human Health Issues (chronic) - *Minor transient health effects or odour*
    - Off-Site Impacts to Aquatic Ecosystem - *Low potential for adverse effects on aquatic ecosystem.*

There are some chemicals that are of greater concern should they be released to an environment where exposure may occur, notably hydrochloric acid, sulfamic acid and amine polymer derivative (with *Moderate* impact to aquatic ecosystem) and ethylene glycol monobutyl ether (with *Moderate* impact to off-site human health), following the definitions below for *Moderate* hazard level:

- *Moderate hazard level*:
    - Off-Site Human Health Issues (chronic) - *Transient effect that may require medical treatment such as respiratory effects, more significant irritation; and*
    - Off-Site Impacts to Aquatic Ecosystem - *Moderate potential for adverse effect on aquatic eco-system*

None of the chemicals have been ranked as of *High* or *Severe* hazard in accordance with the definitions.

8.1.2 Likelihood Analysis

The likelihood that any of the chemicals used in workover activities may be discharged into an environment where any level of exposure may occur depends on the controls in place to manage these chemicals, as detailed in the table in Appendix 1, *TC16 – Suitable tanks*.

The likelihood of a spill or release of the chemicals used in well workover activities were assessed to provide a *likelihood ranking* for workover activities against the definitions in the likelihood scoring table (which forms part of the risk matrix in Section 1.5.4). The results are summarised in Table 23 below (Ref 13, Appendix E).

Table 23 - Likelihood Ranking for Chemicals Used in Well Workover Activities

Activity	Potential Impacts	Likelihood ranking
Accidental release of workover fluids/chemicals	Runoff to the adjacent environment (terrestrial or local aquatic environments where present)	Highly unlikely to Unlikely

These results show that all chemicals utilised in workover activities are associated with a likelihood ranking of between *Highly unlikely* and *Unlikely*, defined as:

- *Highly unlikely*: No pathway of exposure. Management measures in place to prevent surface releases; and

- *Unlikely:* No use of aquifers for any purpose, management measures in place that make releases at ground surface unlikely.

8.1.3 Risk Assessment

The risk matrix used to characterise environmental risk issues is presented in Section 1.5.4 (from the EHIA, Ref 13).

By combining the hazard ranking with the likelihood ranking, the risks to human health and the environment from workover chemicals are defined, as presented in Table 24 below. The risk results are highlighted in orange.

Table 24 – Risk Results for Release of Workover Chemicals at CSG Wells

EHIA risk matrix (Ref 13)		Consequence				
		Negligible	Low	Moderate	High	Severe
		1	2	3	4	5
Likelihood of Exposure at Receptor	Very likely 5	N	L	M	H	E
	Likely 4	N	L	M	H	E
	Possible 3	N	L	M	M	H
	Unlikely 2	N	L	L	L	L
	Highly unlikely 1	N	N	N	N	N

The results show that the risk associated with these chemicals is estimated as either *Negligible (N)* or *Low (L)* with the following interpretations of the risk outcomes:

- *Negligible* risk - no adverse impacts.
- *Low* risk - potential for impacts is very low and potential for impacts to result in adverse effects is low. Risk issues identified can be effectively managed through implementation of appropriate management measures.

8.2 RELEASE OF MATERIALS USED DURING ROUTINE OPERATION - PRODUCED WATER

Very few chemicals are used at the well pad during routine operation; limited to oils, greases, diesel and produced water. The management systems in place to prevent and protect against a spill of oils, greases and diesel are particularly robust, as discussed in Section 3.1.2, and no further risk assessment is required in this HRA. The risk associated with produced water storage warrants further analysis due to the saline nature of this material and the potentially larger quantities stored.

8.2.1 Consequence Assessment

The worst-case scenario of a potentially harmful liquid release during routine operation of the gas well is defined in the EHIA (Ref 13) as … *a produced water storage tank failure which is not detected and is not contained within the bunded area* (EHIA, Ref 13). The EHIA does not identify the causes of a potential tank failure but this could be due to a number of reasons, e.g. flood event (refer to TC16 in Appendix 1). The worst-case scenario would involve the release of the whole volume of fluids or chemicals from the largest container at the well (representing 62kL for produced water during routine operation of the wells).

The EHIA assumed that the released water would flow across the ground surface and, during migration of the released liquid, 10%[28] (that is, 6.2kL) of the released volume would enter a receiving water body at the one time.

Given the minimum distance between the well pad (of 100 m), the assumption of 10% of the liquid reaching the water body <u>at one time</u> (that is, as the result of a

[28] The EHIA assumed that 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). During migration of the leaked fluid, the EHIA 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, the EHIA assumed that is likely that most will not reach the water body due to these processes.

single release event) appears conservative. However, this HRA has also assessed this risk should 50% (that is, 31kL) of the liquid reach the water body at the one time – this would be possible if the liquid was channelled for 100 m into a water body.

Calculations of concentration of chemical in surface water body were performed in the EHIA using the equation below:

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

With:

- C_{sw} = concentration of chemical in surface water body (mg/L)
- V_{sw} = volume of surface water body
- C_F = concentration in the fluid (mg/L)
- V_F = volume of fluid that has leaked (L), based on the assumption that (1) 10% of the total volume of fluid reaches the water bodies at the one time, i.e. 10% of 62,000 L = 6,200 L for produced water or (2) 50% of the total volume reaches the water body at the one time , i.e. 31,000 L

Relevant receiving water bodies identified in the EHIA for the CSG wells within the CGP are farm dams and the Upper Canal. Another possible receiving body of water is the Nepean River and its associated catchment system. Further discussion is as follows:

- Farm Dams: The closest dams to the CSG wells range in size, with the *standard field-farm pond* size/depth of 1 hectare/0.15m depth[29] been considered relevant (Ref 13), with 1,500m^3 water capacity.

- Nepean River: In the event of a flood, there is potential for produced water to enter the Nepean River or associated catchment areas. The flooded river system would have a much higher volume of water available to dilute

[29] 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.

the spill and hence result in lower concentration of pollutant. However, the lower dilution afforded by the farm dam (discussed above) has conservatively been used to represent the case where the spill enters the Nepean River.

- Upper Canal: Contamination that enters the Upper Canal could be transferred into Sydney's drinking water supply via the Prospect Water Filtration Plant. The dilution of any contamination that enters the Upper Canal into the drinking water supply would depend on the ratio of water derived from the Upper Canal, Warragamba Dam and Prospect Reservoir.

  The EHIA (Ref 13) defined the worst-case scenario as when a liquid release at the well pad occurs over a one hour period at a time when only water from the Upper Canal is being treated at the Prospect Water Filtration Plant, that the treatment system has failed and water from the Upper Canal enters the drinking water supply unchanged (i.e. untreated) and that no water is sourced from Warragamba Dam. The flow rate of water in the Upper Canal was set in the EHIA as 250 ML/day[30].

  Considering the key chemicals identified in production water, as presented in Table 8, the consequences of the liquid release scenario is quantitatively evaluated and compared with the adopted drinking water guideline, with the ratio of the estimated concentration at the point of extraction calculated and compared with the drinking water guideline (termed a Hazard Index, HI)[31]. The one instance where the concentration in the receiving body of water may exceed the drinking water guideline is

[30] The flow rate of water in the Upper Canal varies, and is typically around 250 ML/day (10ML/hour), with an upper capacity of 700 ML/day, with the higher rates expected if drinking water is only sourced from the Upper Canal (to meet demands of Sydney's water supply).

