Initial report on the Independent Review of Coal Seam Gas Activities in NSW

NSW Chief Scientist & Engineer

July 2013

NSW GOVERNMENT | Chief Scientist & Engineer

The Hon Barry O'Farrell MP
Premier and Minister for Western Sydney
Parliament House
SYDNEY NSW 2000

Dear Premier,

Initial Report – Independent Review of Coal Seam Gas Activities in NSW

On 21 February 2013, you wrote requesting I undertake an independent review of coal seam gas activities in NSW.

In your letter you drew attention to the "community's concerns about the current operation of CSG activities in NSW" and provided terms of reference for the Review. You also requested that I provide an initial report in July 2013.

I now submit the initial report of the independent review.

This report draws on five months of information gathering, stakeholder meetings, interviews, community consultations, site visits, and technical paper preparation. In undertaking this review I sought the independent advice of several experts whom I commissioned to provide reports on a range of topics relevant to CSG activities in NSW including water, geology, CSG operational processes, and health and environmental impacts. I also sought the views of the community-at-large through the good offices of the Land and Water Commissioner, Mr Jock Laurie, through meetings with community representatives in Sydney and the regions, and by calling for public submissions to inform the Review. The Review received more than 230 responses.

At this stage I make a number of recommendations. In the next phases of the Review I will address in more depth the principles that can underpin setbacks and exclusion zones, international best practice, and risk characterisation and mitigation. One of the most challenging matters yet to be completed is the comprehensive study of industry compliance. I anticipate delivering this in 2014.

In presenting this initial report I wish to acknowledge the assistance of many people – those who took the time to write submissions or talk to my team; colleagues from government departments in NSW and other jurisdictions; colleagues in industry, research organisations and professional associations; and the CSG review team itself which worked hard to make sense of a complex and contentious issue.

Yours sincerely,

Digitally signed by
Mary O'Kane
Date: 2013.07.30
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Mary O'Kane
Chief Scientist & Engineer
30 July 2013

EXECUTIVE SUMMARY

The independent review of coal seam gas (CSG) activities in NSW by the NSW Chief Scientist & Engineer commenced in late February 2013. This is the initial report of the Review, which was requested by July 2013.

Based on consultations and submissions to date, the Review makes a small number of recommendations aimed at improving the information available to the community and assisting the Government to build confidence that it has the intention and capacity to oversee a safe CSG industry.

CSG is a complex and multi-layered issue which has proven divisive chiefly because of the emotive nature of community concerns, the competing interests of the players, and a lack of publicly-available factual information.

The debate has been fuelled by unanswered concerns surrounding landholders' legal rights, land access and use; human health; the environment, particularly relating to impacts on water; engineering and operational processes; and industry regulation and compliance. These issues remain matters of contention.

The challenges faced by government and industry are considerable and a commitment from all parties will be required to improve the existing situation and build trust with the community.

From a technical and scientific standpoint, many challenges and risks associated with CSG are not dissimilar to those encountered in other energy and resource production, and water extraction and treatment.

Some challenges are well defined and can be effectively managed through high standards of engineering and rigorous monitoring and supervision of operations.

Other challenges relating to long-term and cumulative environmental impacts are less obvious and require a commitment to significant and ongoing research, as well as a consequent evolution of engineering practice.

This initial report aims to explore the many issues of community concern – drawing on material learned through listening to stakeholders and applying an evidence-based approach to problems.

Based on the work done to date by the Review, this report recommends the NSW Government commit to adopting a vigilant, transparent and effective regulatory and monitoring system to ensure the highest standards of compliance and performance by the CSG industry.

As a first step, the Government needs to institute a strong and sophisticated policy for data collection and data handling, and establish a whole-of-environment data repository.

The Government should also implement stronger conditions around the training of CSG operators, and champion further research on the unanswered questions around the science of CSG.

There is, however, more work to do.

Based on preliminary investigations, the Review will continue the industry compliance study and the study of best practice in unconventional gas extraction technologies and regulation. It will also commission studies on risk and on exposure pathways for chemicals and contaminants.

In addition, the Review has identified areas around land owner compensation, company insurance and operator penalties which could be strengthened and, as such, has commissioned further legal work in these areas.

The issue of CSG in NSW is a very tough one with many complicated parts. A commitment to sound policy implementation based on highly developed data and further research to fill the knowledge gaps will be essential.

RECOMMENDATIONS

Recommendation 1

That the Government commits to establishing a regime for extraction of coal seam gas that is world class. This involves inter alia:

- *clear public statements of the rationale/need for coal seam gas extraction (including, for example, within the State planning policies on energy and resources; environment and conservation; infrastructure; hazards; agricultural and rural resources; and development assessment being developed following the 2013 White Paper, a New Planning System for NSW)*
- *insisting on world best practice in all aspects and at all stages (exploration, production, abandonment) of CSG extraction*
- *sending a clear message to industry that: CSG extraction high performance will be mandatory; compliance with legislation will be rigorously enforced; and transgressions will be punished with published high fines and revocation of licences as appropriate*
- *treating coal seam gas extraction in NSW as a complex system with appropriate mechanisms to estimate risk both in toto and locally on a dynamic basis*
- *having a clear, easy-to-navigate legislative, compliance and monitoring framework that evolves over time to incorporate new engineering and science developments*
- *high levels of transparency*
- *having a fair system for managing land access and compensation for those whose land is affected by coal seam gas activities*
- *maintaining reliable, complete, current and authoritative data on all aspects of CSG and having this data held in a central, comprehensive, spatially-enabled, open, whole-of-environment data repository. All data collected by the private and public sectors relevant to CSG extraction, coal, other mining, and water would be sent directly to the repository. Such a repository supports transparency and enables rapid compliance checking, fast response to alarms and accidents, increased understanding of cumulative impacts, and research on complex issues*
- *developing within government a system to assess cumulative impacts of multiple industries operating in sensitive environments with formal assessments being updated annually with any major problems identified being addressed promptly*
- *the Ministry of Health continuing to monitor any unusual symptoms reported in areas where coal seam gas is being extracted and looking for correlations with changing environmental factors*
- *committing to high levels of monitoring with an understanding that the amount and sophistication of monitoring is likely to increase rather than decrease over time as sensors become even cheaper and communications and data technologies become even better*
- *adjusting on a regular basis industry levies, bonds and insurance to make sure all financial costs of overseeing the State's coal seam gas system and maintaining infrastructure are covered, as are all contingencies and making sure industry understands that fees can be adjusted at annual notice*
- *ensuring all coal seam gas companies have structures in place to ensure full legislative compliance not only by themselves but also by any subcontractors they retain*
- *ensuring all those working in the coal seam gas industries have appropriate training and certification*

- *ensuring those working in the public sector on CSG legislation and compliance are provided with a sound compliance and monitoring framework within which to operate, and given appropriate on-the-job training to ensure up-to-date knowledge of this fast-moving industry and of latest developments in monitoring and compliance worldwide*
- *commitment to ramping up research on difficult issues such as continuing to develop comprehensive and detailed models of the State's underground water and how to build robust engineering approaches to assessing cumulative impact of multiple industries affecting underground resources in a dynamic way*
- *working closely and continuously with the community, industry, industry bodies, and research organisations to keep the coal seam gas system in NSW up to world standard.*

Recommendation 2

That Government commission the design and establishment of a whole-of-environment data repository for all State environment data including all data collected according to legislative and regulatory requirements associated with water management, gas extraction, mining, manufacturing, and chemical processing activities. This repository would, as a minimum, have the following characteristics:

- *have excellent curatorial systems*
- *be designed and managed by data professionals to highest world quality data-handling standards*
- *be open except for limited exceptions where the data is commercial-in-confidence and to which access is restricted to varying degrees*
- *be not only accessible by all under open-data conventions but also able to accept citizen data input*
- *be able to be searched in real time*
- *be spatially enabled*
- *hold all data electronically*
- *hold data of many diverse formats including text, graphics, sound, photographic, video, satellite, mapping, electronic monitoring data, etc.*
- *be the repository of all research results pertaining to environmental matters in NSW along with full details of the related experimental design and any resulting scientific publications and comments*
- *be the repository of historical data with appropriate metadata*
- *for all bodies governed by relevant legislation, generate an automatic deposit schedule, and notify the regulator and the organisation involved automatically of overdue deposits.*

That any legislation amendments needed to direct all environment data to the Data Repository are undertaken.

Recommendation 3

That a pre-major-CSG whole-of-State subsidence baseline be calculated using appropriate remote sensing data going back, say, 15 years. And that, from 2013 onwards, an annual whole-of-State subsidence map be produced so that the State's patterns can be traced for the purpose of understanding and addressing any significant cumulative subsidence.

Recommendation 4

That all coal seam gas industry personnel including subcontractors working in operational roles be subject to mandatory training and certification requirements and that these mandatory training and certification requirements be included in the codes of practice relevant to CSG.

Recommendation 5

That the Government continue and extend its role as a champion of research relevant to the hard problems related to under-earth especially the development of sophisticated predictive underground models and a formalisation of engineering processes for cumulative impact assessment. The Government should not only lead by example in encouraging and funding such research to be undertaken and discussed in NSW, but should exhort other governments and organisations to take a related approach through mechanisms such as COAG and international partnerships.

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PART ONE: IDENTIFYING THE ISSUES

1 INTRODUCTION

1.1 CSG IN NSW: SIZE AND CONTEXT

Coal seam gas (CSG) extraction has occurred in Australia for over seventy years. Removing methane gas from coal mines has always been a necessary activity in conventional mining for safety purposes, but a practical example of extracting CSG for subsequent use was the early NSW venture at the Balmain Colliery from 1935-1946. However, of all the states, Queensland has been the leader in recent CSG development since companies began exploration in Queensland in 1976 and commercial extraction in 1996. Queensland now produces 97.5% of all CSG produced in Australia (234 PJ/240 PJ), with most of it extracted from the Bowen and Surat basins (Geoscience Australia & BREE, 2012).

In NSW, CSG exploration and production is regulated by the *Petroleum (Onshore) Act 1991*; CSG is classified as petroleum and licences and leases are collectively known as petroleum titles. Recent commercial CSG extraction has been taking place for more than ten years. The AGL Camden Gas Project, in the Sydney Basin, has produced CSG since 2001. AGL Upstream Investments Pty Limited holds five of the six petroleum production leases in NSW (PPL1, 2, 4-6). Santos NSW (Hillgrove) Pty Ltd holds the sixth (PPL 3) around Narrabri. In 2010-11, NSW contributed 2.5% (6 PJ/239 PJ) of CSG production in Australia, with CSG accounting for 11% of Australia's total gas production (up from 2% in 2002-03) (BREE, 2012).

As of July 2013, in NSW, there are 52 petroleum titles related to CSG exploration, assessment and production activities. These include 6 PPLs, 45 petroleum exploration licences (PELs) and 1 petroleum assessment lease (PAL). There are currently 17 applications for PELs (PELAs), 2 applications for PPLs (PPLAs) and 6 applications for special prospecting authorities (PSPAPPs) (DTIRIS, 2013a). See Table 6.1 for an explanation of the types of titles. Maps are given at Appendix 6.

Determining the precise status (i.e. production, production test/trial, suspended, abandoned, capped, cased and suspended, cemented, water bore) of wells drilled for CSG purposes in NSW has proved somewhat difficult. One of the first actions of the Review was to send an official written request to Mineral Resources, Division of Resources & Energy, DTIRIS, in March 2013 requesting data on all information relating to specific licences. According to Mineral Resources, there are 556 wells which have 'coal seam methane' as their 'business purpose', but the information on the status of wells is held in multiple databases and in paper records. Resources & Energy is in the process of supplying the status of the wells to the Review.

Expansion of CSG extraction in Australia is taking place in the context of rapidly developing technological advances in unconventional gas extraction (CSG, shale gas, tight gas), especially in North America. Between 2000 and 2009, unconventional gas in the USA increased from 29% of total to 48% of total natural gas production, with a 14-fold increase in shale gas production in that time (Center for Climate and Energy Solutions, 2012). While there is widespread support in North America for unconventional gas extraction because of the benefits of low-cost energy and energy security, there are still significant studies in progress examining the impacts of unconventional gas extraction on health and the environment. Some notable studies in progress by the US Environmental Protection Authority and the Department of Energy (National Energy Technology Laboratory, 2013, September 2012; US EPA, 2012b).

Concerns about negative impacts of gas extraction have heightened in the USA at a legislative and regulatory level as a result of the Deepwater Horizon accident in the Gulf of Mexico in 2010, and at a community level following the release of the film *Gasland*, also in 2010.

While there is widespread unease and concerns about CSG extraction in Australia (other forms of unconventional gas extraction such as shale gas extraction are not significant here at present), there are also strong factors favouring expanded CSG extraction activities. Asian markets have a growing need for natural gas to supply a growing industry as well as a replacement energy source for nuclear energy in Japan. China is willing to buy Australian gas at high prices and now that the infrastructure for shipping gas to China efficiently is available with the near-completion of the gas processing facility at Port Curtis near Gladstone, there is a strong economic incentive for gas export.

In NSW, maintaining gas provision at the level of prices available at present is likely to be a challenge. The current NSW gas contracts start to end in 2014, and there is concern NSW will have difficulty negotiating new secure domestic supply contracts in light of international export demand at higher prices.

1.2 MAJOR AREAS OF CONCERN ABOUT CSG

There has been widespread concern about CSG activities across Australia and in particular NSW. The major areas of concern are:

- contamination and depletion of groundwater resources and drinking water catchments
- impacts of the co-produced water from CSG activities on the environment
- impacts on the environment of hydraulic fracturing or ‘fracking’
- impacts on human health from air quality, chemicals, noise, etc.
- rapid expansion of the industry
- land access and landholder rights
- potential impact on property values
- fugitive emissions
- uncertainty of the science, a lack of data especially baseline data and a lack of trust in the data sources
- the industry is moving ahead of scientific understanding and regulation
- cumulative impacts of multiple CSG wells and multiple land uses such as other mining and agricultural activities
- inadequate monitoring by government of industry activity and perceived unwillingness by government to enforce legislation
- complex and changing legislation.

1.3 REVIEW OF CSG-RELATED ACTIVITIES ESTABLISHED

As part of the NSW Government response to community concerns, on 21 February 2013 the NSW Premier asked the Chief Scientist & Engineer, Professor Mary O’Kane, to conduct an independent review of CSG-related activities in NSW with a focus on the impacts of these activities on human health and the environment. The Terms of Reference for the Review are at Appendix 1.

Due to the complexity of this issue and the wide-ranging nature of the Terms of Reference, the Review is expected to continue well into 2014.

1.4 PROCESS OF THE REVIEW

The Chief Scientist & Engineer established a small core team within her office (the Review team) to support and facilitate the Review work. Over this first phase of the Review

(February-July, 2013), the team scoped the review; put in place a process of targeted consultation and literature searches to understand the complexities of the issue (this included extensive consultation with government agencies, community groups and industry); called for public submissions and followed up with extensive interviews and some site visits; established a compliance checking process; and scoped and commissioned a range of technical information papers. In short, all the Terms of Reference have been addressed to some degree in this phase.

The Review has pursued a philosophy of operating as transparently as possible; publishing all submissions received apart from those marked 'confidential' on the website of the Chief Scientist & Engineer, talking to the media on request and indicating that all commissioned papers will be published on the website. Those working on the Review were asked to declare all real and possible conflicts with a conflict of interest register established and decisions about how to handle conflicts being determined on a case-by-case basis with decisions formally recorded.