[31] Note that these results are for the Camden North Expansion Project with the EHIA assessment being based on data from the CGP gas wells, a very similar geology and hydrogeology at the CGP compared with that assessed as part of the Northern Expansion Project and the distances to receiving water bodies being very similar. They are therefore expected to be relevant also for the CGP.

highlighted and discussed below. A comparison with the Fresh and Marine Water Quality Guidelines is provided in Appendix 2 Section A2.2 from an environmental perspective.

Table 25 - Calculated Concentrations and HIs in Surface Water Following Accidental Release of Produced from the Well Pad Assuming 10% Reaches the Water Body (Assumption in the EHIA)

Key chemical		Concentration in Fluid (at well pad) (mg/L)	Drinking water guideline (Ref 16) (mg/L)	Concentration in Receiving Body (mg/L)		Hazard Index (HI)	
				Farm dam	Upper Canal	Farm dam	Upper Canal
Total dissolved solids		23500	600	97	14	0.2	0.02
Arsenic		0.113	0.1	0.00047	0.000067	0.005	0.0007
Strontium		10.2	9.3	0.042	0.0061	0.005	0.0007
Barium		35.5	2	0.15	0.021	0.07	0.01
Nickel		0.024	0.02	0.0001	0.000014	0.005	0.0007
Lead		0.026	0.01	0.00011	0.000015	0.01	0.002
Iron		15.4	11	0.064	0.009	0.006	0.0008
Bromine		5.7	2	0.024	0.0034	0.01	0.002
Iodine		0.8	0.16	0.0033	0.00048	0.02	0.003
Fluoride		3.9	1.5	0.016	0.0023	0.01	0.002
Methane (and other C1-C1 gases)		10,516	10,000	43	6.3	0.004	0.0006
Naphthalene		0.0192	0.0061	0.000079	0.000011	0.01	0.002
Benzo(a)pyrene		0.0011	0.00001	4.5E-06	6.5E-07	0.5	0.07
Benzo(b)fluoranthene		0.0018	0.0001	7.4E-06	1.1E-06	0.07	0.01
Benzo(g,h,i)perylene		0.0017	0.001	0.000007	0.000001	0.007	0.001
Benzene		0.01	0.001	0.000041	0.000006	0.04	0.006
Traces of hydro-carbons	TPH C10-C14	21.7	0.09	**0.09**	0.013	**1**	0.1
	TPH C15-C28	38.8	0.09	**0.16**	0.023	**2**	0.3
	TPHC29-C36	17.2	0.09	**0.071**	0.010	**0.8**	0.1

From the EHIA (Ref 13)

Expanding the analysis which was done as part of the EHIA and assuming that an extreme (and highly conservative[28]) 50% of the spilled liquid enters the water body at the one time, the results remain unchanged for potential pollution at the Upper Canal, and the calculated HI for all the chemicals evaluated is less than 1, with the exception of traces of hydrocarbon in the range C15 to C28, where the HI would be 1.3.

The potential for pollution of surface water quality within local farm dams or the Nepean river system would have a HI exceeding 1 with respect to benzo(a)pyrene and the TPH (C10-C36) where the HI is up to 9.

These results are shown in Table 26 below.

Table 26 - Calculated Concentrations and HIs in Surface Water Following Accidental Release of Produced from the Well Pad Assuming 50% Reaches the Water Body

Key chemical	Concentration in Fluid (at well pad) (mg/L)	Drinking water guideline (Ref 16) (mg/L)	Concentration in Receiving Body (mg/L)		Hazard Index (HI)	
			Farm dam	Upper Canal	Farm dam	Upper Canal
Total dissolved solids	23500	600	485	70	0.8	0.1
Arsenic	0.113	0.1	0.0024	0.00034	0.02	0.003
Strontium	10.2	9.3	0.21	0.0305	0.02	0.003
Barium	35.5	2	0.75	0.105	0.4	0.05
Nickel	0.024	0.02	0.0005	0.00007	0.03	0.004
Lead	0.026	0.01	0.0006	0.000075	0.06	0.008
Iron	15.4	11	0.32	0.045	0.03	0.004
Bromine	5.7	2	0.12	0.017	0.06	0.009
Iodine	0.8	0.16	0.017	0.0024	0.1	0.02
Fluoride	3.9	1.5	0.08	0.0115	0.05	0.008
Methane (and other C1-C1 gases)	10516	10000	215	31.5	0.02	0.003
Naphthalene	0.0192	0.0061	0.00040	0.000055	0.06	0.009
Benzo(a)pyrene	0.0011	0.00001	2.25E-05	3.25E-06	2	0.3

Key chemical		Concentration in Fluid (at well pad) (mg/L)	Drinking water guideline (Ref 16) (mg/L)	Concentration in Receiving Body (mg/L)		Hazard Index (HI)	
				Farm dam	Upper Canal	Farm dam	Upper Canal
Benzo(b)fluoranthene		0.0018	0.0001	0.00004	5.5E-06	0.4	0.06
Benzo(g,h,i)perylene		0.0017	0.001	0.000035	0.000005	0.04	0.005
Benzene		0.01	0.001	0.00021	0.00003	0.2	0.03
Traces of hydro-carbons	TPH C10-C14	21.7	0.09	0.45	0.065	5	0.7
	TPH C15-C28	38.8	0.09	0.8	0.115	9	1.3
	TPHC29-C36	17.2	0.09	0.355	0.05	4	0.6

Expanded from the EHIA (Ref 13) but for 50% of the released volume would enter a receiving water body at the one time

The results show the following:

- 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** except the extreme (highly conservative) case where 50% of the spill reaches the waters in any one time, where the HI for TPH C15-C28 where the HI is evaluated to be 1.3. This means that under the scenarios 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 all bar one instance. Following the consequence scoring table in Table 5, the consequence ranking at the Upper Canal would be between Negligible to Low for the 10% scenario and Low to Moderate for the 50% scenario.

- In relation to the potential for accidental releases impacting on surface water quality within local farm dams or the Nepean river system, the calculated HI is less than 1 for most of the chemicals assessed that may be present in produced water, with the exception of TPH (C15-C28), where the HI is up to 2 for the case where up to 10% of the released spill reaches the receiving water body at one time. For the extreme scenario, where 50% of the released spill reaches the receiving water body at one time, HI may be up to 9 for TPH C10-C36, and up to 2 for benzo(a)pyrene. Following the consequence scoring table in Table 5, the consequence ranking at a local farm would be Low. While these HI's are higher than the target of 1, the EHIA (Ref 13) reported that no health impacts would be expected for the 10% case 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); and

- 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.

These findings are valid also should the spill end up in the Nepean River and associated catchment areas.

8.2.2 Likelihood Analysis

The likelihood of a worst case release of produced water where any level of exposure may occur depends on the controls in place to manage these chemicals (refer Appendix 1, *TC 16 – Suitable tanks*).

In the case of produced water, it also depends on the likelihood that a leaking vessel contains sufficient produced water to generate the calculated concentrations at the receiving water body, since the concentration depends on the size of the spill as well as the percentage of the spill that reaches the receiver.

The likelihood was assessed using Table 5, and the results are presented in Table 27 below.