1.4.1 Building an understanding of the CSG issue

CSG and the problems associated with establishing a CSG industry have been studied extensively in recent years in NSW and elsewhere. The Review was able to draw on studies such as the NSW Legislative Council Inquiry of 2011/12 into Coal Seam Gas. There is also now a burgeoning scientific literature, some of it mature, but much of it, especially in the very contentious areas, reporting findings which are still subject to lively peer investigation and debate.

Many of the topics raised in the CSG debate are areas where extensive information exists for other purposes (e.g. groundwater and well drilling). Such literature has been drawn on extensively.

1.4.2 Technical information papers commissioned

A series of technical information papers on specific sets of issues related to the CSG industry and operations was commissioned by the Review and more will follow. These papers address issues such as geology, groundwater, produced water, health, CSG extraction processes, legislation, regulation and insurance, seismicity, and subsidence as well as others. The papers form a key component of the Review as both an information source and assisting in developing reports and informing compliance activities.

In developing and commissioning the papers, the Review team sought the advice of technical experts and senior figures for recommendations on potential authors for the papers, as well as on detailed expression of the topics to be investigated.

Several individuals and groups were approached to submit quotations for undertaking the work, with groups asked to provide information on their experience, approach to the paper, and information on conflicts of interest, costs and timeframes for delivery.

Given concerns expressed by many in the community about the need for independent scientifically-based information, the Review placed a great deal of emphasis on engaging experts to write the background papers, who were independent and had minimal or no actual, potential or perceived conflicts of interest. Thus the Review sought out experts who are recognised in their area of expertise but who are not employed in some capacity either by the CSG industry (including subcontractors) or as advisors to the anti-CSG groups. This proved challenging in several cases as the industry is expanding rapidly and therefore needing specialist expertise. In a limited number of cases teams of experts included some who are retained by CSG companies or assisting some CSG opponents in some capacity; but these instances have been declared and documented. In most cases though, the Review sought quotes for information papers from people working within universities or public sector research organisations, or smaller consulting firms that didn't have significant current or previous gas industry clients.

To assist in managing conflicts of interest issues at the commissioning and management stage, the Review (with assistance from the Procurement Unit and the Legal Unit in the Department of Trade and Investment) put in place a procurement framework for selecting authors as well as a conflicts management framework – *the consultant declaration of interests and associations form* – to manage any conflicts that were identified or that may emerge through the course of writing the Review information papers. This form was reflected in the contract of engagement.

The processes and systems put in place to develop and refine the paper outlines, and source and commission expertise, meant that it took a significant amount of time to find, select and commission experts. This was important, however, to ensure that the processes fitted with Government procurement requirements and that the information received contained no biases and would be of high quality.

In commissioning reports, the Review asked most of the experts commissioned to write reports to provide worst case scenarios along with an estimate of their likelihood and to describe how such incidents would be managed, contained or remediated should they occur. Identifying and quantifying these worst case scenarios and recommending approaches to address them has proven difficult and surprisingly challenging but is important and will be pursued further through the course of the Review.

A challenge, and strength, of science and research is that experts bring their own perspective to issues based on their speciality and research background, meaning that there is the possibility for disagreement on issues, or at least different perspectives and priorities. To address and also take advantage of this factor, the approach of the Review has been, where possible, to obtain multiple pieces of advice and information papers on a given topic. Being able to bring together and triangulate across multiple background papers on specific topics helps to ensure coverage of the issue, identification and comparison of different perspectives, and can also identify where there is disagreement. Due to the relatively new nature of CSG in Australia, in some areas of examination it has proved challenging to find multiple experts without conflict. In such cases, the Review is seeking peer comment on individual papers and where appropriate, advice from experts in cognate disciplines.

All final papers will be published on www.chiefscientist.nsw.gov.au/coal-seam-gas-review. It is intended that this process will continue throughout the Review as more background papers will be commissioned and further issues and concerns come to light.

A list of the papers commissioned to date is given at Appendix 2.

1.4.3 Government agency consultations in Australia

Consultation with Government agencies formed an important part of the Review work to date. Relevant NSW Government offices consulted include: the Environment Protection Authority (EPA); the Office of Resources and Energy and the Office of Coal Seam Gas (OCSG) in the Department of Trade and Investment (DTIRIS); the Department of Premier and Cabinet (DPC) - including the Office of Environment and Heritage; the Ministry of Health, the NSW Office for Water (NOW), the Sydney Catchment Authority (SCA), the NSW Department of Planning; the Planning Assessment Commission; the Natural Resources Commission, and the Department of Finance and Services.

The Review has worked closely with the Land and Water Commissioner, drawing on his ongoing consultations across the State on CSG. The Land and Water Commissioner provides independent advice to the community about exploration activities on strategic agricultural land throughout NSW. The role of the Land and Water Commissioner was created by the NSW Government at the end of 2012 to build community confidence in the processes governing exploration activities in NSW and to facilitate greater consultation between government, community and industry.

The Review team met with relevant Queensland Government agencies to understand the processes and issues being dealt with in that state. The agencies visited included: Queensland Health, Environmental Health Branch; Department of Natural Resources and Mines; Department of Science, Information Technology, Innovation and the Arts; Office of the Queensland Chief Scientist; Department of Environment and Heritage Protection; Office of Groundwater Impact Assessment and the Gas Fields Commission Queensland.

The Review held discussions with various Commonwealth Government agencies including the Department of Resources, Energy and Tourism (RET) including its Bureau of Resources and Energy Economics (BREE); Geoscience Australia (GA); the Department of Sustainability, Environment, Water, Population and Communities (SEWPAC) including the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC), and the Office of Water Science; and the Bureau of Meteorology.

The Review team also sought advice from the Department of Primary Industries and Resources South Australia (PIRSA) and the South Australian Chief Scientist.

1.4.4 Research organisation consultations

The Review drew on assistance from universities in NSW and elsewhere in Australia. It also sought help from publicly funded research organisations including CSIRO and ANSTO and from a range of research centres such as NICTA and various Cooperative Research Centres. The Review also sought assistance from Fellows of the Australian Academy of Science (AAS) and of the Australian Academy of Technological Sciences and Engineering (ATSE). Assistance from these individuals included commissioned papers, occasional advice on formulating issues and assistance with identifying experts.

1.4.5 Call for public submissions

While considerable material exists produced by organisations on all sides of the CSG debate, it became apparent early in the Review that there was strong expectation from stakeholders that they would provide formal input to the Review. Accordingly in the week of 18 March 2013, the Review put out a call for public submissions. This call was advertised in local and regional newspapers, on the CSE website, and on the NSW Government's 'have your say' website (http://www.haveyoursay.nsw.gov.au/). The submissions were due by 26 April 2013; however additional input from the public after that date has been welcomed and will continue to be welcome.

More than 230 submissions were received. These submissions, along with meetings held with interested groups, provided insights into the concerns held by the community, interest groups and industry. The material from these submissions and consultations also provides a rough-and-ready way to gauge movement in the CSG debate since the call for submissions for the Legislative Council Inquiry into CSG in 2011. It is noted by the Review that the vast majority of issues raised in the Inquiry remain relevant today.

A list of those who provided submissions to the Review is provided at Appendix 3 and at www.chiefscientist.nsw.gov.au/coal-seam-gas-review. The submissions can be accessed there, except for those submissions which were marked 'confidential'. An analysis of the issues raised in the submissions is given in Chapter 2.

1.4.6 Stakeholder meetings following submissions

Various stakeholders from the CSG industry, the industries providing services to the CSG industry, community groups, industry bodies and associations were invited for discussions with the Review team to discuss key issues and concerns - especially those raised in their submissions.

A list of those who met with the Review can be viewed at Appendix 4.

1.4.7 Site visits and meetings with local government and community groups

The Review team undertook a limited number of site visits (more will continue throughout the Review) to see the CSG areas and meet with the various local councils dealing with CSG issues and local community groups. To date, sites in Gloucester, Camden, Narrabri/Pilliga State Forest, and Gunnedah/Liverpool Plains have been visited, with more visits planned as the Review progresses.

1.4.8 Understanding good practice internationally

At this stage most of the direct consultations for the Review have taken place in Australia, but a limited amount of work has been done to identify good practice in both technology developments and legislation regulating unconventional gas extraction overseas.

Alberta, Canada, has been identified as a jurisdiction with extensive hydrocarbon reserves which has wrestled for many years with issues similar to those facing NSW at present and which has evolved its legislative approach to an interesting level of sophistication. Discussions via teleconference and email were held with groups managing CSG and other unconventional gas resources in the Government of Alberta, Canada. These included the Energy Resources Conservation Board, the Ministry of Environment and Sustainable Resource Development (now combined to form the Alberta Energy Regulator) and Alberta Energy.

Alberta has three aspects that the Review wishes to study. One is the play-based approach that the Alberta regulators have been investigating for licensing activities in a particular region; another is its new structure, the Alberta Energy Regulator (AER), that brings together gas extraction development regulation and compliance with environmental licensing and oversight; and the third is the Digital Data Submission Service of the AER. The AER is a model that enables improved coordination between well development and environmental conditions compliance, while being funded through industry monies.

International best practice will be a focus in the next phase of the Review.

1.4.9 Study of industry compliance

The first of the Review Terms of Reference is to perform a study of industry compliance.

1.4.9.1 Analysis of relevant legislation

The first step in addressing this matter was to commission an analysis of the explicit compliance requirements on industry in each piece of relevant legislation, State and Commonwealth. At this stage the most relevant Acts have been analysed but, as many Acts and Regulations apply, more work is needed. A table of the main legislative, regulatory and policy instruments relevant to CSG activity is at Table 1.2.

A complexity of the legislative environment is that some wells and developments currently operate under different pieces of legislation depending on where or when titles were granted e.g. the *Water Act 1912* and the *Water Management Act 2000*.

The legislation analysis not only provides the Review with an agenda for checking compliance, but it also provides insight into the form of defaults used in structuring the legislation (e.g. when an exploration licence is up for renewal and the company has applied for a renewal, the licence is assumed to continue in force until an explicit decision is made on its renewal. In addition, the legislation provides that a licence to explore confers an entitlement to a production lease). This analysis has been useful as these issues are often raised in community consultations.

Table 1.1: NSW and Commonwealth principal acts and regulations pertaining to CSG

NSW		
Principal act	**Regulations**	**Statutory instruments**
Petroleum Onshore Act 1991	Petroleum Onshore Regulation 2007	
Protection of the Environment Operations Act 1997	• Protection of the Environment Operations (Clean Air) Regulation 2010 • Protection of the Environment Operations (General) Regulation 2009 • Protection of the Environment Operations (Waste) Regulation 2005	
Environmental Planning and Assessment Act 1979	Environmental Planning and Assessment Regulation 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) Regulation 2011	
Water Act 1912		
Wilderness Act 1987		
Environmentally Hazardous Chemicals Act 1985		
Heritage Act 1977		
National Parks and Wildlife Act 1974	National Parks and Wildlife Regulation 2009	
Threatened Species Conservation Act 1995		
Pipelines Act 1967	Pipelines Regulation 2005	
Work Health and Safety Act 2011		
COMMONWEALTH		
Principal act		**Statutory instruments**
Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (note June 2013 amendments requiring CSG developments with a potentially significant impact on water resources to be referred to, and possibly approved by, the Commonwealth Environment Minister)		
National Greenhouse and Energy Reporting Act 2007		National Greenhouse and Energy Reporting (Measurement) Determination 2008
Note: There are a range of other policies and guidelines relating to the CSG industry.		

1.4.9.2 Survey of CSG data holdings in NSW Government agencies

The Review also instituted a data collection and management survey, sent out in mid-June, to NSW Government agencies that collect and manage data in relation to CSG and conventional gas. The survey was aimed at helping the Review team understand the types, format, and extent of data that is currently collected by the agencies, and to find out how the data is managed, stored, accessed and shared. A discussion of this survey can be found in Chapter 14.

1.4.9.3 Determining the status of CSG wells

As indicated in Section 1.1, the details of the status of CSG wells in NSW are yet to be supplied. The Review understands the data will be supplied within the next week.

1.4.9.4 Tracking a company test case

As part of developing the methodology for the compliance study, a set of requests was made to agencies to ascertain where and how information about licensing and leasing applications, approvals, reporting and compliance activities is held and how difficult it is for agencies to provide either the data or access to relevant documentation. A single company at a single site with a mix of exploration, assessment and production titles was selected for this purpose. The initial request was for licensing and leasing material (leaving aside annual and activity reports).

This proved an instructive sampling exercise illustrating some of the complexities and challenges for those tasked with ensuring compliance and for the public wishing to understand compliance matters regarding any particular well.

1.4.9.5 Some much discussed incidents

A number of examples of environmental breaches have been repeatedly raised by those meeting with the Review, most notably the Eastern Star Pilliga incident in 2010, and in Camden, the AGL air monitoring reporting breaches over the period 2009 to 2012. The Review has commenced preliminary studies of these incidents.

Santos – Pilliga

The EPA fined Eastern Star Gas Ltd a total of $3000 for two cases of discharging polluted water containing high levels of total dissolved solids into Bohena Creek, near Narrabri, in March and November 2010, offences under s120 of the *Protection of Environment Operations Act 1997*. The maximum penalty which may be imposed by a court for a breach of this section by a corporation is $1m. However Division 3 of the Act, together with Chapter 6 of the *Protection of the Environment Operations (General) Regulation 2009,* permits the EPA to issue penalty notices for certain offences, including s120. Payment of the penalty notice by the offender means the offender is not liable to further proceedings for the offence. The prescribed penalty payable under a penalty notice for this offence is $1500 for a corporation. In determining what action to take in respect of an act of pollution, the EPA is guided by its Prosecution Guidelines (publicly available at http://www.epa.nsw.gov.au/legislation/prosguid.htm).

At the time of the offences the site was licensed by Eastern Star Gas Ltd. It is now licensed and operated by Santos NSW (Hillgrove) Pty Ltd.

In June this year, DTIRIS commenced legal proceedings against Santos NSW Pty Ltd for alleged breaches of the *Petroleum (Onshore) Act 1991*.

The proceedings allege that:

> Santos Pty Ltd (previously known as Eastern Star Gas) … failed to lodge accurate environmental management reports in the period June 2010 to September 2011. It is also alleged that Santos Pty Ltd failed to report a spill of untreated production water from the Bibblewindi Water Treatment Plant, in June 2011, an incident which threatened to harm the environment (DTIRIS, 2013b).

The proceedings have been listed before the Land and Environment Court on 26 July 2013.

AGL – Camden

As part of its Environment Protection Licence (EPL), AGL Upstream Investments Pty Ltd is required to obtain and publish emission data from its three gas compression engines, from onsite Continuous Emission Monitoring System (CEMS) units and routine independent stack testing.

In March this year, the NSW EPA reported that it is investigating an alleged breach of the company's EPL involving failure to conduct mandatory continuous monitoring of nitrogen oxide emissions from gas compressor engines at AGL's Rosalind Park Gas Plant, near Menangle between 2009 and 2012.

Also in March this year, the EPA issued a penalty notice for the prescribed amount of $1500 for a breach of a licence condition after emissions of nitrogen oxides were recorded above limits permitted by its EPL during September, November and December. The EPA reported that the incidents were self-reported by AGL to the EPA, and that the cause of the exceedances had been investigated and fixed. The maximum penalty for such a breach which may be imposed by a court is $1m (s64(1)(a) *Protection of the Environment Operations Act 1997)*.

In a separate incident, in July this year the EPA issued AGL Upstream Investments Pty Ltd a penalty notice for the prescribed amount of $1000 for failing to publish monitoring data under 'community right to know' requirements of the *Protection of the Environment Operations Act 1997 (s.66(6)(a))*. The maximum penalty for such a breach which may be imposed by a court is $4,400. The EPA requires a monthly summary of CEMS data to be published on the company's website within 14 days of the last data being obtained for that month, but no data was published for the months of February, March and April 2013. The EPA reported that AGL published the data as soon as it was notified of the breach, and that the data indicated that emissions were not above the permitted limits.

Metgasco – disposal of produced water

In 2012, it was found that Metgasco had been disposing of excess produced water in the Casino sewage treatment plant, owned by the Richmond Valley Council and licensed by the NSW Environmental Protection Agency. Over the period from May 2011 until March 2012, 1.36 ML had been processed through the plant; the process was outside of the licence terms. The EPA issued a formal warning to Council and advised them that it was in breach of their Environment Protection Licence to permit the disposal of produced water at any of Council's sewage treatment plants.

In a one off response to the increasing volume of produced water, the NSW Office of Water, the EPA and Council worked together to authorise the disposal of 5ML to the Casino sewage treatment plant.

Metgasco has, subsequent to these events, ceased operations and is not generating any additional produced water. Metgasco will be required by the EPA to dispose of the currently stored produced water in a satisfactory manner.

Data on other incidents has been gathered based on responses provided by the relevant agencies. However, a full picture of all incidents has not, to date, been made clear. These matters will be explored further under the compliance investigation in the next phase of the Review.

1.5 HOW THE REPORT IS STRUCTURED

- Chapter 2 provides an analysis of the issues raised with the Review.
- Chapter 3 examines the factors that have made CSG such an emotive issue in NSW at present.
- Chapters 4-14 deal with the major issues raised with the Review topic by topic.
- Chapter 15 concludes the report and provides recommendations.

2 WHAT ARE THE ISSUES WITH CSG?

To understand the issues various stakeholders have with CSG, the Review called for public comment on 13 April 2013. More than 230 submissions have been received to date. All submissions, apart from confidential material, are available at www.chiefscientist.nsw.gov.au/coal-seam-gas-review.

Further, throughout the initial Review process, the Review team met with stakeholders from community groups, local councils, environmental groups, business groups, government agencies and companies involved with CSG in NSW. A complete list of stakeholders who met with the Review is at Appendix 4.

Diverse concerns overlapped in meetings, community submissions and the commissioned reports. Local councils want to provide constituents with adequate information on CSG in their areas. Stakeholders from every sector, including industry, government, and the public, emphasised the current atmosphere of mistrust and frustration, the importance of science in working to understand the issues, and the desire for clarifying the rules for all parties involved in CSG activities. The Review noted that distrust of Government, including the Environment Protection Authority as regulator, was strong among communities.

2.1 SUMMARY OF ISSUES IDENTIFIED BY THE LEGISLATIVE COUNCIL INQUIRY INTO CSG

The issues discussed in meetings and submissions shared similarities with those made to the Legislative Council Inquiry conducted by the General Purpose Standing Committee no.5. The Inquiry was established on 5 August 2011, to inquire into and report on the environmental, health, economic and social impacts of CSG activities. The role of CSG in meeting the future energy needs of NSW was also examined. The Inquiry Committee delivered its report in May 2012, and provided a sound basis for understanding the issues of community concern in recent years.

As well as covering community concerns about the potential impacts of CSG extraction on water, health and the environment and the connected concerns over 'fracking', the Committee's report highlighted a number of significant areas of community angst including: land access and fear of loss of land, behaviour of CSG companies and contractors, the rapid pace of industry development, the extent of activity at exploration phase, licences held by 'two dollar' companies, potential mental health impacts, community consultation and the impact of CSG revenue on Government decisions.

The Committee's Final Report made 35 recommendations to Government, to which the Government responded in November 2012. Both the report and Government response can be found at www.parliament.nsw.gov.au under the Reports section of Committees. It is noted that a number of the recommendations have been implemented by Government which has since announced a reform package in relation to CSG: the Strategic Regional Land Use Policy.

2.2 ISSUES RAISED IN SUBMISSIONS TO THE REVIEW

As is not uncommon with community submission processes, a high level of opposition is expressed in the more than 230 submissions received by the Review. The majority of submissions to the Review were opposed to CSG taking place in NSW (only 5% expressed positive interest). The top 20 issues raised have been listed in Figure 2.1. However, it should be noted that a wider range of more detailed issues was canvassed at community and industry meetings and these are not reflected in Figure 2.1. A more detailed analysis is given at Appendix 5.

Though 75% of submissions expressed concerns about water, CSG is not a single issue topic. Contributors to the Review articulated an average of six subjects per submission across a range of subjects; several listed as many as 18 separate issues.

Seventy-five per cent of submissions to the Review expressed concerns revolving around water: groundwater, water catchments, surface water and aquifers (75%); produced water removed from coal seams (18%); how both are managed; and what effect CSG activities – in particular the chemicals used in the hydraulic fracturing process (24%) – have on water quality. Additionally, many expressed concerns about current gaps that exist in what is known about hydrogeology and connectivity in general.

Issues related to water also included:

- human (physical) health (51%)
- the environment generally (49%)
- air (35%) and fugitive emissions (23%)
- agriculture and other land use industries including concern for the nation's food supply (37%)
- seismic activity and subsidence (12%).

Additionally, 43% of submissions expressed concerns over the industry's relatively recent arrival and the apparent lack of available scientific data surrounding the industry and its impacted regions, including the issues aforementioned.

Several submissions expressed belief that impacts of CSG activities on human health have yet to be properly assessed. Many suggested that appropriate independent assessments of baseline health data, and ongoing monitoring of the impact of human exposure to CSG pollutants in all communities potentially affected by CSG industrialisation, be undertaken.

It is notable the Review did not receive any submissions from

Figure 2.1: Most common CSG concerns submitted to Review, out of a total of 233 submissions received between 26 March and 11 July 2013.

companies or industry groups which use CSG as part of their business (e.g. manufacturers, chemical companies, factories, etc.). This is of interest given the strong public position from such groups on the issue of domestic gas supply and predicted rising gas prices.

Themes of mistrust were evident in a portion of submissions. More than one in ten submissions to the Review expressed suspicion of government intentions, many stating the government prioritised monetary gain over the will – and sometimes even the health – of the people. An additional one in ten expressed distrust of companies involved in CSG activities. This topic of trust is further illustrated in 2.3.4 below.

2.3 COMMISSIONED STUDY REFLECTS CONCERNS EXPRESSED IN SUBMISSIONS TO REVIEW

The Review also drew on previous studies and commissioned a report to explore how CSG activities are managed in relation to people and communities, and how people respond to these activities.

Public contributions to the Review were largely mirrored in the findings of a study the Review commissioned from Dr Melanie Taylor, Ms Natalie Sandy and Professor Beverley Raphael from the University of Western Sydney (UWS). Professor Raphael has held senior government and academic posts in psychiatric health in various Australian jurisdictions.

The UWS team examined community concerns in relation to CSG activities (discussed below), using secondary data including media reporting, and the potential impacts of these concerns (discussed in Section 11.5), drawing from government and technical reports, and peer-reviewed academic literature. As with the summary of submissions to the Review in 2.2, this study's approach was not to comment on the validity of concerns, but to represent concerns as people in NSW see them. This report will be available at www.chiefscientist.nsw.gov.au.

2.3.1 Water

The UWS report also found water to be the major concern with CSG and noted that "the significance of water to communities – their health, livelihoods, and the environment, makes concerns in this area particularly emotive". See Chapter 7 for further comment.

2.3.2 Agriculture and natural environment

The UWS report identified five concerns relating to agriculture and the natural environment. These included potential impacts on:

- noise pollution (from trucks travelling to and from CSG well sites)
- animal health (which may suffer from exposure to produced water)
- air pollution (from fugitive emissions)
- agricultural and land value issues (where livelihoods and primary investments are affected by threats to other criteria listed herein)
- risks of landslides and earthquakes (from hydraulic fracturing).

2.3.3 Land owner and community rights

Land owner rights and anxiety over property access were found to be primary areas of concern to the public. "Community concerns in this area relate to the perceived lack of rights of land owners and the local communities in terms of access to their land, consultation, compensation, loss of property value, lack of rehabilitation of tangible benefits to the land owners or their communities" (Taylor, Sandy, & Raphael, 2013). This 'trilateral ownership', in a sense, involves private land owners, the Crown as holder of mineral rights, and private CSG companies with a legal title to extract CSG. Unlike in the US, where many longstanding landholders also own their mineral rights, “owning the land but not the resources under the ground is a difficult concept for many [Australian] land owners” (Taylor et al., 2013). This issue is also discussed in Chapter 4, Land Access and Property Issues.

2.3.4 Trust

Further, the UWS report found that the perception that Government obligingly supports the CSG industry is just one aspect of an atmosphere of mistrust. Sections of the community also demonstrated high levels of distrust in relation to:

- the lack of available data and verifiable evidence (or beliefs of biased data created by government or gas companies)
- the regulatory process (including concern about the approval process around granting licences, monitoring operations and safety, and perceived special allowances)
- CSG companies (viewed by many as operating with impunity, without care to harm they may be doing communities and the environment; perceived lack of fairness or balance in the risks and benefits associated with CSG; doubt in claims of CSG as ‘cleaner’ energy; misleading advertising)
- science, either mistrust or confusion, caused by the use of scientists and experts by opposing sides in a debate (especially one that is emotive) can lead to mistrust of the science and scientists
- members of their own community (who have been viewed as ‘selling out’ to CSG companies, which can lead to social tension and animosity between neighbours).

This final criterion of mistrust can also be identified in land owners and community members “in favour of CSG [who] feel that the debate has been taken over by environmental activists” (Taylor et al., 2013).

2.3.5 Media

The UWS report argues “the media plays a pivotal role in framing the CSG debate. On balance, media reporting appears to be more anti-CSG than pro-CSG, most likely because this is the side of the debate that makes a better story and garners more interest” (Taylor et al., 2013). Though they referenced several documentaries and domestic media, like ABC’s program *Four Corners* (Carney & Agius, 2013), the UWS report claimed that the film *Gasland*, which focuses on the US shale gas boom, is “unduly shaping the coal seam gas debate and heavily influencing Australia”.

Further, their report noted:

> The media coverage of CSG is what most of the population know about CSG, hence there is probably a greater fear or wariness in the general public when it comes to the subject of CSG activities. Most people, even if unaffected directly by CSG activities, will find some part of the mosaic of concerns that resonate with them; whether it be safe drinking water, health concerns, concerns for the environment, or human rights.

2.3.6 Health

Health impacts overlap many of the previously addressed concerns, including pollution or contamination of the surrounding environment. The UWS report found that the public was concerned about potential physical and mental health impacts, but that certainty was currently unattainable as the public believed there was little research or data to accurately confirm or deny health-related CSG fears.

The commissioned report focused largely on potential impacts on psychosocial wellbeing and mental health. These impacts are discussed in more detail in Chapter 11.

2.3.7 Knowledge gaps

The UWS paper reported that communities believe there are many 'unknowns' when it comes to CSG. The report acknowledged that one "gap in knowledge is the prevalence of these concerns in potentially-affected communities and the broader population… Those who want to be heard can get coverage in the media, but that does not necessarily provide information about how representative their views are in the community. Therefore the *scale* of the community concerns is not fully known" [author's emphasis] (Taylor et al., 2013).

2.4 COMMUNITY GROUPS' CONCERNS EXPRESSED IN STAKEHOLDER MEETINGS AND SITE VISITS

The Review team met with stakeholders from the following community groups either at the Office of the Chief Scientist & Engineer or onsite in Gloucester, Campbelltown, Camden, Narrabri, Gunnedah, Tamworth and neighbouring regions.

- NSW Farmers Association
- Lock the Gate Alliance
- Bellata-Gurley Action Group Against Gas (and separately with Chair, Penny Blatchford)
- Southern Highlands Coal Action Group
- Barrington-Gloucester-Stroud Preservation Alliance
- Lower Waukivory Residents Group
- The Wilderness Society
- Scenic Hills Association
- Stop CSG Macarthur
- Rivers SOS Alliance
- Stop CSG Sydney Water Catchment Association
- Namoi Water
- North West Alliance
- Great Artesian Basin Protection Group
- Caroona Coal Action Group.

Views on the future of CSG varied at public stakeholder meetings. While many organisations reported that they were not wholly opposed to CSG in their area, provided appropriate regulations and environmental protections are in place, others called for the complete cessation of CSG activities.

Main concerns expressed in stakeholder meetings echoed both submissions made to the Review and expressed in the UWS report. For example, Fiona Simson, President of NSW Farmers, voiced her members' primary concern as water.

Several stakeholders reported that some concern for CSG was justified, but that organisations had other more primary concerns such as existing mining, especially coal mining, projects in their areas.

2.4.1 Licence proposal assessment

In response to the complicated regulatory framework, Ms Simson of NSW Farmers suggested the traffic light scenario for quick, upfront assessments for mining licences. For example, a 'red light' category would show a project has great risk, but is not stopped forever; rather, it will require further data. An 'orange light' would likely represent the majority of applications with additional data collection required, and a 'green light' would show the project evidences little risk.

Further, beyond the red light, Ms Simson suggested pre-emptively ruling out areas where mining activity would be risky and identify areas where it may be low risk. The existing Camden Gas Project was referred to by several as a good example of a low risk CSG location due to the geology of the area and distance from the water catchment.

2.4.2 Insurance covering environmental impacts

Stakeholders expressed concerns over the level of land access agreements with subcontractors who are under contract from the petroleum title holder or operators, and the question of who covers the damage if an accident occurs on their land. The Review has raised a question of the level of insurance that subcontractors hold while conducting activities for the CSG producer and further work is being undertaken to explore this issue (see also 2.5.3).

2.4.3 Other issues

Other issues expressed in stakeholder meetings that overlapped in submissions to the Review involved:

- concerns for truthful and available data and reporting
- beliefs that government is disinterested, powerless or colluding with industry and, as a consequence, concerns over company non-compliance and apparent government failures to hold guilty parties accountable. This includes a belief that government agencies are under-resourced, leaving private citizens responsible for reporting and testing cases of accidents and legal infringements, and resulting in an inability to trust CSG companies or the government
- questions of the appropriateness of certain CSG locations and requests for CSG exclusion zones
- the precautionary principle.

2.5 INDUSTRY CONCERNS EXPRESSED IN MEETINGS WITH THE REVIEW TEAM

Between 8 April and 10 July, the Review team met with stakeholders from industry, including petroleum title holders Metgasco, Santos, Dart Energy, AGL, and Apex Energy; operator/subcontractor Halliburton; industry body APPEA; industry environmental consultant ERM; and the NSW Business Chamber.

2.5.1 Regulatory clarity and consistency

A common theme that emerged from meetings with industry stakeholders included frustrations with a shifting regulatory climate. Several industry representatives stated that an environment of policy and regulatory certainty would be welcome even if the conditions laid down by Government were tough. Such certainty would allow for investment planning and decisions to be made with more accuracy and confidence.

Companies stressed the importance of scientific data in considering regulatory decisions. For example, many expressed confusion in the reasoning behind the determination of 2 km as the distance for exclusion zones from residential areas, townships, etc., and noted the coal mining industry's exemption from the same restriction.

2.5.2 Perceived reasons for public outcry

Though representatives expressed confidence in their industry, they acknowledged the industry's poor reception and cited reasons for the public's negative reactions against CSG. Several of the issues raised corresponded with submissions made to the Review and issues found in the UWS study. The reasons industry referenced include:

- a void in the industry side of the story (e.g. the absence of their public representation to discuss CSG benefits and safe engineering practices, and additionally that this information is not as appealing to the public as the emotive anti-CSG story)
- a lack of trust in governments, CSG companies and the data they both produce
- the state and federal election cycles, which highlight the CSG issue
- evocative images of ‘bubbling methane’, a ‘foaming well’ and the media’s anti-CSG portrayals.