Table 27 - Potential Impacts and Likelihood – Produced Water Release

Activity	Potential Impacts	Likelihood ranking
Accidental release equivalent to a full vessel of produced water where 10% reaches body of water at one time	Runoff to the adjacent environment (terrestrial or local aquatic environments where present)	Highly unlikely to Unlikely
Accidental release equivalent to a full vessel of produced water where 50% reaches body of water at one time	Runoff to the adjacent environment (terrestrial or local aquatic environments where present)	Highly Unlikely

This evaluation is confirmed through the groundwater monitoring program at the CGP since 2011 (Ref 31[32]) comprises 11 monitoring bores at three monitoring sites. Data indicate that there are no observable impacts to groundwater levels or quality that could be attributable to CSG operations; and no evidence of connectivity between the shallower monitored zones and the coal seams, in agreement with the conceptual model.

8.2.3 Risk Assessment and Comparison with Risk Criteria

The risk to human health and the environment from produced water are estimated as between *Negligible* and *Low* in accordance with the definitions in Table 5, with the following interpretations of the risk outcomes:

[32] The title of the report refers to 2014/15 results but the introduction and results discussed in the report refer back to 2011 data.

- *Negligible* (N) risk - no adverse impacts are expected.
- *Low* (L) risk - the potential for impacts is very low and that the potential for impacts to result in adverse effects is low; risk issues identified can be effectively managed through implementation of appropriate management measures.

The risk ranking is depicted graphically (in orange) in Table 28 below.

Table 28 – Risk Results for Releases of Produced Water at CSG Wells

EHIA Risk Matrix (Ref 13)		Consequence				
		Negligible	Low	Moderate	High	Severe
		1	2	3	4	5
Likelihood of Exposure at Receptor	Very likely 5	N	L	M	H	E
	Likely 4	N	L	M	H	E
	Possible 3	N	L	M	M	H
	Unlikely 2	N	L	L	L	L
	Highly unlikely 1	N	N	N	N	N

Further, by using the input from the analysis in the EA and EHIA, and translating these into the CGP conditions, the existing operational and design measures utilised at the CSG wells at the CGP are deemed sufficient to manage potential risks, to ground and seepage into groundwater associated with the CSG well production activities, to acceptable levels. The groundwater monitoring program carried out since 2011 in the CGP area confirms the absence of impact on groundwater level or quality (Ref 31).

9 TECHNICAL RISK CONTROLS

Each key risk pathway identified for the CSG wells is associated with one or several technical controls.

The methods in place by AGL to adhere to each technical control has been critically reviewed against what is required in the Code of Practice for CSG well integrity (Ref 2), the Chief Scientist and Engineer's (CSE's) review into CSG activities (Refs 4, 5 and 6) and this HRA.

The results of the critical review is presented in the form of tables in Appendix 1, with the following columns:

1. Identifier (TC# or ATC#) referring to the *technical control* and *additional technical control* marked out on the key risk pathway in Figure 4 and Figure 5;
2. Source of the requirement (i.e. CSE Risk Report and/or Codes of Practice for Coal Seam Gas);and
3. How the control is implemented at the AGL Camden Project

The review shows that all of the requirements for CSG well integrity and safe management are included in AGL methods in place for their CSG wells that form part of the CGP.

10 DISCUSSIONS AND CONCLUSION

This holistic hazard and risk assessment (HRA) has been carried out in order to assess the risk to human safety, health and the environment associated with the above ground portion of the AGL CSG wells within the CGP, and to demonstrate that health, safety and the environment are protected in all circumstances in the vicinity of the above ground portions of the CSG wells.

The assessment includes a review of the measures in place by AGL to protect the community and the environment from the operation of the aboveground CSG well equipment.

The HRA takes into account possible CSG, produced water and other liquid emissions from all types of wells operating at the CGP during routine and non-routine operations.

The HRA includes triggers for potentially hazardous incidents from a failure at the aboveground equipment at the well itself; and an upset condition at *upstream facilities* (i.e. belowground components of the well) and *down stream* facilities (i.e. gathering line, gas plant).

This HRA has been prepared in accordance with the guidelines for hazard analysis developed by the NSW Department of Planning and Environment (NSW DP&E) in their Hazardous Industry Planning Advisory Paper No 6, *Hazard Analysis*.

As per the guidelines for Hazard Analysis, the HRA assesses the risk outside of the site boundaries of the well site and does not include workplace health and safety aspects for people working within the site boundaries.

The assessment was carried out by Planager Pty Ltd, an independent Australian risk engineering consultancy specialising in risk minimisation and inherent safe engineering and management practices for the oil and gas, energy and mining sector.

The risk associated with the potentially hazardous incidents identified for the CSG wells was estimated for the case where all controls and management systems fail. The results are presented below:

CSG release

- *Failure of well integrity and fire leading to potential human safety risk from heat radiation:* The separation distances between the gas wells and any of the land uses neighbouring the wells is in excess of the minimum separation distances established through Quantitative Risk Assessment (QRA) methodology by the NSW DP&E (Refs 3) and by Planager (Refs 22, 23 and 24). With such separation distances between the CSG wells and neighbouring land use, the risk to human safety from a fire at a CSG well is acceptable and well within the criteria for land use planning.
- *Ignition of gas from a Pressure Relief Valve (PRV) leading to potential human safety risk*: The flammable gas concentrations of CSG are below the lower flammable limit (LFL) outside of the well compound (defined by the security fence line) and do not descend below the height of the PRV (minimum 3 metres above ground level) at any location past the opening of the PRV. A PRV opening does not pose a human safety risk from ignition of the CSG from human activity outside of the well site boundaries.
- *Generation of noise leading to potential human health risk*: The maximum exposure time at the noise level experienced at the closest resident from a PRV opening is 120 minutes (two hours) without a risk of hearing damage (Ref 8). This corresponds to twice the worst case (Planager assumed) duration of a PRV release and is four times the maximum duration estimated by AGL. According to the criterion, a person can be exposed to this noise level every day for a maximum duration of two hours without a risk of hearing damage. The likelihood of the PRV opening at one specific well and emitting this sound level, even for a few seconds, is 2×10^{-4} times per year (or 1 in 4,600 years) and the likelihood of it staying open is much lower than this. Hence, the risk at the nearest resident of hearing damage from PRV opening is extremely low and well within the acceptable range.

- *Air quality impact from fugitive emissions leading to potential human health risk*: The concentrations of all CSG components during normal operation of the wells are well below all screening level guidelines for fugitive emissions. The methane concentration at ground level from a PRV release corresponds to the background concentration in the area. The CGP well sites have no significant air quality impacts as the emissions from the development contribute only a small fraction to the regional air quality which remains below the National Environment Protection Measure goals. All fugitive emissions were repaired within the timeframe, as specified in AGL's Environment Protection Licence. It then follows that the risk to human health from impact on air quality from the CSG wells which form part of the CGP is low and well within the acceptable range

Potentially harmful liquid release, leading to risk of impact on soil, air and water quality and health risk from direct exposure to contaminants or indirect exposure through ingestion of contaminated food or environmental risk, is consistently rated as either Negligible (N) or Low (L).

The review shows that all of the requirements for CSG well integrity and safe management are included in AGL methods in place for their CSG wells that form part of the CGP.

Provided continued successful implementation of the technical controls included in this HRA (and detailed in the tables in Appendix 1), the risk to human safety, health or the environment associated with the AGL CSG wells adhere to all International or National criteria identified and specified in this holistic hazard and risk assessment.

It is recommended that AGL regularly conduct a review of this HRA to ensure that the relevant hazards and risks are identified and that the technical controls continue to be successfully implemented.