And, the foremost reason all representatives cited for reasons behind public outcry:

- the substantial influence of the emotive 2010 US documentary *Gasland* and the well-publicised scene of the flammable kitchen tap water.

A number of industry representatives expressed dissatisfaction with the level and quality of public support and advocacy provided by the industry’s peak national body, the Australian Petroleum Production and Exploration Association (APPEA).

2.5.3 The subcontractor issue

In meetings with industry groups, the Review raised the issue of quality control of subcontractors hired as service providers for the large company producers to undertake on-the-ground work including drilling. The Review team asked industry how this was managed to ensure quality control of safety and operations as well as compliance.

It was felt by one representative that the practice of using subcontractors is becoming increasingly more prevalent and that subcontractors could be subjected to strengthened safety and training conditions.

In general, the responses have prompted further investigation into the issue and the development of Recommendation 4.

2.5.4 Key issues in CSG extraction

Public debate has focused, in large part, on the practice widely known as ‘fracking’, or hydraulic fracturing, and its perceived association with water contamination, air pollution, and negative health and environmental effects. However, in Review meetings with industry stakeholders, many officials placed hydraulic fracturing low on the list of risks involved in CSG extraction.

While all expressed confidence in the industry’s technology and engineering developments, as well as their company training and safety procedures, they provided other issues that represented greater challenges to the industry:

- managing the large amount of water produced from coal seams
- bad practice in well construction and other offences by earlier ‘cowboys’ or smaller companies in the industry with fewer resources (leaving larger contemporary companies to re-plug/ stabilise many of these old wells and account for public mistrust).

On this final point, several representatives reported how larger companies followed more stringent international standards even when they operated in countries with fewer or lower environmental standards.

Industry noted the barriers to proceeding with CSG operations in light of the strengthened Government policies and regulations announced in the past year, and the impact of the 2 km exclusion zone on planned exploration projects inhibiting companies such as AGL from expanding its exploration activities. Other companies including Dart and Metgasco are withdrawing activity from NSW. Most recently, on 10 July 2013, the NSW Planning

Assessment Commission refused Apex Energy's exploration drilling project modification application, under the *Environmental Planning and Assessment Act 1979,* in the Sydney Water Catchment area between Wollongong and Sydney.

2.5.5 Shared community and industry concerns

Industry concerns and community concerns overlapped in three key ways, in that both:

- were frustrated with complicated and confusing legislation overseeing CSG practices
- called for scientific testing to inform the public, and policy makers, on the true effects of CSG
- questioned policy decisions on the 2 km exclusion zone, and its scientific basis.

2.6 LOCAL COUNCIL CONCERNS WITH PROVIDING INFORMATION TO CONSTITUENTS

The Review team undertook a number of regional site visits to inspect CSG operations and meet with local communities. Meetings with the local Councils of Gloucester, Campbelltown, Camden, Narrabri and the Gunnedah Shire provided new insight into previously unrepresented issues in NSW.

The constructive meetings held by the team with a number of affected local councils demonstrated the experiences and concerns of local authorities at the sharp end of the CSG issue.

Camden and Campbelltown have co-existed with CSG operations in their areas for more than twelve years. The councils have had difficulty obtaining and distributing information about CSG to their constituents and Camden Council gave two key examples. The first involved difficulties in the Council obtaining a map of CSG wells in their area from AGL. Secondly, they mentioned a problem with an unalterable state planning and zoning form (Certificate under Section 149 [2]).

The 149(2) is commonly used by prospective property buyers to learn about both the history of and plans for potentially environmentally impactful activities on or around their land. It includes information, under *EP&A Regulation (2000*), regarding 'zoning and land uses under the planning control', mine subsidence, heritage information, 'Council and other public authority policies on hazard risk restrictions… [and] matters arising under the *Contaminated Land Management Act 1997'* (Camden Council, 2012). The fixed state of this form does not include or allow 'CSG activity' to be entered on its list of relevant criteria. This potential omission keeps prospective property or homebuyers in the dark about CSG activity previously, currently, or planned in or around their neighbourhood. Whether or not this information impacts their decision, the Council felt buyers have a right to all of the facts about their property before making the purchase.

Additionally, a Certificate 149(5), which contains a category for 'other' information, including CSG activity, on a property may be ordered at the same time as a 149(2); however the cost, is two-and-a-half-times that of ordering the more common 149(2).

Campbelltown Council is also concerned about the potential impact of CSG activities on a proposed urban land release area at Menangle Park.

Narrabri Council echoed community concerns about 'self-administering companies' and the need for independent assessment of projects before drilling commences and an independent body to conduct monitoring of operations to ensure companies are adhering to their licence conditions. It argued independent checks should also be undertaken on the integrity of CSG wells, including at the abandonment stage.

Property rights were another issue raised by Narrabri Council as causing local residents concern. Landholders are against ‘their land’ being impacted by CSG because of the ‘fear of the unknown’. Councillors also pointed to the spider web-like impact a network of CSG wells would have on agricultural land in the region as another reason for community concern.

In Gloucester, the Council highlighted the geological complexity of the Gloucester Basin as a critical issue and raised specific concerns about the potential impact of CSG exploration and production on the region’s water table. The flow-on effect to communities downstream of Gloucester is also of concern.

Gloucester Council also expressed concerns about the potential cumulative impacts of CSG activities on top of a growing coal mining industry in the Gloucester Valley and called for more independent scientific research prior to additional development.

Gunnedah Shire Council said there should be a ‘total rewrite’ of the *Petroleum (Onshore) Act 1991,* stating it is out of date and does not effectively deal with land ownership issues. Council also stressed the need for local government to be more involved in the approval process for the exploration phase for CSG, citing an example of a CSG company commencing exploration drilling within the LGA without notifying council.

Finally, all councils consulted for the Review referenced challenges in informing constituents and making decisions surrounding a relatively new industry with little scientific data, especially regarding water resources. All councils identified the need for independent scientific research to be undertaken to address communities’ health and environmental concerns, particularly around potential water impacts.

All councils expressed strong concerns about the availability of ongoing funding for the local infrastructure and services needed to support CSG operations in the area, including local roads and medical services and facilities. Various ideas around councils receiving some form of revenue from CSG industry producing in their respective local government areas were put forward.

2.7 GOVERNMENT AGENCY CONCERNS

The Review frequently consulted with NSW government agencies including the NSW EPA, NSW Office of Water (NOW), Mineral Resources in the Division of Resources and Energy, Office of Coal Seam Gas (OCSG), the Office of Environment and Heritage, NSW Ministry of Health and Sydney Catchment Authority.

In discussions with NSW government agency representatives, the Review found that agencies are facing challenges with being under-resourced in undertaking compliance activities. Other agency concerns include:

- community confusion or being poorly informed about government roles and activities
- the collection of significant amounts of data not being used to its full potential
- the need to revisit the legislative framework of the *Petroleum (Onshore) Mining Act 1991*, including addressing inconsistencies with the *Mining Act 1992*
- the difficulty in holding on to skilled officers who are poached into industry.

2.7.1 Queensland consultation

In Queensland, the Review team met with various departments in science, resources, environment, health and water. A complete list of the departments the Review team met with is listed at Appendix 4. Queensland has more CSG extraction activity, and government representatives discussed challenges they have encountered which echoed concerns felt in NSW:

- most significantly, groundwater impacts (particularly for Western Queensland , which is highly dependent on groundwater supplies that already have quality issues), and groundwater modelling
- understanding the nature of produced water, chemical composition, pathways, etc.
- environmental health and impact assessments
- poor data sharing (e.g. addressing 'commercial-in-confidence' claims, overcoming agency silos, and improving collection, management capacity and compatibility of data)
- monitoring (device placement and type), improving quality of water-related data and ability to use it
- risk assessments (e.g. with the fast pace of expansion, inexperienced managers unable to identify hazards, new machine operators, older machinery; unclear subcontracting 'bridging documents' blurring responsibilities in the field)
- safety oversight challenges for government (e.g. government agencies train staff who are then hired by companies leading to shortage of expertise to execute oversight and compliance roles)
- land access compensation issues.

2.7.2 Commonwealth agency issues

The Review team held several discussions with various Commonwealth Government agencies including the Department of Resources, Energy and Tourism (RET), Geoscience Australia, the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC), and the Office of Water Science in the Department of Sustainability, Environment, Water, Population and Communities (SEWPAC). Agencies were interested in the Review and discussed:

- concern for upcoming expirations of NSW contracts with gas providers beginning in 2014, and how that may affect gas prices
- the need to better understand chemical exposure pathways underground
- the need to understand how surface water relates to aquifer interference.

2.7.3 An international perspective from Alberta, Canada

Officials in Alberta, which has an estimated 80% of the natural gas produced in Canada, contributed information on their experiences with CSG during several teleconference meetings. They referenced issues including:

- water (they currently require companies to test existing wells in a 600m radius where drilling is planned) to obtain baseline information
- safety issues of vehicles on rural roads
- dust
- flaring and venting of hydrogen sulphide, with this issue being a key factor in deciding setbacks [this is not an issue in NSW]
- land access issues (as Canada has a similar system where the Crown owns the resource).

Representatives from the Energy Resources Conservation Board, now part of the Alberta Energy Regulator, noted the following:

- the importance of data, and how critical it is to compliance activities
- their success story in providing public access to data (they provide monthly updates on enforcement activities with a strong focus on information transparency and require hard evidence as an industry performance measure, which creates public confidence)
- different groundwater zones have different legislation based on well depth (stronger legislation for shallower wells that are within the groundwater zone but not as stringent if going below base of groundwater).

2.8 COMMENTS FROM THE REVIEW

The Review notes the many and complex issues of community concern around CSG activities and that these issues have not altered in recent years. The Review team heard constructive information from various sections of the community affected by CSG and gained a good understanding of the feelings of frustration and confusion felt by people on the ground. Many of the comments and concerns expressed by stakeholders have informed the Review's investigation of issues and are reflected in the second half of this report.

Further meetings with affected councils and community groups are planned, and will continue to be welcomed by the Review, as will additional public submissions. Further meetings with industry and relevant stakeholders are also being scheduled.

The Review is continuing to conduct investigations into how national and international jurisdictions manage the interface between CSG activities and communities, townships, residential areas, farms and properties.

2.9 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- "Community concerns and their potential effects", Dr Melanie Taylor, Natalie Sandy and Professor Beverley Raphael, University of Western Sydney.

3 CSG IN NSW: A PERFECT STORM

3.1 GLOBAL, NATIONAL AND STATE CONTEXT

3.1.1 World gas context

In the past five years there has been a significant increase in demand for gas worldwide with surging gas consumption in Asia and the United States.

In the US, concerns over energy security, CO_2 emissions from fossil fuels and overdependence on the Middle East prompted a major foray into its relatively untapped energy sources, including unconventional gas reserves. The country improved estimates of its very large unconventional gas resources and put great effort into developing and improving technologies to extract unconventional gas. The result was perhaps more successful than anticipated. In 2000, shale gas provided only 1% of US natural gas production; by 2010, it was over 20% and it is predicted that by 2035, 46% of the United States' natural gas supply will come from shale gas. The US is now energy secure, CO_2 emissions have dropped by 12% since 2005, and the country is currently considering the terms under which it exports gas as LNG (Gold, 2013).

The dramatic rise of the industry has resulted in the potential for significant volumes of liquefied natural gas (LNG) to be exported to Asia. China has growing demands for gas on the back of a gas shortage in 2009, and the rising importance of gas as a worldwide energy source. It is therefore looking to increase its domestic supply, construct more gas pipeline infrastructure and storage facilities, as well as strengthen its supply of gas imports.

In Japan, the disastrous events at Fukushima Daiichi nuclear power plant, following the 2011 earthquake and tsunami, and the subsequent shutdown of Japan's reactors, have resulted in the country looking to change its energy system and expand its gas imports and use.

3.1.2 Gas in Australia

Gas is Australia's fastest growing energy source, with investment in gas-fired electricity generation a key driver. Gas production in Australia increased by 8% in 2011-12 (BREE, 2013).

Gas production, largely through conventional gas extraction, has been a part of the country's resources industry for many years, with significant fields in the North West Shelf off Western Australia, the Cooper Basin and the Bass Strait. Australia currently has three disconnected markets – west, north and east.

Australian CSG production increased from 2% to 11% of total gas production in the five years to 2010–11, and future output will be bolstered by three CSG-to-LNG projects, worth $50 billion, being built near Gladstone in Queensland to take advantage of the high international price for gas (Commonwealth of Australia, 2012).

On the east coast of Australia, the proven and probable gas reserves more than tripled between 2005 and 2012 due to the discovery of more CSG reserves (Wood, Carter, & Mullerworth, 2013).

Australia also expects to see a ramp-up of demand in gas domestically. Gas demand is driven by the reluctance of governments to commission new coal-fired power stations because of concerns about emissions generated and because renewable energy technologies are currently unable to supply sufficient baseload power for our current grid configuration.

Australia is also worried about its declining manufacturing industry, a major user of gas, concerned it will be adversely affected by soaring gas prices.

3.1.3 Gas in NSW

About 11% of NSW's installed electricity generation capacity of 2238 megawatts (MW) is powered by natural gas (AEMO, 2011). Gas in NSW is used domestically for two main power sources: electricity and national gas supply to homes and industry. Gas consumption for power generation and the capacity of installed gas-fired generation are both expected to continue to grow in NSW.

The Camden Gas Project in the southern coalfields of the Sydney Basin began production under an exploration title in 2001, which limited 'production' to 5 PJ. By 2008, production in Australia had ramped up to 138.5 PJ, of which 5.3 PJ (roughly 3.8%) came from Camden. It remains the only NSW facility formally in production; however, Santos holds a production lease for several wells in the region around the Pilliga Forest, one of which is a CSG well, with the other wells being conventional gas wells.

As discussed in Section 1.1, as of July 2013, in NSW, there are 52 petroleum titles related to CSG exploration, assessment and production activities. These include 6 PPLs, 45 PELs and 1 PAL. There are currently 17 PELAs, 2 PPLAs and 6 PSPAPPs.

In NSW, CSG supplies 5% of the state's gas needs and this is all sourced from the AGL production sites at Camden (in Queensland, their CSG activities supply 90% of their current gas needs) (D. o. N. R. a. M. Queensland Government, 2013). NSW sources 95% of its gas through contracts with pipeline owners operating the Moomba to Sydney Pipeline system out of the Cooper Basin located on the borders of NSW, South Australia and Queensland; via the Eastern Gas Pipeline (Longford to Horsley Park) out of the Gippsland Basin, Victoria; and the NSW/Victoria Interconnect system drawing gas from the Otway Basin, offshore of Victoria.

3.2 THE EAST COAST GAS SUPPLY ISSUE

There has been a great deal of commentary around NSW's future domestic gas supply, with interstate pipeline contracts due to expire in the next three years and the export potential with Asia becoming a closer reality. The subsequent export parity price which will arise due to the higher prices Asia pays for gas has prompted some to predict soaring domestic gas prices and a domestic gas shortage in NSW.

The interstate pipeline contracts under which NSW is supplied gas begin to run out in 2014 and will be completely exhausted in 2017 (Wood et al., 2013).

Gladstone's LNG plants in Queensland will prepare huge volumes of gas for export to Asia where the gas price is significantly higher, meaning pressure on gas supply and price rises at the domestic level are anticipated in the short to medium term. This impending increase in export capacity is anticipated, by 2014, to lead to a greater production need, and will also mean that Australian east coast prices will rise to meet higher international prices (Wood et al., 2013).

Large users of gas, such as the manufacturing industry, as well as some members of parliament, have called for legislative intervention via a national gas reservation policy, similar to that currently in place in Western Australia. However, the Commonwealth, noting in its *Energy White Paper 2012* that Australia is set to become the biggest gas exporter by 2017, argued against a reservation policy. The oil and gas industry is also opposed to this notion of protectionism, asserting a gas reservation policy will not increase supply to the domestic market because it is a disincentive to investment and will stifle innovation.

In addition to the benefits of meeting local energy demand through increased CSG production, it is claimed that greenhouse gas emissions from such development are significantly lower than emissions from burning coal (Geoscience Australia & BREE, 2012); it will produce large amounts of irrigation water; and provide clean energy for developing Asian countries. The methodologies behind these assertions have been questioned by various media commentators and academics including from the Global Change Institute at the University of Queensland.

The Grattan Institute report released in June 2013 asserts one answer to the domestic gas issue is to ramp up CSG operations in NSW, but there are also options to increase production from the Cooper Basin in South Australia and to increase capacity of gas pipelines from Victoria to NSW (Wood et.al. 2013).

Pipeline owner Jemena has indicated it is planning an expansion of capacity, by way of two additional compressor stations, of 106PJ per annum to 130PJ per annum, to secure gas supply to NSW which has been historically sourced from the Cooper Basin (Green & Jemena Pipelines, 2013).

In response to the pending expiring interstate contracts, gas producers earmarking reserves for exports, the expected decline in gas reserves and the increase in costs of gas production, the NSW Government has shown support for the growth of a sustainable industry in NSW and the investigation by companies of local sources of gas.

NSW currently consumes about 138 PJ of gas per annum. In a report prepared for APPEA by ACIL Allen Consulting, proven and probable CSG reserves in NSW stood at 5,018 PJ at December 2011 – enough to provide 36 years of supply to NSW, while proven, probable and possible (less certain) reserves stood at 9,497 PJ – enough to provide about 69 years supply to the NSW (ACIL Allen Consulting, 2013).

3.3 WHAT FACTORS CONTRIBUTED TO CSG'S CONTROVERSIAL RECEPTION IN NSW?

3.3.1 An expanding industry's early mistakes

At the same time that pressure to export gas is being applied and the industry in Australia is expanding, a public debate has taken hold about the potential impacts of CSG. The debate has been primarily fuelled by the failure of industry and government at all levels to adequately address community concerns before proceeding with development. Those concerns relate to a lack of evidence-based, impartial, publicly available information and conclusive scientific data around the impact of CSG activities on human health, the environment and the community at large.

The former Federal Resources and Energy Minister Martin Ferguson, who supported the CSG industry, conceded in a press conference in November 2011 that the CSG industry had "grown too quickly" and called for strict adherence to scientific principles. He also called for greater focus on communication over investment (Franklin, 2011).

Unfortunately, the early stages of CSG activities in Australia have been characterised by some well-publicised instances of poor safety and compliance practices resulting in environmental incidents, companies appearing to behave badly under scarce supervision and an ill-prepared and inadequate governance framework. A number of environmental incidents occurred in Queensland and then in NSW, one of which, a produced water spill in the Pilliga State Forest, has recently resulted in legal prosecution of the operator by the NSW Government.

3.3.2 Poor communication: Failures with stakeholder engagement and addressing community concerns

One of the most significant and widely acknowledged mistakes to arise from the rapid growth of the CSG industry in Australia has been identified as the industry's poor performance in stakeholder engagement and project communication.

That industry and government did not move quickly to address the concerns of those opposed to CSG and provide adequate factual and appropriately represented information about project safety and efforts to minimise environmental impacts, as well as describing advanced engineering technologies and economic benefits, has left them on the back foot in the public relations battle.

As a result, communities are not only vexed about potential impacts from the CSG activity, but have developed a mistrust of industry and government in the process. There is a widespread perception that industry and government are, at worst, colluding against the public's best interests. At best, government is seen to be powerless against the might of the industry's influence and growth.

3.3.3 Greens and farmers unite as the political focus sharpens

Along with growing community consternation, the groundswell of discontent among many farmers and environmentalists, unusual allies, emerged at the end of the last decade following a number of developments on the national and international scene.

Agricultural and environmental groups campaigned strongly against CSG development in Queensland from 2009, as the industry was rapidly expanding in that state. Community opposition to CSG development in Queensland grew louder in the lead up to the August 2010 Federal election and included protest activity. The Australian Greens were vocal in their support for landholders' rights and their concerns about the environmental impacts of CSG.

A large section of the farming and environmental communities formally joined forces in late 2010, when the Lock the Gate Alliance was incorporated. The alliance coordinated a 'non-cooperation campaign' which resulted in hundreds of land owners locking their gates to resources companies, particularly CSG companies. Landholders sent a clear message to the industry that they were determined to refuse entry to companies despite the legal requirement to negotiate access. As the Review has progressed and further consultation has taken place, it has become clear that the issue of property rights is a key tenet of community concerns over the CSG industry (see Chapter 4).

Lock the Gate's membership now comprises thousands of individuals and more than 160 community groups across Australia.

In 2013, the Stop CSG Party was formed ahead of the Federal election in the second half of the year.

Due to the complex, and in many cases, uncertain, aspects around CSG extraction, and the impact upon the community and certain geographical locations, the issue has become a key policy platform among state and federal politicians on all points of the political spectrum.

It should be noted that many of the stakeholders the Review team met with were not wholly opposed to CSG, but wanted to see rigorous regulation and fair and reasonable policy developed with the community. However, some sections of the community do wish to see CSG extraction banned altogether and these sections have been extremely vocal and demonstrative in their protests. The protest movement has gained support arguing that while the CSG industry is well-established in Queensland, it is still small enough to be stopped in NSW.

3.3.4 International controversy: The US shale gas story as told in *Gasland*

The documentary *Gasland* by Josh Fox was released in Australian cinemas in November 2010. It focused on communities in the US who felt impacted by natural gas drilling and, specifically, the use of the production enhancing method known as fracture stimulation or 'fracking'.

The emotive documentary was largely well received by critics, nominated for an Academy Award and quickly developed a cult following among environmentalists and anti-CSG campaigners in Australia and elsewhere. Arguably, the film has also triggered the formation of new groups of anti-CSG campaigners.

Despite the disparity in issues faced here and in the US, and identified factual inaccuracies in the film (notably rebutted in the lesser known film *FrackNation*), *Gasland* has made a significant impression on the Australian CSG debate.

3.3.5 Unanswered scientific questions: Is there enough data, and is it trusted?

In a country that has experienced severe drought conditions over many years and is so reliant upon its agricultural resources, water is an iconic trigger issue in Australia and people feel passionately about it.

The CSG industry as a whole could extract 300 billion litres per year over the next twenty-five years, most of it from the Great Artesian Basin, according to Federal Government estimates (National Water Commission, 2010).

In 2010, the National Water Commission expressed concern that CSG development represented a substantial risk to sustainable water management given the combination of material uncertainty about water impacts, the significance of potential impacts, and the long time period over which they may emerge and continue to have effect (National Water Commission, 2010).

As with the largely unknown nature of groundwater and geology, Australia is in the early stages of understanding its total water system. Many studies have been conducted on parts of the system or aspects of the whole system but there is still not an adequately reliable model to give reasonable long-term confidence about the impact of mining and CSG on the system.

Another important area that needs greater research and analysis is the connectivity of deep aquifer systems to shallow aquifers. Shallow aquifers are fairly well understood due to the considerable number of alluvial water bores across the country, in place for measurement and extraction. Many of these water bores enable the collection of data that provides considerable understanding of the water connectivities in the depths to about 120 metres below the surface. The deeper aquifers have far fewer bores drilled into them and as such are not as well known.

The community has also expressed concern over the level of scientific knowledge on the related issue of naturally occurring (or induced) geological fracturing and its impact on groundwater flows and connectivities. How this can be understood, predicted, controlled and or remediated needs substantial investigation.

Cumulative impacts of CSG are also a complicated factor that needs further understanding. These include cumulative effects over time, cumulative impacts over a region, and cumulative impacts from competing industries—in particular where the presence of one industry or extractive activity changes the background conditions of the system, such as longwall mining and its impacts on geology.

Key to providing a scientific understanding, as suggested by many submissions to the Review and also in media commentary, has been the development of baseline scientific data on factors such as human health, emissions, and water characteristics.

This is where data becomes critical in addressing some of the issues around CSG.

Along with concern by some in the community at a lack of scientific understanding is a lack of trust in the data, measurements, and calculations undertaken by individuals and organisations with a vested interest in the outcomes, that is, industry and environmentalists. There is a perception that data collected by groups on either side of the debate will only be provided if it supports the argument of the data holder. Further, even when data is available, many people do not either understand or trust it.

There are additional complexities in determining which information to collect and how to manage information from groups with vested interests and biased positions, while establishing a mechanism to give people faith in the data being used to make decisions.

Good, publicly available data may suppress the ‘dust’ that clouds the scientific debate on a variety of likely non-issues.

3.3.6 Land use conflicts

While some farmers and land owners have allowed CSG companies to operate on their land, some primary producers fear CSG development will negatively impact prime agricultural land by depleting aquifers and contaminating groundwater reserves. They also argue CSG infrastructure on their farming land will result in reduced food production.

Further, the apparent competing rights of land owner and petroleum title holder are made even more worrisome to landholders by the rapid expansion of CSG development. As highlighted in Section 2.4.1, the NSW Farmers Association has proposed a more transparent application assessment process with a traffic light approach to approvals and development.

Issues relating to land use and access are further explored in Chapter 4.

3.3.7 Complex and opaque legislation

Governments in Australia have not helped with the management of CSG as an issue.

The Review has heard argument from both sides of the debate that the legislation and regulations around CSG in NSW are complex and opaque. This situation can lead to considerable regulatory burden for those needing to comply and those judging compliance, and can conceivably lead to gaps, overlaps, contradictions, and wasted time in inefficient oversight.

A list of relevant legislation is in Section 1.4.9.

3.3.8 NSW Government actions

The NSW Government has made several policy announcements in the attempt to better regulate the CSG industry.

Following the NSW election in March 2011, the newly-elected O'Farrell Government placed a 60-day stay on granting and renewing any petroleum exploration or production titles as it worked to implement new controls regulating the CSG industry.

A number of policy announcements were made following the release of the Committee report from the Legislative Council's Inquiry into CSG, in May 2012.

The Government announced a moratorium on hydraulic fracturing, which was extended but eventually lifted in September 2012 when new codes of practice for well integrity and hydraulic fracturing were released, as well as other policies including the Aquifer Interference Policy and establishment of the Land and Water Commissioner role.

In September 2012, the NSW Government also released its Strategic Regional Land Use Policy (SRLUP) to better balance growth in the mining and CSG industries with the need to protect agricultural land and water resources. It contained twenty-seven measures to identify, map and protect the state's most valuable agricultural land and critical water resources.

In February 2013, the Government decided to further strengthen what it had previously described as the nation's toughest regulations covering CSG, quarantining residential areas and 'critical industry clusters' such as vineyards and horse studs, within 2 km of CSG development.

At the same time, the Premier tasked the Chief Scientist & Engineer with undertaking an independent review of CSG activities in NSW, and also established the Office of Coal Seam Gas to administer petroleum titles for CSG exploration assessment and production approvals in addition to other regulatory enforcement capabilities.

3.4 COMMENTS FROM THE REVIEW

The NSW Government has recognised the economic benefits of locally produced CSG and has encouraged the growth of the industry, while at the same time attempting to address community concerns through legislative and policy changes.

However, in light of the contributing factors outlined in this chapter and the strong community concerns about CSG, the government has significant work to do in getting the policy settings right and building the trust of the public.

In addition, as this report will discuss, there is further research and investigation required into several aspects of CSG before the mood in NSW is altered.

PART TWO: INVESTIGATING THE ISSUES

The concerns about CSG summarised in Chapter 2 reflect the diversity of issues that surround CSG. Technical background papers commissioned by the Review address these topics and the material in these papers has informed the following chapters. The Review asked experts to examine a range of issues involving policy, potential risks from CSG extraction activities at all stages, including risks to water, air, the environment, and human health. The Review also asked most paper authors to discuss best practice approaches and methods to assess and manage risk and to provide worst-case scenarios, and ways to address them.

4 LAND ACCESS AND PROPERTY ISSUES

A fundamental point of conflict exists in the space where land ownership and use varies in accordance with NSW legislation. Private landholders own the surface of their property. The Crown through the NSW Government owns the minerals and petroleum under the land and thus has the power to authorise companies to explore on public and private properties and extract resources. Companies licensed to undertake this work in respect of CSG are beholden to the Government under the *Petroleum (Onshore) Act 1991* to ensure optimal resource extraction in the interests of maximum benefit to the economy.

The Crown also manages the water underground, and industry seeking to extract water, in most cases, needs to obtain a water access licence from the NSW Office of Water.

A number of issues were repeatedly raised with the Review during the community consultation about property matters and the rights of landholders when it comes to CSG activity on their properties. The tied issues of land access and concerns over property use and value have become trigger points for communities where the CSG industry is active. There is widespread concern about the seemingly invasive and disruptive nature of CSG wells appearing in grid-like fashion across populated and often expensive land. Many in these communities are also worried about the potential impacts of the activity on their land.

Many local government and community representatives and rural landholders have cited examples of unacceptable intrusion on property by CSG companies, as well as the apparent lack of land owner rights in granting land access to the companies.

4.1 LANDHOLDER RIGHTS AND ACCESS AGREEMENTS

For a company to explore on privately owned or public property it must obtain a title and licence (PEL) granted by the Minister for Resources and Energy under the *Petroleum (Onshore) Act 1991*, sometimes also requiring development consent under the *Environmental Planning and Assessment Act 1979*, and must enter into a land access agreement with the landholder.

The property owner ultimately has no legal right to refuse access to their property and must negotiate a land access agreement. If an agreement cannot be reached through direct negotiation, the matter then proceeds to arbitration and the final stage is the Land and Environment Court should the arbitration decision be appealed by the landholder. The Review has been advised by the Office of CSG that to date arbitration has happened infrequently, with companies deciding to explore alternative arrangements such as other land sites or by using different drilling approaches, such as directional drilling.

Evidence submitted to the Legislative Council Inquiry into Coal Seam Gas demonstrates that affected land owners have been given limited guidance on this process and believe they have no bargaining power whatsoever, only being able to delay land access to the company for a period of time. This view was summarised by the NSW Farmers Association, which described arbitration as “farmers negotiating with a gun to their heads” (NSW Legislative Council General Purpose Standing Committee No 5, 2012) and spoke further on the seeming one-sidedness of the land access process in a meeting with the Review team on 13 April 2013.

One of the Inquiry Committee’s 35 recommendations was for the *Petroleum (Onshore) Act 1991* to be revised to strengthen landholder rights. No amendments have been made to the

Act specifically regarding landholder rights since the Inquiry Committee's report was handed down in May 2012. There are however some amendments to the Act currently before the NSW Parliament which include provisions to aid landholders, including the requirement for the company to cover landholder legal fees, a new land access code, strengthened inspection requirements, as well as new environmental assessment permits, with the latter angering sections of the community and farming representatives as it is seen as another means of granting companies access to private land.

During meetings with the Review, a number of landholders raised the issues of coercion by companies of poorly informed land owners to enter into signing land access agreements (with allegations of bullying or bewildering more vulnerable members of the community), lack of information about the process and what the landholder is entitled to, as well as the fact landholders are not legally entitled to legal representation during the arbitration process. This last point was rectified in an announcement by the NSW Premier at the NSW Farmers' Association Conference on 17 July 2013.