Appendix 1

Technical Controls and Additional Technical Controls

Camden Gas Wells Hazard Risk Assessment

Appendix 1 – Technical Controls and Additional Technical Controls

A1.1 Assessment of implementation at AGL CGP wells of Technical Controls defined in the CSE Review

The following *technical controls* are identified in the CSE report as required for suitable management of CSG wells.

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
TC1	**Site selection**		
	Includes both project site selection (e.g. which area of a basin) and activity site selection (e.g. choosing location of well). Sites selected for drilling and fracturing have appropriate geological conditions (aquitards, overburden, fracture gradient, stress regime, etc.). Geological and hydrogeological characterisation is used to determine this including understanding features such as: fractures, faults and dykes (and whether these are conduits or inhibitors to flow), aquitards, overburden depth, stress regime, cleating, fracture gradient, location and condition of existing wells, physical properties of surrounding rocks.	Section 2.1 of the Code of Practice outlines the requirements associated with Preliminary Approvals covering: title approvals; land access; approval of exploration proposals; activities requiring approval under other legislation, and approval of production proposals. The requirements include the preparation of an environmental impact assessment in accordance with Part 5 of the *Environmental Planning & Assessment Act 1979.*	Hydrogeological and geological characterisation of the project area as well as potential impacts from the wells on air quality, groundwater and noise levels are determined during the Environmental impact assessments stage. The report entitled *Hydrogeological Summary of the Camden Gas Project area* (Ref 32 produced by AGL in 2013 is publicly available on the AGL website). This report provides a summary of the hydrogeological environment within the Camden Gas Project (CGP) area. It has been compiled from available data including publicly available reports collected from AGL activities in recent years. Further, the selection of well site locations follow the requirements under the NSW Department of Planning and Environment (the NSW DP&E at the time of writing this report, then the *NSW Department of Infrastructure, Planning and Natural Resources*) *Locational guidelines for development in the vicinity of operating CSG wells* (described in the guidelines as Coal Seam methane wells,

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
			Ref 3). The Locational guidelines describe the separation distance required to ensure an appropriate buffer between a development and an existing or future operating CSG well. The minimum separation distances in the guideline are determined based on the accepted level of risk of fatality from an ignited loss of containment event, with reference to the State's risk criteria for land use planning (NSW DP&E, HIPAP4, 2011). Further, gas well sites are selected to ensure a minimum distance of 40m between wells and nearby water bodies.
TC13	**Blowout preventers fitted to well heads**		
	Well heads, blowout prevention and production tree equipment accord with API standards including API Specification 6A/ISO 10432, Specification for Wellhead and Christmas Tree Equipment; API Specification 16A, Specification for Drill Through Equipment; API Recommended Practice 53, Blowout Prevention Equipment Systems for Drilling Operations and API 11IW Recommended Practice for Independent Wellhead Equipment.	According to Section 4.1.2 in the Code of Practice, it is mandatory that the Design Basis for CSG wells incorporates provision for Blow Out Preventor (BOP). Section 4.4.3 details good industry practice during workovers is to ensure wellhead seal tests are conducted to test the mechanical integrity of the wellhead sealing components (including valve gates and seals) and confirm they are capable of holding against well pressure.	AGL reviews the API specifications when purchasing equipment associated with the wells and when engaging service providers for workovers, including for BOP. Workover operations are performed in accordance with API standards. Accordingly, BOPs and fluid weights are used to prevent blow outs during workover operations. Each workover crew includes staff who are appropriately trained and competent for well control including operation of the well BOP. A Program for each workover is prepared by AGL and submitted to DRE for assessment in accordance with the

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
		Section 4.4.4 specifies that the CSG Titleholders should review at least the following when selecting wellhead, Blowout Prevention and Production tree equipment: API Specification 6A/ISO 10432, Specification for Wellhead and Christmas Tree Equipment; API Specification 16A, Specification for Drill Through Equipment; API Recommended Practice 53, Blowout Prevention Equipment Systems for Drilling Operations; API 11IW Recommended Practice for Independent Wellhead Equipment	High Risk Activity (HRA) process, under the Work Health and Safety (Mines and Petroleum sites) Act 2013 .
TC14	**Detailed and robust groundwater models** Use of multiple model realisations combined with local, empirically derived model parameters along with the reporting of upper bound or "worst case" estimates. Modelling should be able to predict pressure, level and quality of groundwater and surface water. Baseline monitoring for up to two years prior to activity, initial pump testing and monitoring to determine if rapidly realisable connections exist between coal seams and groundwater	-	A conceptual model for groundwater flow within the Camden area is described in the AGL Hydrogeological summary report (Ref 32). It includes depressurisation and aquifer interactions; and potential for drilling impacts and contamination. There have been no further field development activities since the CSE Risk Report was released in 2014 so the specific recommendations in the CSE report are not relevant. However, AGL continues to monitor groundwater in accordance with Ref 33.

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
	systems as well as to inform predictions of water extraction rates.		
TC15	**Depressurisation monitored** Measurements include assessment of pressures, levels and yielded gas levels from the coal seam and potentially connected aquifers and surface waters as well as water quality analysis. Specific details of the monitoring that would be applied would be based on case-by-case considerations, for example, if the likelihood of subsidence is high, surface movement can be assessed using tilt meters and satellite imaging.	Section 2.1.4 states that NSW Office of Water (NOW) regulates water bore drilling, including groundwater monitoring bores drilled by coal seam gas titleholders under the Water (Part 5 - Drillers Licenses) Regulation 1995 and the Water (Part 5 – Bore Licences) Regulation 1995. These Regulations along with the Minimum Construction Standards for Water Bores in Australia require adherence to certain minimum standards and reporting to NOW. Title holders should contact the NSW Office of Water to determine licensing and approval requirements if they intend to undertake any CSG operations that involve drilling, testing and may interfere with aquifers.	Government (through the NOW, now named DPI Water), in February 2011 placed a number of monitoring program conditions on AGL's water bore licences. These generally relate to: A formal groundwater management plan; more precise monitoring of pumped volumes; installation of dedicated monitoring bores when directed; collection of periodic water level and water quality data; and annual reporting of data and trends. The proposed monitoring program, as outlined in the AGL Groundwater Management Plan (Ref 33) is designed to give reasonable spatial representation to allow for characterisation of the groundwater systems within the area, in order to identify trends within each system and potentially identify whether there is a relationship between systems. Monitoring will occur at dedicated monitoring locations, CSG wells, and other receptors (water supply bores and perched water bearing zone area/s). AGL's programs to monitor and protect groundwater include: designing and constructing gas wells with multiple casings, pressure cemented to ensure long life and to

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
			exclude shallow groundwater; monitoring the integrity of gas wells constructed throughout the field to ensure that steel casings are cemented to full depth and that the pressure cementing of casing strings is to surface so as to isolate all aquifers; containment of all drilling/fracturing fluids in lined pits and tanks, tankering of fluids away for disposal at licensed wastewater facilities thereby minimising the potential for impacts to surface water or groundwater; monitoring and recording of produced water flows from gas wells; water sampling of selected gas wells to characterise the deep groundwater quality; and tracking the performance of selected water supply bores (into the Hawkesbury sandstone aquifer). A series of management response procedure is set up, based on changes in water level and quality, and produced water volumes. A technical compliance report must be submitted to DPI Water annually. In addition, compliance with the EPL 12003 is reported annually to the EPA. The reports include analysis and interpretation of monitoring results and actions to correct identified adverse trends. The potential for subsidence was assessed in Ref 34 which concluded that 'the potential for subsidence to occur as the