As with many issues raised with the Review team however, there seems to be widespread scepticism about government responses to community concerns. It should be noted that the policies announced by the government to address landholder concerns and strengthen CSG regulation, including the Strategic Regional Land Use Policy, community consultation guidelines, Aquifer Interference Policy and Codes of Practice for Well Integrity and for Fracture Stimulation Activities, are fairly recent developments and it is arguable whether they have been tested properly at this stage. Much of the consternation over CSG-related practices and processes does, however, relate to poor policies and communication channels in the recent past and the Review considers much work needs to be done by both government and industry to build trust with the community. Recommendation 1 (see Chapter 15) addresses this issue.

4.2 CONCERNS BY LANDHOLDERS ONCE ACCESS IS GRANTED

CSG exploration licences can be granted for up to 6 years and over an area between 1 and 140 blocks. A block is a 'graticular' section of the Earth's surface where graticular sections are made up of 5 minutes of latitude and 5 minutes of longitude (*Petroleum (Onshore) Act* 1991) .

A licence holder who is granted access to a private property cannot explore on any land within 200 metres of a 'dwelling house' within 50 metres of a garden, vineyard or orchard or over any improvements or valuable work/structure, except with the written consent of the landholder (*Petroleum (Onshore) Act* 1991).

Despite this, there are a whole range of problematic issues which have been identified by property owners including uncertainty over well locations, invasion of privacy, poor safety practices and communication by sub-contractors, e.g. landholders are not regularly advised when activities are happening on their land. Many landholders feel the companies, often sub-contracted by the licence holder, show no professional respect for them and have no motivation to do so.

In addition, there is concern that once an exploration licence is granted it is easily renewed without consultation, or in some cases exploration work is allowed to carry on when a licence has expired. Further, one farmer described how a 'two-dollar' shelf company held the exploration licence which covered the farmer's property despite having no financial security to undertake the activities. Variations on this theme have been raised with the Review in several meetings.

Farmers also expressed concerns about the process the NSW Government has announced for production proposals on agricultural lands, arguing the Gateway Process under the Strategic Regional Land Use Policy seems to allow projects to progress, despite not meeting the criteria, by applying further requirements that need to be addressed only at the development application stage.

4.3 POTENTIAL LOSS OF VALUE OF PROPERTY

Evidence presented in meetings demonstrates there is ill feeling around the fact that neighbouring (in some cases) property owners subject to conventional mining exploration can have the mining industry buy their land for substantial sums of money. In contrast, land affected by CSG is potentially devalued by the activity (and especially by the controversy surrounding the issue) as industry does not require purchase of the land to operate. Compensation for property owners who have CSG wells constructed on their land is significantly lower as it does not require the purchase of property, seems to vary in amount from company to company, and is felt by some to be disproportionate to the level of devaluation of their property. (In some cases, under negotiated land access agreements, it is the neighbour who feels the impact and does not receive any compensation).

This has resulted in some land owners experiencing high amounts of legal, financial and psychological distress. The latter is discussed in Section 11.4 of the report.

As indicated in the Inquiry Committee's report, there is conflicting information about the effects of CSG activity on private property values. The NSW Valuer-General is commissioning a study to investigate whether the CSG industry is having a material impact on land values in NSW. However, there is evidence the resources boom has sustained property prices in many areas. The Queensland Valuer-General's 2013 Property Market Movement Report found that state's property market is generally subdued in most sectors with the exception being in those areas influenced by the resources sector, including the mining, gas, energy and mineral processing industries. However, the Report found rural land sales are generally static except for properties within the Tara district (where CSG activities are taking place), where sales have shown a moderate decrease.

4.4 POTENTIAL IMPACTS ON LAND

As noted in earlier chapters, many property owners are concerned about the potential impacts on their land from CSG activities including impacts on their water sources (groundwater and aquifers), as well as from subsidence, erosion, and cumulative impacts of multiple land uses and impact to land from activities in neighbouring plots.

In the recent past there have been a number of environmental incidents which have suggested poor practices by some companies and have resulted in damage to the environment and subsequent need for remediation. The produced water incident at the Pilliga Forest in 2010 by Eastern Star Gas is one such example, resulting in the recent prosecution of Santos (which took over Eastern Star in 2011) by the NSW Government. The incident is also referred to in Chapter 1.

The Review has commissioned a paper by the legal firm Hicksons to investigate company structuring and insurance arrangements for CSG companies undertaking exploration and production activities. Preliminary findings indicate a potential issue in that the industry may be significantly underinsured with existing insurance practices and arrangements appearing inadequate. Hicksons advises that currently, in general, CSG operators in NSW rely on third party liability policies or are not insured at all.

The Review is commissioning further work to explore options for improving requirements on companies in the interest of minimising risk to government and the taxpayer, and ensuring industry accountability over the long term.

4.5 POLICY TO PROTECT LAND

The NSW Government has made a number of announcements aimed at addressing landholder concerns under its Strategic Regional Land Use Policy including:

- the mapping of strategic agricultural land across the Upper Hunter and New England North West Regions
- the requirement for Agricultural Impact Statements at exploration stage
- the establishment of a Land and Water Commissioner to oversee regulation of exploration activity before it occurs, and oversee land access agreements between landholders and miners
- an Aquifer Interference Policy that codifies assessment and protection of underground water
- the new Gateway assessment by an independent panel of experts to scientifically assess impacts on agricultural land and water before any mining proposal on Strategic Agricultural Land can proceed to a Development Application stage
- Codes of Practice for the Coal Seam Gas industry covering well integrity and hydraulic fracturing
- establishment of the Office of Coal Seam Gas to meet the increased assessment, compliance and community liaison functions required by the new policy package (see www.nsw.gov.au/strategicregionallanduse).

However, as previously discussed, these are new developments which are yet to be properly tested by affected parties. In addition, as at July 2013, the *Mining State Environmental Planning Policy,* which contains the Gateway Assessment Policy, had not been formally executed.

One of the dominant concerns of many farmers and rural landholders relates to their exemption from the Government's 2 km exclusion zone policy announced in February 2013, which prohibits CSG exploration and production activity within 2 km of residential zones and proposed future residential areas, including critical industry clusters such as viticulture and horse breeding properties. The decision has been received by these sections of the community as politically motivated and inequitable to land owners. In addition, as the policy is not retrospectively applied, areas affected by approved exploration activities will continue to be, and this has been met with frustration and anger by communities.

While issues relating to indigenous land were not directly raised with the Review team, it is understood there are mixed views among indigenous communities about CSG. The Review intends to explore this matter further in the next phase of work.

Early investigations into international practice for the setting of exclusion zones or setbacks suggests that there is no common distance applied and that location-specific criteria are developed taking into account such factors as the uses of the land, its geology and water issues, and the nature of the gas and impurities. Further work is being undertaken in the next stages of the Review to understand better the effectiveness of such policies.

4.6 COMMENTS FROM THE REVIEW

In investigating the complex and interconnected issues associated with CSG activities, the Review has identified land as a key issue and one that strikes an emotional chord due to the strong connection people have with their land and its central role in the livelihood of rural communities.

It is very clear that better processes around land access arrangements and information for landholders need to be put in place at every stage of the CSG process. This is the job of government, industry and concerned communities.

The Review believes policies recently announced by the NSW Government should be subject to strict monitoring and evaluation as they are being tested by the community. Recommendation 1 (see Chapter 15) addresses this.

In addition, options need to be explored to ensure companies have adequate financial cover for any impacts their operations have on the surface land of private property owners. This should include ensuring appropriate training and monitoring of sub-contractors working on private land, and establishing a robust insurance arrangement for the industry which would better protect the Government, landholders and the taxpayer.

5 GEOLOGY AND CSG

To provide a context for examining many of the issues surrounding CSG it is important to understand the origins and locations of the methane that is the target of CSG activities.

Geology is arguably the single most important factor in selecting a site to explore for CSG resources, in that the rocks have to be the 'right' rocks. In other words, the geology has to include a methane-bearing coal seam, and that coal seam has to be thick enough to produce sufficient methane at a commercially viable rate and volume.

Geology provides a picture of the Earth's history, plate tectonics, evolution of life (through fossils) and past climates. The study of geology is a commercially important endeavour for the mineral, oil and gas industries to enable exploration and exploitation, and for determining the quality and quantity of groundwater resources. Petroleum geologists study sedimentary basins, their formation and history, because it is in these basins that coal and gas reservoirs tend to be located. Geology is also vital in assessing the impact of exploitation on sedimentary basins and the range of resources in them.

5.1 COAL SEAMS AND GAS

CSG (also known as coal bed methane [CBM] or coal mine methane [CMM]) is a naturally occurring gas, comprising up to 97% methane, which is held in subsurface coal seams, adsorbed to the coal. Coal seams are found in many of the sedimentary basins in Australia (see Section 5.5). Exploitable CSG occurs in seams which are typically located between 300 - 1,000 m below the surface.

Coal is a carbonaceous (carbon-rich) sedimentary rock, composed essentially of preserved and lithified (converted into rock) plant debris. Coal is formed from peat, which was laid in swampy sedimentary environments, in the case of NSW, mostly in the Permian-Triassic eras 298-201 million years ago, and the Jurassic-Cretaceous eras 201-66 million years ago. The peat is modified in both texture and composition eventually to form coal, by long term exposure to elevated temperatures and pressures as it and the associated strata (layers of sedimentary rock) are buried, often to great depths, over long periods of geological time.

Methane in coal can be generated by two mechanisms:

- **thermogenic processes**, where gas is released as part of the chemical changes in the organic matter (macerals) associated with rank advance (maturation, the rank of the coal is an indication of the extent to which the organic matter has been modified during its burial history). Organic matter is made largely of long-chain carbon molecules, but with heat, pressure and time, these chains break down to form methane (CH_4) molecules.
- **biogenic processes,** where methane is produced by the interaction of micro-organisms in the pore water of the coal with some of the organic components. Here it is the action of bacteria introduced in the groundwater that breaks down the long chain carbon molecules in the coal to form CH_4.

Section 5.3 contains further discussion on methane formation and the investigation of their origins.

The structure of coal in the seam can be thought of as a coal matrix divided into 'blocks' by a system of orthogonal fractures (cleats) (see Figure 5.1). Methane is adsorbed inside the cleats and on the surface of the micro-pores within the coal matrix, which has a large internal surface area. The methane represents approximately 5-9% of the total volume in the coal seam (Close, 1993; Pineda & Sheng, 2013), and is present at a near-liquid state depending on the pressure. Methane adsorption is maintained by pressure, e.g. hydrostatic water pressure. If the pressure is decreased enough, the methane is able to 'de-sorb' from the coal and become mobile.

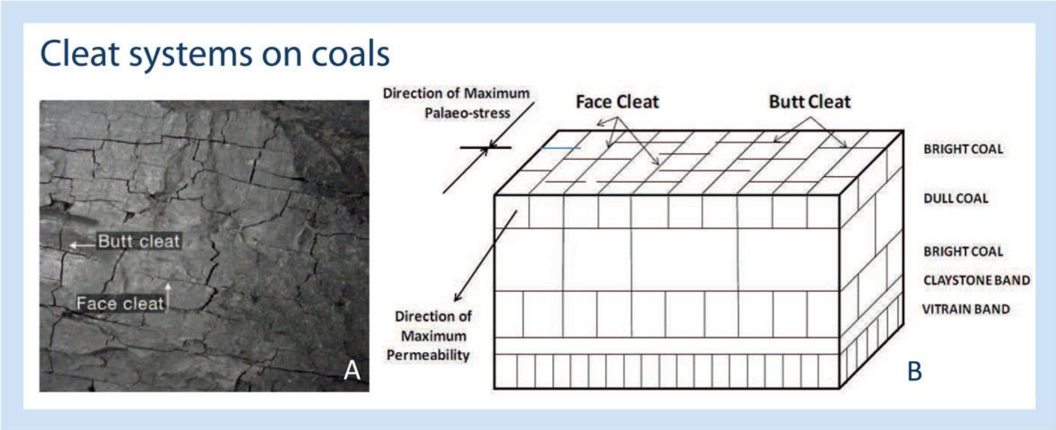


Figure 5.1: Cleat systems on coals A) http://www.undergroundcoal.com.au/outburst/fracturing.aspx; B) Schematic diagram showing cleats (face and butt) in a coal seam (Ward & Kelly, 2013)

As previously mentioned, gases such as methane adsorbed on to coals in the subsurface are kept in place by the confining pressure of the groundwater within and surrounding the coal seam. A sufficient reduction in water pressure, whether natural or artificially induced, will allow the gas to desorb (Figure 5.2), and if there is a flow pathway, it can move towards a well, mine face or outcrop, depending on the geological structures involved (Ward & Kelly, 2013). The outcrops of some coal seams are visible at cliff faces, for example in the Illawarra.

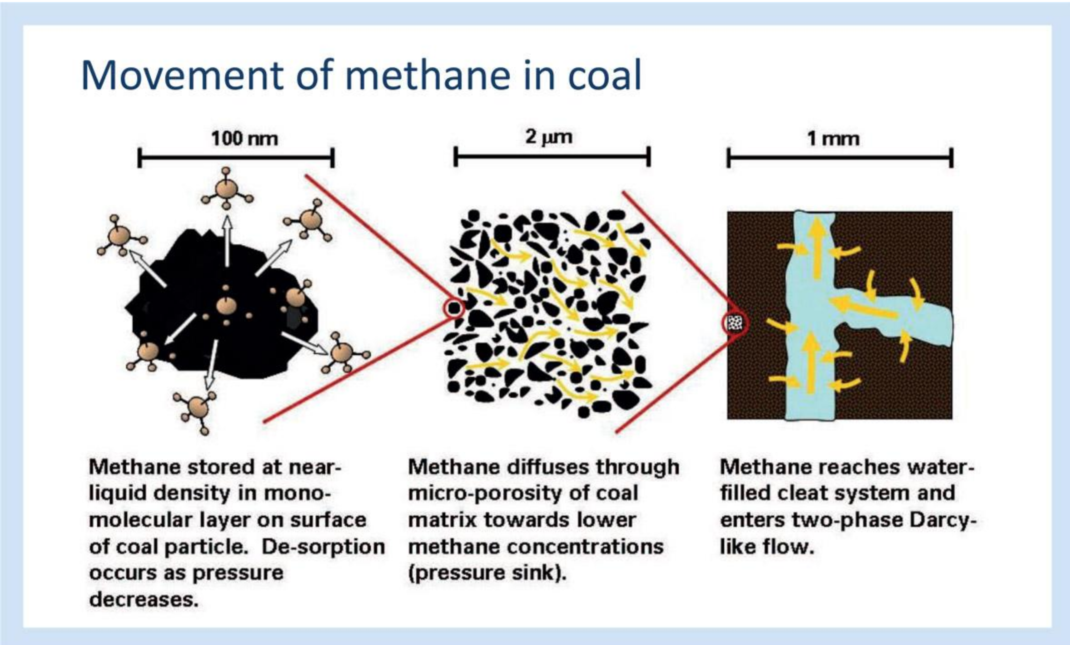


Figure 5.2: Movement of methane in coal (Loftin, 2009 as cited in Pineda & Sheng, 2013)

The potential release of methane from the coal is analysed using the Langmuir isotherm which is unique for each coal formation. The Langmuir isotherm describes the gas storage capacity as a function of the pore fluid pressure. In other words, it represents the maximum storage capacity of a coal in a formation at a given pressure (Pineda & Sheng, 2013).

Individual seams of coal may display a wide range of features, derived from the depositional environment of the original peat and the post depositional history of the sedimentary basin. These features include: splits on the coal seam, washout structures (where coal is replaced by other sedimentary rock), faults (fractures that may cause displacement), igneous intrusions (magma intrusions) and cleats and joint patterns within the coal seam (natural fractures within the coal seam) (Figure 5.3).