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
			gas is extracted is almost negligible'. Consequently, AGL does not monitor subsidence across the CGP.
TC16	**Suitable tanks** Tanks are well designed, constructed, maintained and monitored.	 Section 4.7 sets the mandatory requirements for well monitoring. Ongoing well conditions must be monitored to ensure integrity of the well and well equipment. Monitoring mechanisms and frequencies are to be determined by a comprehensive risk assessment. In addition, the Code states that a Preventative Maintenance (PM) program should be put in place to service all surface equipment at the wellsite. During well intervention, or workovers, a breakdown or visual inspection should take place and records taken of then condition of the equipment after being in service. Routine operational visits by well operators should monitor, identify and report any abnormal well conditions including wellhead leaks. These visits should also be used to monitor regular well pressures in addition to	(Applies to pressure vessels and atmospheric storage tanks) **Design and construction:** Vessels and tanks are designed and constructed by suitably qualified companies with engineering expertise to meet applicable industry standards. Tanks and vessels are designed to minimise storage quantities. Produced water tanks are emptied regularly to maintain minimum water levels. As a well matures and stops producing water, the Management of Change Procedure can be initiated and the water tank may be removed from the well site. Water levels are closely monitored in open top tanks on workover sites to maintain a 20% freeboard. Bunding is also used on open top tanks at workover sites. Vacuum tankers, used to transfer produced water from the produced water tank into the vacuum truck, are purpose designed and fit-for-purpose. All chemicals used during workover activities are stored in lined bunds or contained areas. Fuel cells are double skinned. **Maintenance:** Regular maintenance, inspection and integrity monitoring are carried out to determine the

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
		SCADA where used. Wellhead pressures, gas and water production rates of all CSG wells should be continuously monitored.	mechanical integrity of tanks, vessels and other containers. Maintenance and inspection activities include: regular (fortnightly or monthly depending on the well's production status) inspections for corrosion and other mechanical defects associated with the pressure vessels, pipework, and water storage tanks; 3-monthly fugitive emissions program; and pressure vessels certified and inspected to regulatory requirements, regular recording of water levels in the tanks. Frequencies of monitoring activities have been set based on the well's production status and associated risks. Failure of plant and equipment is assessed as a risk on the AGL Environmental Aspects and Impacts Register (2016) and the controls in place are critically evaluated. Operational activities at each well location typically include monthly inspection of meters and recording of meter readings / pumped volumes; collection and disposal of produced water from tanks; and recording of trucked volumes (and reconciliation with metered volumes). Abnormal conditions are reported to management via AGL's Well Check Procedure (DCS_CM_SOP_FO_104) and the Well Check Form (DCS_CM_FO_CK_001 via the HASIF form).

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
			Vacuum tankers are owned, operated and maintained by AGL and maintenance activities are scheduled in the PM program. **Monitoring:** Electronic monitoring of the status of the gas well conditions is assured through the use of a number of electronic sensors installed at the well, including for produced water levels and gas flow rates. Data from the wells is sent to the gas plant via a computerised system for remote monitoring and control (SCADA). Signals from the sensors are monitored on a 24 hour basis by the operator at the gas plant and can be checked locally at the well. Using the data received from the electronic sensors the operator can decide to shut in a well using the remote controlled isolation valve. If the manual shut-in is not done in a timely manner, an automatic shutdown is initiated through a number trips. These are initiated on excursion of water level in the separator and in the produced water tank above the set-points. All wells can be shut-in both manually (by the operator, either remotely from the gas plant or locally at the well) and automatically using the SCADA trips. AGL carries out regular maintenance, inspection and integrity monitoring of their plant and equipment to

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
			determine the mechanical integrity of all associated well plant and equipment. Scheduling of activities is done via AGL's Preventative Maintenance program (MEX) which is also used to record the results of inspections and to schedule further repair work if needed.
TC18	**Suitable pipeline**		
A	Ongoing monitoring of pressure, flow and physical inspections of integrity is used to help detect and stop leaks early.	Section 4.4.2 sets the mandatory requirements for Operators to monitor wellheads for leaks or emissions. Section 4.7 further sets the mandatory requirements for well monitoring. Ongoing well conditions must be monitored to ensure integrity of the well and well equipment. Monitoring mechanisms and frequencies are to be determined by a comprehensive risk assessment. In addition, the Code states that a Preventative Maintenance (PM) program should be put in place to service all surface equipment at the wellsite. During well intervention, or workovers, a breakdown or visual inspection should take place and	**Monitoring of pressure and flow:** Electronic monitoring of the status of the gas well conditions is assured through the use of a number of electronic sensors installed at the well, including for pressure and gas flow rates. Data from the wells is sent to the gas plant via a computerised system for remote monitoring and control (SCADA). Signals from the sensors are monitored on a 24 hour basis by the operator at the gas plant and can be checked locally at the well. A pressure control valve will automatically regulate the pressure to desired levels. Using the data received from the electronic sensors the operator can decide to shut in a well using the remote controlled isolation valve. If the manual shut-in is not done in a timely manner, an automatic shutdown is initiated on excursion of pressure above the set-points. Further, fire detection in the form of a fusible loop is fitted to the emergency isolation valve - if

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
		records taken of then condition of the equipment after being in service. Routine operational visits by well operators should monitor, identify and report any abnormal well conditions including wellhead leaks. These visits should also be used to monitor regular well pressures in addition to SCADA where used. Wellhead pressures, gas and water production rates of all CSG wells should be continuously monitored.	the fusible loop burns through, the emergency isolation valve will close. **Monitoring of physical integrity:** Failure of well integrity is assessed as part of the Environmental Aspects and Impacts Register and the associated technical controls are critically evaluated. AGL carries out regular maintenance, inspection and integrity monitoring of their plant and equipment to determine their mechanical integrity. Scheduling of these activities is done via AGL's Preventative Maintenance program (MEX) which is also used to record the results of inspections, and to schedule further repair work if required. Maintenance and inspection activities include: Regular inspections for corrosion and other mechanical defects associated with the pressure vessels and pipework; 2-monthly fugitive emissions program for producing wells, 3-monthly for suspended wells; and pressure vessel and pressure safety valve certified and inspected to regulatory requirements, a Leak Detection And Repair (LDAR) program is implemented, specifying time for repair in function of the size of the fugitive emissions (Ref 35).

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
TC18 **B**	Pipelines should be fit-for-purpose with respect to the soundness of their design and construction.	Section 4.7 sets the mandatory requirements for mechanical integrity.	**Design and construction:** All plant and equipment associated with the wells, including tanks, pressure vessels, pipelines, electronic sensing equipment and mechanical safety devices (such as pressure safety valves and check valves), are designed and constructed, following Codes and Standards, by engineers and suitably qualified tradespersons with input from experts in their fields. Please note that there have been no pipelines designed and constructed in Camden since the Code and CSE Report were released. The well head and shut down valve are rated to fire conditions (API spec 6A) and designed to withstand in excess of the maximum pressure capable of being produced from the reservoir formation, as per Code requirements. Each well is fitted with pressure relief valves (PRVs), as a last bastion of defence, to protect against damage due to overpressurisation. The capacity of the PRV is sufficient to relieve at full flow from the well, including in a bush fire situation as per Code requirement. The vent line (from the PRV) is vertical and at least 2 m above the top of the vessel (or enclosure, if it is enclosed), or 3 m above ground level or any platform on which a person can stand, whichever is the higher, in line with Code requirements. This design aids in

Identifier	CSE Risk Report	Additional information in Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Project
			the dispersion of an unignited release and minimises consequences should the PRV release ignite. A non return valve (*check valve*) is fitted to the CSG pipe downstream of the well equipment but before the line enters the ground to join into the gathering line. The check valve prevents backflow of gas pressure from the gathering line into well piping and equipment. A Cement Bond Log process at the well casing is completed during construction or otherwise as part of the well decommissioning (plug and abandonment) phase from 2017 onwards to measure the thickness of the cement around the casing annulus.