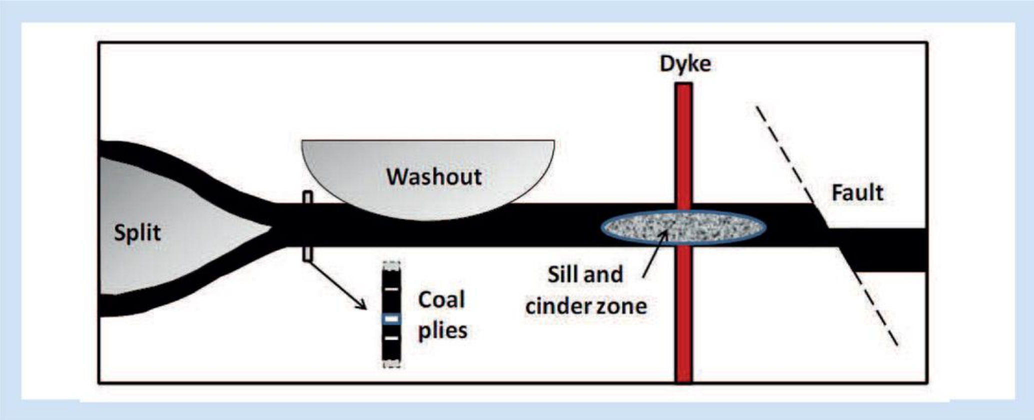


Figure 5.3: Schematic cross section illustrating a split, washout, individual plies, in igneous intrusion (duke, sill and cinder zone) and a fault in a coal seam (Ward & Kelly, 2013)

The economic viability of CSG deposits depends on the capacity for recovery of the gas at acceptable rates and volumes, with acceptable environmental impacts. The rate of gas recovery in turn depends on the permeability of the coal seam and the prevailing subsurface confining pressure (or stress) conditions.

Coal is described using a range of terms that cover its physical and chemical nature, such as:

- **rank** – or stage of coal maturation (e.g. peat → brown coal → black coal)
- **density** – depends on the proportion of admixed mineral material and moisture held within the fracture network
- **reflectance** – can be used as an indicator of coal rank: the reflectance of vitrinite (particles of well-preserved plant tissue) macerals in polished sections of coal increases with the rank of the coal
- **saturation** – amount of a particular gas that the coal can hold
- **permeability –** a measure of the ability of the coal allowing fluids to pass through it. Permeability generally decreases with depth. Hydraulic fracturing is used to increase permeability in some coals.
- **porosity** - the ratio of pore volume to its total volume: controlled by factors such as rock type, grain size, and pore distribution etc.

5.2 RESOURCE ASSESSMENT

There are three levels of economic certainty (commerciality) used to describe gas and other petroleum resources, based on a classification developed by the Society of Petroleum Engineers (http://www.spe.org/index.php). From least to most certain these are: prospective resources, contingent resources and reserves (Figure 5.4). Different levels of data are required for material reported in each category.

Three different levels, based on geological certainty (proved, probable and possible), are used within the reserves category (Ward & Kelly, 2013):

- **proved reserves (1P)** are those quantities which, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under defined economic conditions, operating methods, and government regulations

- **probable reserves** are those additional reserves which analysis of geosciences and engineering data indicate are less likely to be recovered than the proved reserves but more certain to be recovered than possible reserves. It is equally likely that actual remaining quantities recovered will be greater than or less than the sum of the estimated **proved plus probable reserves (2P)**.
- **possible reserves** are those additional reserves which analysis of geoscience and engineering data suggest are less likely to be recoverable than probable reserves. The total quantities ultimately recovered from the project have a low probability to exceed the sum of **proved plus probable plus possible reserves (3P)**, which is equivalent to the high estimate scenario.

There are also **contingent resources** that are estimates of quantities to potentially be recoverable from known accumulations, but where the projects may not be mature enough for development.

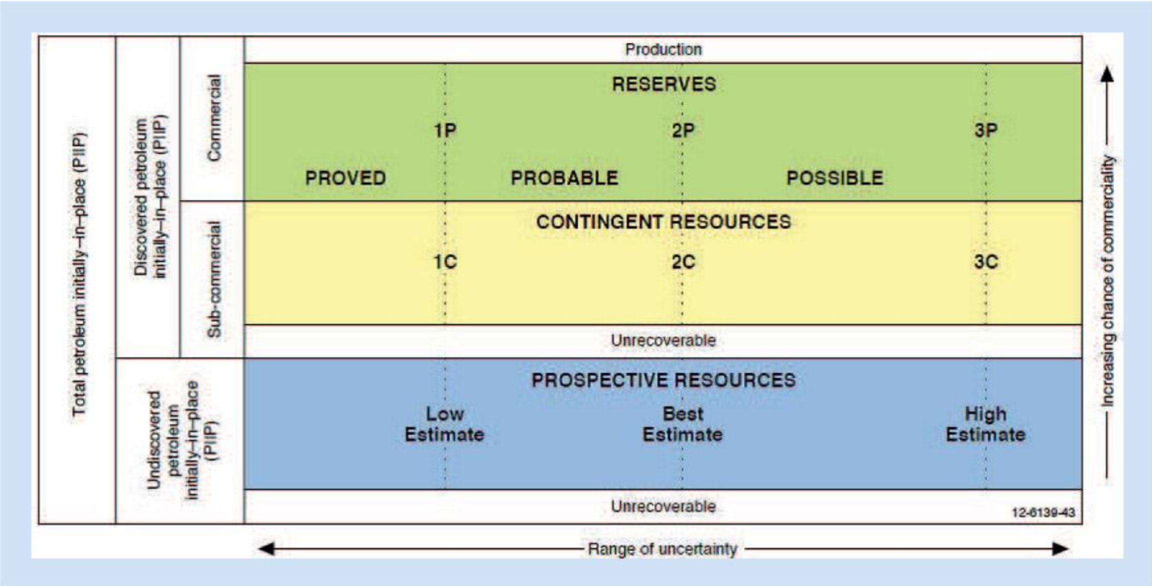


Figure 5.4: Resource classification framework based on the Petroleum Resources Management System of the Society Petroleum Engineers Source: (Geoscience Australia & BREE, 2012)

5.3 METHANE ORIGINS AND IDENTIFICATION

As mentioned in section 5.1, methane in coal can be generated through thermogenic or biogenic processes. However, methane is also formed in environments other than the coal seam.

Biogenic methane may be formed in environments such as in the digestive system of animals (including humans), garbage dumps, land fill and also by microorganisms breaking down organic matter in aquifers, and in accumulations of organic matter (peat) in modern-day swampy environments. The methane from these and other sources can escape the ground surface, and may be detected or observed variously as swamp gas, or as bubbling in lakes and stream beds as part of the natural set of near-surface geological processes, or as cattle emissions.

The gases produced by these thermogenic and biogenic processes may be distinguished from each other by the ratios of the particular carbon and hydrogen isotopes. For example, Carbon typically exists as Carbon-13 (^{13}C) or Carbon-12 (^{12}C), depending on the number of neutrons in the atom. The isotopic ratio of Carbon $\delta^{13}C$ ($^{13}C/^{12}C$), will be characteristic of the process used to deposit the carbon molecules, and allows identification of the source of the chemical.

It appears that thermogenic processes for methane production favour heavier ^{13}C atoms (Kresse et al., 2012), while biogenic methane is produced in anaerobic conditions by bacteria, a process which favours lighter ^{12}C so the sample will be enriched in ^{12}C and depleted in ^{13}C. Typically biogenic methane $\delta^{13}C$ values are less than -55‰ (‰ = per mill - one part per thousand); thermogenic methane $\delta^{13}C$ values typically are higher than -55‰ (Schoell, 1980; Rice & Claypool, 1981; Grossman et al, 1989; Aravena & Wassenaar, 1993; Whiticar, 1999 as cited in Kresse et al., 2012).

Similarly, water from different sources can also be aged using isotopic ratios of hydrogen and uranium, so that groundwater and surface water can be characterised, which is of relevance to environmental testing and monitoring activities.

5.4 CONVENTIONAL AND UNCONVENTIONAL GASES

Natural gas occurs in various geological environments that provide the basis for classifying the gas as 'conventional' (gas produced from porous and permeable rock such as sandstones) or 'unconventional' (shale gas from deep brittle shales; tight gas produced from low permeability sands; and CSG from coal seams). The geological setting for these types of gases is illustrated in Figure 5.5. Table 5.1 compares the different features, settings and extraction requirements of conventional and unconventional gas resources.

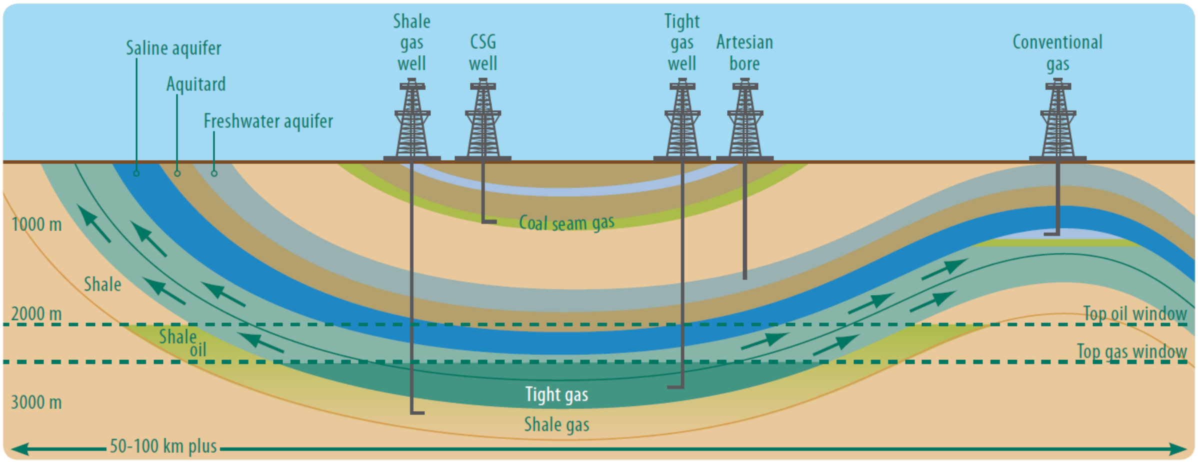


Figure 5.5: Examples of geological settings for conventional and unconventional gas
Sources: (Cook et al., 2013; US Energy Information Administration, 2010)

Table 5.1: Key differences between CSG, shale gas, tight gas and conventional gas
Source for CSG, shale and tight gas: modified from (Day, Connell, Etheridge, Norgate, & Sherwood, 2012).
Source for conventional gas: modified from (Hutton, 2009; RobSearch Australia, 2010; Scott et al., 2007; USQ, 2011 as cited in Sydney Catchment Authority, 2012a)

	Coal seam gas	Shale gas	Tight gas	Conventional gas
Source rock (Organic material origin)	Coal (Peat)	Low permeability fine grained sedimentary rocks (Silt mudstones & shale mudstones) (Algae, plant, and animal derived organic debris deposited as muds in estuaries and in deep basins)	Various source rocks have generated gas that has migrated into low permeability sandstone and limestone reservoirs	Porous and permeable reservoir rocks, such as sandstones (Algae, plant, and animal derived organic debris deposited as muds in estuaries and in deep basins)
Depth	300-1000 m	1000-2000+ m	> 1000 m	1000 – 6000 m
Gas occurrence	Adsorbed on coal organic matter including pores of coal	Stored within pores and fractures but may also be adsorbed on organic matter	Within pores and fractures	In geological structures or traps (e.g. anticlines)
Gas composition	Usually > 95% methane. Small amounts of CO_2 and other gases may be present	Mostly methane but may also contain significant higher quantities of higher hydrocarbons (condensate)	Mostly methane	70-90% methane 0-20% ethane, propane, butane Trace pentane 0-8% carbon dioxide 0-5% nitrogen 0-5% hydrogen sulphide
Extraction technology	Vertical or directional wells; hydraulic fracturing is sometimes required	Hydraulic fracturing and horizontal wells are usually necessary	Large hydraulic fracturing treatments and/or horizontal drilling are required	Vertical wells; natural pressure drives gas to the surface
Water usage	Water must be pumped from seams to reduce reservoir pressure and allow gas to flow. If hydraulic fracturing is necessary, water is required for the fracturing process.	Water is required for hydraulic fracturing	Water is required for hydraulic fracturing	Little or no water produced initially but water production rates increase with time
Extraction challenges	Removal of seam water and its subsequent disposal	Overcoming low permeability Minimising the amount of water required for hydraulic fracturing Reducing infrastructure footprint	Reducing infrastructure footprint	Often located offshore

5.5 SEDIMENTARY BASINS

Sedimentary basins are large, long-lived depressions in the Earth's crust formed by local geological subsidence, subsequently filled with sediments sourced from surrounding uplands. Over 60% of NSW is covered by sedimentary basins. Sedimentary basins have formed throughout geological time.

Depending on the setting at the time of formation, the nature of the sub-basin crust beneath, and the post-sedimentation history, these basins can host a variety of geological resources or products including (Rawling & Sandiford, 2013):

- groundwater, which supports agricultural, commercial and human water supplies
- fossil fuel resources, e.g. oil, gas and coal
- mineral resources, e.g. iron ore, uranium, base metals and mineral sands
- industrial material, e.g. construction aggregates, limestone and building stone
- waste fluid storage, such as contaminated surface waters
- temporary storage of natural gas.

They are also being investigated for:

- carbon storage, or storage of CO_2 waste from energy production
- novel energy storage options, e.g. subsurface compressed air storage
- geothermal energy, which is thermal energy recovery from natural geothermal heat, for electricity generation and direct heat applications
- geothermal energy from underground fires (e.g. coal seams).

Sedimentary basins provide a key role in sustaining natural surface water flows through basin groundwater systems. This is especially important in regions subject to drought, as maintained flows are crucial to the health of riverine and associated wetland ecosystems.

The general geological setting of a basin is an important exploration consideration in any sedimentary basin. One of the first prerequisites is that the geological history of the rocks is favourable for methane generation and trapping. For example, the geometry of the coal deposits is directly influenced by the nature of the original sedimentary environment – this influences the way in which an exploration program is undertaken. Hydrogeological and geomechanical properties of the coal (e.g. porosity, permeability, tensile strength etc.), as well as the local stress conditions for the seam and surrounding formations, can be determined through exploration boreholes in combination with ground based geophysical surveys. This information is required to properly predict the response of a coal seam to hydraulic fracturing for example (Cook, 2013).

5.5.1 NSW sedimentary basins

From the perspective of coal and CSG resources the most important of these basins in NSW are (Figure 5.6):

- the Sydney-Gunnedah-Bowen Basin System (Permian to Triassic)
- the Gloucester Basin (Permian)
- the Clarence-Moreton Basin (Triassic to Cretaceous).

The location of the basins and estimated CSG reserves on the east coast of Australia are shown in Figure 5.7.

Other basins that contain coal and CSG resources include the Oaklands (low rank Permian), Surat and Eromanga (Jurassic to Cretaceous) basins. A small wedge-shaped body of coal bearing strata also occurs as Ashford, within the New England Fold Belt (Ward & Kelly, 2013).

Many of these basins also have major coal mining activities, with 61 coal mines (open and longwall) in NSW in 2010/11.