A1.2 Assessment of implementation at AGL CGP wells of Additional Technical Controls defined in the Code of Practice for well integrity or through HRA process

The following *additional technical controls* are identified as required for suitable management of CSG wells, either in the Code of Practice or through this HRA process. They have not been discussed in the CSE report.

Identifier	Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Gas Project
ATC1	**Fencing**	
	Section 2.3.3 stipulates the mandatory requirements for fencing, as follows: Titleholders should construct fencing for well sites for safety and to exclude livestock and wildlife. Titleholders must also abide by any additional measures regarding fences set out in the Access Agreement. The titleholder must ensure that if fencing around the well head is removed during an operation, the fencing is replaced immediately after the operation is completed. Further, Section 4.8.2 stipulates that suspended well sites must be secure with a locked fence around the well.	All well enclosures are fenced with access to the site through locked gates. Well site enclosures are fitted with danger signs prohibiting unauthorised access, smoking and ignition sources within the fenced area. All fencing needs to be semi permanent so that it can be dismantled to allow access for workovers Most well sites are on private property with multiple locked gates to access. Landholder relationships are maintained.
ATC2	**Suitable well head**	
	The primary purpose of a wellhead is to provide the suspension point and pressure seals for the casing strings that run from the bottom of the hole sections to the surface pressure control equipment. The wellhead ensures well integrity at the surface and enables the installation of Blow Out Preventers. Wellheads are threaded or welded onto the first string of casing, which has been cemented in place during drilling operations, to form an integral structure of the well.	No new well heads have been installed by AGL since the Code of Practice was introduced. All wellheads installed by AGL prior to the Code comply with API requirements. Well heads installed by the previous operator the Camden Gas Project (Sydney Gas) are Independent Wellheads which comply with API11IW. AGL's programs to monitor and protect groundwater include: designing and constructing gas wells with multiple casings, pressure cemented to ensure long life and to exclude shallow groundwater;

Identifier	Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Gas Project
	Wellhead design needs to facilitate installation of Blow Out Preventer Equipment. Section 4.4.2 sets the mandatory requirements for Operators to use wellheads compliant to API Specification 6A/ISO 10432.	monitoring the integrity of gas wells constructed throughout the field to ensure that steel casings are cemented to full depth and that the pressure cementing of casing strings is to surface so as to isolate all aquifers and to prevent CSG migration to the surface.
ATC3	**Well suspension**	
	Section 4.8 requires that a well must be made safe in accordance with relevant standards. A suspended well must be sealed in a manner that prevents leakage and facilitates safe recommencement of operations. The site is to be made secure to exclude persons and stock. A program must be put in place for regular inspections to check for gas leaks and other health and safety matters with a record kept of all inspections.	AGL must receive approval from the DRE before suspending a well. The well is isolated using the Master Valve, all pipework is removed from the well head and 2” plugs are installed. All valve handles are removed or otherwise chained and locked closed. A pressure gauge is installed on the top of the tubing and the wells are periodically opened to monitor and record well head pressures. AGL’s suspended wells are inspected by the DRE on a regular basis to ensure they are safe in accordance with the DRE’s approval. The wells are also inspected by the NSW EPA when performing gas leak checks. Suspended wells are sealed in a manner that prevents leakage and facilitates safe recommencement of operations. All suspended wells are fenced and accessed through a locked gate. Suspended wells are inspected every three months in accordance with the AGL’s leak detection and repair (LDAR) program (Ref 35).
ATC4		**Suitable noise management**
		AGL uses site selection to avoid sensitive receivers (where possible), restricted hours of operation, selection of specially noise attenuated drill rig, equipment orientation (where possible) to reduce off site noise impacts, scheduling on site work tasks to

Identifier	Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Gas Project
		avoid loud work at more sensitive times of the night (where possible), landowner and neighbour notification of drilling operations, drilling program, pre start checklists, daily toolbox meetings, preventative maintenance of equipment, noise walls installed around site, noise logging onsite and at nearby receivers to monitor compliance with noise criteria or alternatively determine areas where more mitigation measures may be required, community consultation during EA phase and via CCC during drilling. A Noise management Sub-Plan is available for the project (Ref DCS_CM_MP_HSE_010).
ATC5	**General risk assessment**	
	Section 2.2.2 requires for all significant risk to safety or the environment is managed through an effective risk management process that includes identification of hazards, assessment of risks, implementation of control measures and monitoring integrity and effectiveness of control measures. A Significant Hazard Risk Register is to be documented for operations, identifying the specific controls put into place for these hazards.	AGL's Risk Management and Assessment Standard, modelled on ISO 31000, provides guidance to determine the hazards associated with their operations, including workovers, and the control measures required to manage these hazards. The Environmental Aspects and Impacts Register is maintained for the day to day environmental risks, and Periscope is maintained for the significant business risks. Controls are determined and include workover programs; hazardous area zoning; audits and inspections; permit to work; preventative maintenance programs). Where possible, inherent safety, health and environment principles are implemented, for example in the use of non hazardous / non Dangerous Goods (DG) chemicals in the operation of the wells, and by avoiding confinement wherever possible allowing CSG to disperse into the atmosphere without a risk of fire or explosion. Major activities, such as workovers and well suspension, are treated as Projects and require further documentation, including risk assessments. Records of the condition

Identifier	Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Gas Project
		of the equipment are taken before and after being in service. Well intervention and workovers are scheduled based on the wells production performance.
ATC6	**Safety management plan**	
	Section 2.2.3 requires a rigorous, risk based approach to the safety of operations and possess a comprehensive asset integrity regime to minimise risks associated with their operations. The safety management plan must describe the safety standards and safety and maintenance procedures for each stage of well operations. The safety management plan must include identification and assessment of specific risks from ignition sources, or potential ignition sources.	A Safety Management Plan (SMP) is used to set the framework for managing safety and health for the Camden Gas Project. Environmental and Health and Safety Policies are available on site and online over the AGL intranet. Section 3 of the SMP details Risk Management requirements and includes High level risk register; Standard Operating Procedures / Job Safety and Environment Analysis (JSEA); Safety and wellbeing conversations; and Action close outs. Workover Programs are prepared to communicate the requirements for various work activities, including for workovers. Standard operating procedures (SOPs) are available for well operation, including for inspection and maintenance, well start-up and shut-down, isolation, venting, and transfer of produced water. The SOPs provide step-by-step instructions in an easily accessible format. Pre-start checklists and daily toolbox meetings are conducted prior to major work commencing. AGL's SMP specifies the use of *Hazard Zones* to manage potential ignition sources in accordance with API RP 505 "Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone O, Zone 1, and Zone 2", 1st Edition, November 1997. Classification of zones according to API RP505 is also acceptable under AS/NZS 60079.10.1:2009 Explosive atmospheres - Classification of areas -

Identifier	Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Gas Project
		Explosive gas atmospheres (IEC 60079-10-1, Ed.1.0 (2008) MOD). The SMP requires that all electrical equipment to be used within the Hazardous Zones is to be compliant with AS2381 and shall be certified for service in the zone in which it is to be used. The following controls are managed: • Hazardous Area classification, including well site dossier and drawings specifies correct instrument and equipment, including Anti-Static Hoses (FRAS); • The hazardous area for each well is contained inside of the fenced area; • "Controlled Workplace" (inside the well compound, requiring application of a Permit To Work (PTW) system; • PTW System; • Fusible loop activates emergency isolation of well; • Well site signage, including removal of ignition sources and dematching; • Induction training.
ATC7	**Incident and emergency response** Section 2.2.5 lists the following mandatory management plans to meet various legislative requirements: • Pollution Incident Response Management Plans (PIRMP) • Emergency Response Plan	A PIRMP is available, covering the Camden Gas Project (including the gas wells). It sets out incident notification procedure, actions following incident, communication, training, etc. An Emergency Response Plan and Procedures (including bush fire response flood management) are available for the Camden Gas Project, including for the wells. Spill kits are kept at the gas well site when chemicals are used. Surface water controls are in place on SCA canal and are maintained by SCA.
ATC8	**Training** Subsection (e) of the Preliminary section of the Code specifies that worker training and certification is central to good practice and the mitigation of safety and environmental risks; and that workers must have the knowledge and skills necessary to perform	Competency training is carried out for all field workers. Workover staff are trained and competent in accordance with NSW Petroleum Drilling and Well Servicing – Competencies (Guideline).

Identifier	Codes of Practice for Coal Seam Gas – Well integrity	How the control is implemented at the AGL Camden Gas Project
	their work safely and to the highest possible standard.	
ATC9		**Inherent design** Properties of methane (CSG): The properties of methane state that it is lighter than air and therefore rises into the atmosphere, does not pool within low lying areas or confined spaces, reducing the risk of fire or explosion.

Appendix 2

Risk Criteria and Fresh and Marine Water Guidelines

Camden Gas Wells Hazard Risk Assessment

Appendix 2 – Risk Criteria and Fresh and Marine Water Guidelines

A2.1 NSW DP&E Risk Criteria in Context

The following tables, drawn from the NSW DP&E HIPAP4 guidelines (Ref 7), contain useful background information on the risks of various types of activity and the consequences of individual exposure to heat radiation and explosion overpressure. While some of the information is slightly outdated, it provides a context against which some of the suggested numerical risk criteria can be compared and demonstrates the significant degree of conservatism in the criteria when compared against risks from normal daily activities.

Table A2.1 – Risk to individuals in NSW

Activity or exposure	Chances of Fatality per million person years (pmpy)
Voluntary Risks (average to those who take the risk)	
Smoking (20 cigarettes/day)	
• All effects	5000
• All cancers	2000
• Lung cancer	1000
Drinking alcohol (average for all drinkers)	
• All effects	380
• Alcoholism and alcoholic cirrhosis	115
Swimming	50
Playing rugby football	30
Owning firearms	30
Transportation Risks (average to travellers)	
Travelling by motor vehicle	145
Travelling by train	30
Travelling by aeroplane	
• Accidents	10
Risks Averaged over the Whole Population	
Cancers from all causes	

Activity or exposure	Chances of Fatality per million person years (pmpy)
• Total	1800
• Lung	380
Air pollution from burning coal to generate electricity	0.07-300
Being at home	
• Accidents in the home	110
Accidental falls	60
Pedestrians being struck by motor vehicles	35
Homicide	20
Accidental poisoning	
• Total	18
• Venomous animals and plants	0.1
Fires and accidental burns	10
Electrocution (non-industrial)	3
Falling objects	3
Therapeutic use of drugs	2
Cataclysmic storms and storm floods	0.2
Lightning strikes	0.1
Meteorite strikes	0.001

In setting risk criteria, as discussed in Section 1.5.1, it is also necessary to account for variations in the duration of exposure to that risk at any particular point by any one individual. People's vulnerability to the hazard and their ability to take evasive action when exposed to the hazard also need to be taken into account.

The one in a million criteria (i.e. the 1 pmpy risk criteria) from Table 2, as applies to the maximum risk at residential areas from a potentially hazardous facility, assumes that residents will be at their place of residence and exposed to the risk 24 hours a day and continuously day after day for the whole year. In practice this is not the case and this criterion is therefore conservative.

People in hospitals, children at school or old-aged people are more vulnerable to hazards and less able to take evasive action, if need be, relative to the average residential population. A lower risk than the one in a million criteria (applicable for residential areas) may be more appropriate for such cases. On the other hand, land uses such as commercial and open space do not involve continuous occupancy by the same people. The individual's occupancy of these areas is on an intermittent basis and the people present are generally mobile. As such, a higher level of risk (relative to the permanent housing occupancy exposure) may be tolerated.

A2.2 Comparison Against Fresh and Marine Water Quality Guidelines

A comparison of the pollutants found in water against the Fresh and Marine Water Quality Guidelines is provided in Tables A2.2 and A2.3 for context from environmental perspective.

Table A2.2 – Comparison of key components in produced water against the Fresh and Marine Water Quality Guidelines Table 4.2.3 (for livestock drinking water) and Table 5.2.3 (water suitable for recreation)

Activity	Chemical	Concentration in Fluid (at well pad) (mg/L) (from the EHIA Ref 13)	Fresh and Marine Water Quality Guidelines (Ref 16) (mg/L)	
			Table 4.3.2 - livestock drinking water	Table 5.2.3 – water suitable for recreation (swimming)
Produced Water (where maximum concentrations exceed drinking water guidelines)	Total dissolved solids	23,500	N/A	1,000,000
	Arsenic	0.113	0.5	50
	Strontium	10.2	N/A	N/A
	Barium	35.5	N/A	1,000
	Nickel	0.024	1	100
	Lead	0.026	0.1	50
	Iron	15.4	*not sufficiently toxic*	300
	Bromine	5.7	N/A	N/A
	Iodine	0.8	N/A	N/A
	Fluoride	3.9	2	N/A
	Methane (and other C1-C1 gases)	10,516	N/A	N/A
	Naphthalene	0.0192	N/A	N/A

Activity	Chemical	Concentration in Fluid (at well pad) (mg/L) (from the EHIA Ref 13)	Fresh and Marine Water Quality Guidelines (Ref 16) (mg/L)	
			Table 4.3.2 - livestock drinking water	Table 5.2.3 – water suitable for recreation (swimming)
	Benzo(a)pyrene	0.0011	N/A	0.01
	Benzo(b)fluoranthene	0.0018	N/A	N/A
	Benzo(g,h,i)perylene	0.0017	N/A	N/A
	Benzene	0.01	N/A	10
	Traces of hydrocarbons (TPH C10-C14, C15-C28 and C29-C3)	77.7	N/A	N/A

Table A2.3 - Comparison of Calculated Concentrations in Surface Water Following an Accidental Release of Produced from the Well Pad Against the Fresh and Marine Water Quality Guidelines Table 4.2.3 (for livestock drinking water) and Table 5.2.3 (water suitable for recreation)

Key chemical	Concentration in Fluid (at well pad) (mg/L)	Concentration in Receiving Body (mg/L) (from EHIA, Ref 13)		Fresh and Marine Water Quality Guidelines (Ref 16) (mg/L)	
		Farm dam	Upper Canal	Table 4.3.2 - livestock drinking water	Table 5.2.3 – water suitable for recreation (swimming)
Total dissolved solids	23500	97	14	N/A	1,000,000
Arsenic	0.113	0.00047	0.000067	0.5	50
Strontium	10.2	0.042	0.0061	N/A	N/A
Barium	35.5	0.15	0.021	N/A	1,000
Nickel	0.024	0.0001	0.000014	1	100
Lead	0.026	0.00011	0.000015	0.1	50
Iron	15.4	0.064	0.009	*not sufficiently toxic*	300
Bromine	5.7	0.024	0.0034	N/A	N/A
Iodine	0.8	0.0033	0.00048	N/A	N/A
Fluoride	3.9	0.016	0.0023	2	N/A

Key chemical	Concentration in Fluid (at well pad) (mg/L)	Concentration in Receiving Body (mg/L) (from EHIA, Ref 13)		Fresh and Marine Water Quality Guidelines (Ref 16) (mg/L)	
		Farm dam	Upper Canal	Table 4.3.2 - livestock drinking water	Table 5.2.3 – water suitable for recreation (swimming)
Methane (and other C1-C1 gases)	10,516	43	6.3	N/A	N/A
Naphthalene	0.0192	0.000079	0.000011	N/A	N/A
Benzo(a)pyrene	0.0011	4.5E-06	6.5E-07	N/A	0.01
Benzo(b)fluoranthene	0.0018	7.4E-06	1.1E-06	N/A	N/A
Benzo(g,h,i)perylene	0.0017	0.000007	0.000001	N/A	N/A
Benzene	0.01	0.000041	0.000006	N/A	10
Traces of hydrocarbons (TPH C10-C14, C15-C28 and C29-C3)	77.7	0.321	0.046	N/A	N/A

N/A = Not available

11 REFERENCES

1 *Hazardous Industry Planning Advisory Paper No. 6: Guidelines for hazard analysis*, NSW Department of Planning, 2011 Edition

2 *Code of Practice for Coal Seam Gas Well Integrity*, NSW Trade & Investment, Resources & Energy, 2012 http://www.resourcesandenergy.nsw.gov.au/landholders-and-community/coal-seam-gas/codes-and-policies/code-of-practice-for-coal-seam-gas-well-integrity

3 *Locational Guidelines - Development in the Vicinity of Operating Coal Seam Methane Wells* (*the Guidelines*), NSW Department of Planning,, 2004

4 O'Kane M, *Initial Report on the Independent Review of Coal Seam Gas Activities in NSW*, NSW Government Chief Scientist & Engineer, 30 July 2013

5 O'Kane M, *Independent Review of Coal Seam Gas Activities in NSW - Managing environmental and human health risks from CSG activities*, NSW Government Chief Scientist & Engineer, 30 September 2014

6 O'Kane M, *Final Report of the Independent Review of Coal Seam Gas Activities in NSW*, NSW Government Chief Scientist & Engineer, 30 September 2014

7 *Hazardous Industry Planning Advisory Paper No. 4: Risk criteria for land use planning*, NSW Department of Planning, 2011 Edition

8 *National Hazard Exposure Worker Surveillance, Noise exposure and the provision of noise control measures in Australian workplaces*, Commonwealth of Australia 2010 available on website www.safeworkaustralia.gov.au

9 AECOM, *AGL Camden Gas Project – Northern Expansion Environmental Assessment*, AECOM, Oct 2010

10 AECOM, *AGL Camden Gas Project – Northern Expansion Submissions Report*, AECOM, Oct 2012

11 *CSG and Health in the Camden Gas Project Area fact sheet,* NSW Health, South Western Sydney, Local Health District, June 2016 http://www.swslhd.nsw.gov.au/populationhealth/PH_unit/pdf/CSG.pdf

12 *AGL Fugitive Methane Emissions Monitoring Program –Technical Report, AGL Upstream Investments Pty Ltd*, Pacific Environment Limited, February 2014

13 *Environmental Health Impact Assessment - Camden North Expansion Project for AGL Energy*, EnRisks, October 2013

14 AS3788-2001 *Pressure Equipment In-service Inspection*, Standards Australia

15 CSIRO on *What is unconventional gas?* https://www.csiro.au/en/Research/Energy/Hydraulic-fracturing/What-is-unconventional-gas, Last updated: 25 February 2015

16 *Australian Drinking Water Guidelines*, National Health and Medical Research Council, 2011

17 *Fresh and Marine Water Quality Guidelines*, Australian and NZ Environment and Conservation Council, 2000

18 *Australian Code for the Transport of Dangerous Goods by Road & Rail*, National Transport Commission, December 2015

19 *Periscope Risk Register*_SSCR_Rev3, AGL, 19 November 2015, AGL Energy

20 *HAZOP Study, Camden Wellheads*, ICD Asia Pacific for AGL Energy Limited, 21 to 24 September 2015

21 *Environmental aspects and impacts register-Camden*, AGL, 20 November 2014

22 Nilsson K., *Quantitative Risk Assessment of the Coalbed Methane Production Wells at Camden, NSW*, Planager Pty Ltd, November 2002

23 Nilsson K., *Quantitative Risk Assessment, Coal Seam Methane Production Wells for up to Six Well Head for AGL Gas Production (Camden) Pty Limited*, Planager Pty Ltd, September 2007

24 Nilsson K., *Preliminary Hazard Analysis Camden North Gas Project*, Planager Pty Ltd, July 2010

25 *Yellow Book, Methods for the Calculation of the Physical Effects of the Escape of Dangerous Material*, *CPR 14E, Parts 1& 2*, Committee for the Prevention of Disasters, TNO, 3rd edition 1997

26 API Standard 521, *Pressure-relieving and Depressuring Systems*, 6th Ed., American Petroleum Institute, January 2014

27 *Camden Gas Project Noise Management Sub Plan*, AGL Energy, Report No. 06159-L, Wilkinson Murray, May 2015

28 *National Code of Practice for Noise Management and Protection of Hearing at Work*, National Occupational Health and Safety Commission, [NOHSC: 2009(2004)]

29 Safe Work Australia guideline on Noise https://www.safeworkaustralia.gov.au/noise, Downloaded 15 January 2018

30 Downloaded 8th June 2016 from https://www.agl.com.au/-/media/AGL/About-AGL/Documents/How-We-Source-Energy/Camden-Document-Repository/Environmental-Reports

31 *2014-2015 Groundwater and Surface Water Monitoring Status Report - Camden Gas Project, AGL Upstream Investments Pty Ltd*, Parsons Brinckerhoff, October 2015

32 Fry N., Ross J.; *Hydrogeological Summary of the Camden Gas Project Area, AGL Energy*, 31 January 2013

33 *Groundwater Management Plan – Camden Gas Project*, AGL, October 2015

34 *Camden Gas Project Proposed Expansion of Stage 2, Report on The Potential for Coal Seam Methane Gas Extraction to Result in Subsidence at the Surface*, Mine Subsidence Engineering Consultants Pty Ltd, April 2007

35 *Standard Operating Procedure Gas Leak Detection and Repair,* DCS_GN_SOP_FO_014, AGL Gas Operations and Gas Developments, December 2015