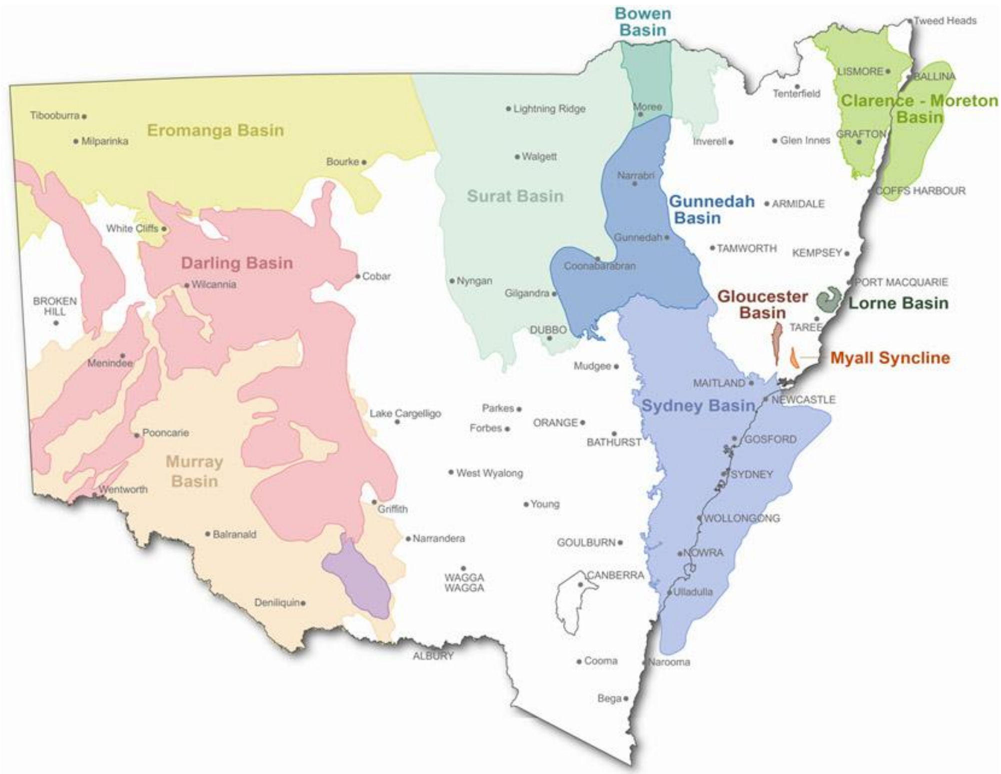


Figure 5.6: NSW Sedimentary Basins (NSW Division of Resources and Energy, 2013)

5.5.1.1 The Sydney-Gunnedah-Bowen Basin

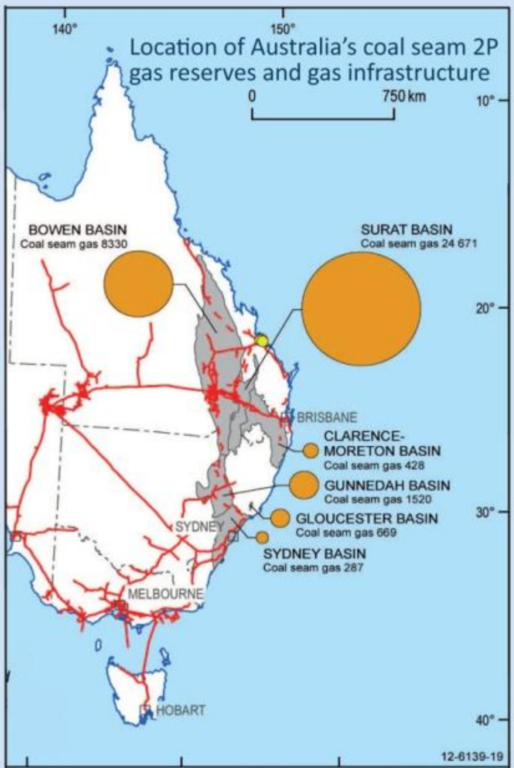
The Sydney-Gunnedah-Bowen Basin is a major north-south Permian to Triassic structural basin, extending over 1,700km from near Batemans Bay on the NSW south coast to near Collinsville in Northern Queensland. It covers an area of over 260,000 km^2. The Sydney, Gunnedah and Bowen Basins are discussed separately in this section.

5.5.1.1.1 Sydney Basin

The Sydney Basin extends for approximately 350 km (north–south) and an average of 60 km wide (Ward & Kelly, 2013) and covers an area of approximately 37,000 km^2 onshore and 15,000 km^2 offshore (Bambrick & Lonergan, 1976 and Alder et al, 1998 as cited in O'Neill & Danis, 2013). The stratigraphic sequence varies from region to region. Coal bearing formations in Permian aged sediments are extensive in the Sydney Basin and range in depth from near surface to over 1 km. Coal thickness is greatest in the northern part of the Sydney Basin (Hunter and Newcastle coalfields) and decreases towards the south and west.

The **Southern Coalfield** is regarded as the most prospective for CSG in the Sydney Basin (Scott & Hamilton, 2006, 2009 as cited in Ward & Kelly, 2013). The coal thickness is mostly in the range of 10-25 m (Ward & Kelly, 2013). The coal rank has reached the main stage for thermogenic gas generation, and there is the potential for biogenic generation. Current reserves, including the proposed northern expansion project of AGL at Camden, are estimated at 148 PJ 2P and 195 PJ 3P (AGL, 2013b as cited in Ward & Kelly, 2013).

Coal mine methane has been extracted in this area for many decades; it is extracted from the coal mines to reduce the risk of outburst and explosions during mining operations. Much of this gas is now used for power production at the mine sites (Ward & Kelly, 2013). CSG has been extracted since 2001 from the AGL Camden Gas Project which currently has 95 producing gas wells, a project developed under Petroleum Exploration Licence (PEL) 2, and Petroleum Production Leases (PPLs) 1, 2, 4, 5, and 6.



BASIN	PRODUCED CSG (in PJ)	REMAINING CSG (in PJ)
Bowen (Qld)	693	8330
Clarence-Moreton (NSW, Qld)	0	428
Gloucester (NSW)	0	669
Gunnedah (NSW	0	1520
Surat (Qld)	309	24671
Sydney (NSW)	30	287

Figure 5.7: Location of Australia's east coast coal seam 2P gas reserves and gas infrastructure Modified from (Geoscience Australia & BREE, 2012)

Areas in the **Hunter** and **Newcastle Coalfields**, and also the extreme north of the **Western Coalfield** have been identified as being prospective for CSG development. Coal thickness is up to a total of 80 m, with more than 20 separate seams being recognised on some areas (Ward & Kelly, 2013).

The principal CSG exploration activity in the Hunter Coalfield is the AGL Hunter Gas Project, which is currently focused on an area to the south of Singleton (PEL 267). An initial reserve estimate (October 2010) indicates a total of 142 PJ 2P and 271 PJ 3P (DTIRIS, 2012 as cited in Ward & Kelly, 2013). Other activities have included exploration by Santos and Dart Energy in the area between Murrurundi and Gulgong. Dart Energy has also been exploring the Tomago Coal Measures in the Fullerton Cove area, although the company has recently announced suspension of their activities in NSW (Dart Energy, 2013).

5.5.1.1.2 Gunnedah Basin

The Gunnedah Basin is a structural trough in northeast NSW. The basin appears continuous with the Bowen Basin in the north and the Sydney Basin in the south. The Great Artesian Basin overlies the Gunnedah Basin. Several areas of the Gunnedah Basin have been indicated as having potential for CSG resources. Discoveries of gas have been made in the Permian Porcupine Formation and Black Jack Group and Triassic upper Digby Formation.

Significant exploration has been carried out for the Narrabri Coal Seam Gas Project by Santos and previously Eastern Star Gas (PEL 238) in the Bohena Trough west of Narrabri (targets being the Early Permian Maules Creek Formation and the Late Permian Black Jack Group) (Budd & Edgar, 2008 as cited in Ward & Kelly, 2013), including core drilling and seismic surveys, borehole completion testing and pilot gas production. Initial 2P reserves of 185 PJ and 3P reserves of 1300 PJ were reported by the previous licence holder, Eastern Star Gas (Eastern Star Gas, 2010 as cited in Ward & Kelly, 2013). Santos acquired Eastern Star Gas in 2011. Santos also has other exploration areas in the basin under PEL 450, 452, 462, 433, and 434 (as well as PAL 2 and PPL 3).

5.5.1.1.3 Bowen Basin

The Bowen Basin is an elongate, north-south trending, asymmetrical basin extending from northern NSW through central Queensland covering an area of about 200,000 km^2. Only a fraction of the Bowen Basin is present in NSW. No significant finds have been made in the NSW portion of the Bowen basin to date (O'Neill & Danis, 2013). The GAB overlies the Bowen Basin.

5.5.1.2 The Gloucester Basin

The Gloucester Basin is a north-south trending trough about 38 km long and 9.5 km wide filled with coal bearing strata of Early to Late Permian age. The basin is heavily faulted (especially the South East portion) with a complex series of normal and reverse faults (O'Neill & Danis, 2013; Ward & Kelly, 2013). The continuity of coal seams at depth and laterally is poor. This deep faulting has the potential to interconnect deeper coal seam aquifers with near surface fractured rocks aquifers. “The extensive faulting, displacement of strata across faults, folded and discontinuous lithologies and lack of any fault seal analysis” (Ward & Kelly, 2013) makes understanding the hydrogeology in this area incredibly difficult.

The best known CSG resources in the Gloucester Basin occur in the Gloucester Coal Measures. Most exploration to date has been focussed on a small area East of Stratford, where up to 11 major seams (<2.5 m thick) and numerous minor seams occur, with an average total coal thickness of 30-60 m (Bilston, 2008 as cited in Ward & Kelly, 2013).

The Gloucester Basin is an active CSG prospect, with AGL Upstream Investments Pty Ltd actively exploring (PEL 285), and lodging a PPL application in late 2012. The company has received State planning approval under the *State Environment and Planning Act 1979* for the project’s overall concept plan and Stage 1, and Commonwealth approval, with 36 conditions, under the *Environment Protection and Biodiversity Conservation Act 1999*. In the basin CSG target seams are generally >200m below the depth of shallow fractured rock aquifers (O'Neill & Danis, 2013). Current 2P reserves of 669 PJ and 3P of 832 PJ for the Basin (NSW Trade & Investment, 2012 as cited in Ward & Kelly, 2013).

Active open cut coal mining is occurring at both Duralie and Stratford, with the Stratford mine currently looking at expanding their activities in the basin.

Overall the Gloucester Basin is a small Permian basin, for which detailed understanding of its relatively complex geology is lacking. The region is currently the focus of considerable interest for two coal mining consortia and CSG extraction by AGL, all on the eastern side of the Gloucester Valley, and toward the north which is located close to communities. Although the aquifers in the valley are not a major source of water for the residents and farmers given the quality of the groundwater and the considerable surface water resources, residents remain concerned about the groundwater impacts due to the down-stream reliance of other communities on the surface water and groundwater.

5.5.1.3 The Clarence-Moreton Basin

The Clarence-Moreton Basin is an elliptical shaped intracratonic basin in northeast NSW extending into Queensland. The NSW portion covers 16,000 km^2 and contains mainly fluvial Triassic, Jurassic and possibly Cretaceous sedimentary strata (Stewart & Alder, 1995 as cited in Ward & Kelly, 2013). These include 3 important coal bearing intervals, one being the Walloon Coal Measures which have the greatest significance for CSG development. These coal measures, in particular their extensions into the Surat Basin in Queensland, are extensively used for CSG extraction, supplying some 60% of Queensland gas (Queensland Government, February 2013) .

Extensive exploration for CSG has been carried out in the Walloon Coal Measures near Casino (PEL 13 and 16). Metgasco has identified 11 seams near Casino with a net coal thickness of between 2 and 9 m. The seams generally have high gas contents (~98% saturation with methane); gas composition analysis indicates approximately 98% or more methane and a negligible CO_2 content (Metgasco, 2013 as cited in Ward & Kelly, 2013). Metgasco indicates that the seams in the area of PEL 16 have high gas content and tend to be oversaturated with gas. Metgasco has reported that the region covered by PEL 16 has methane reserves of 2P 397 PJ and 3P of 2,239 PJ, while the region covered by PEL 13 has

2P reserves of 428 PJ and 3P are indicated at 2,542 PJ. Metgasco indicates an additional contingent 2C resource of 2,511 PJ (Metgasco, 2013).

5.5.2 Queensland sedimentary basins

The Bowen Basin and Surat Basins provide more than 79% of the total gas produced in Queensland (Sydney Catchment Authority, 2012a).

5.5.2.1 Bowen Basin

In the Queensland areas of the Permian Bowen Basin, such as the region around Fairview, high coal permeabilities have resulted in significant production of CSG. There are well defined CSG ‘fairways’ in the Queensland Bowen Basin extending from the Fairview area into Scotia, Moranbah and Moura and it is from these areas that a major part of CSG production is or will be delivered to the LNG export projects being developed on the coast in Gladstone. The production of CSG from the Bowen Basin is complicated by the fact that much of the basin is overlain by the Surat Basin, which not only contains CSG producing coals but also major aquifers.

5.5.2.2 Surat Basin

The Surat Basin is a Jurassic-Cretaceous north-south elongate system that overlies the Gunnedah Basin and the Bowen Basin. It covers an area of about 270,000 km^2. No commercial oil or gas discoveries have been made in the NSW part of the Surat Basin. The Surat in NSW has not been considered a CSG exploration target due to its low coal rank which reduces the methane content of the coal reservoirs.

From 2000 onwards in Queensland, the Surat became the focus for CSG companies as it was realised that the basin was similar to the Powder River Basin in the US which was producing commercial quantities of CSG (Queensland Government, February 2013).

Commercial production of CSG from the Walloon Coal Measures began in January 2006. CSG produced commercially is typically obtained from seams 300-600 m deep (Queensland Government, February 2013).The coals in the Surat Basin are less thermally mature with generally lower gas contents, but generally have high permeability. The Surat Basin is now the major source of CSG in Queensland. Certified 2P reserves have been estimated at 26,897 PJ (2012) (Queensland Government, February 2013).

5.5.3 Comparison of NSW and Queensland sedimentary basins

There are a number of important differences between NSW and Queensland coals; these differences have much to do with the geology of the coal bearing sedimentary basins (Cook, 2013a). Essentially most of CSG exploration and production in NSW is from rocks of Permian age, whereas in Queensland production is from both Permian and Jurassic-Cretaceous Basins. This coupled with the proximity of related seams and aquifers has a major influence on many aspects of CSG production in the two states, particularly the large amounts of water produced by CSG operations in Queensland compared to the quite small amounts produced by NSW operations .

Permian basins are more likely to require hydraulic fracturing than Jurassic Basins due to the differences in permeability (Jurassic being more permeable). This means that basins such as the Sydney (NSW), Gunnedah (NSW), Bowen (NSW/Qld) and Gloucester (NSW) are more likely to require hydraulic fracturing in comparison to the Surat (NSW/Qld) and Clarence-Moreton (NSW/Qld) (Cook, 2013b). Table 5.2 compares the major CSG producing basins in NSW and Qld.

Table 5.2: Comparison of a NSW and Qld basin: The Illawarra Coal Measures (Sydney Basin) with the Walloon Coal Measures (Surat Basin) (Hutton, 2009; RobSearch Australia, 2010; Scott et al., 2007; USQ, 2011 as cited in Sydney Catchment Authority, 2012a)

	NSW Illawarra Coal Measures Sydney Basin	**Qld Walloon Coal Measures Surat Basin**
Depth	400-800 m	300-400 m
Geological age	Permian (older)	Jurassic (younger)
Coal type	Bituminous	Sub-bituminous – bituminous
Coal measure thickness	Maximum 520 m in the northern part of Southern Coalfield	~ 300 m
Net coal thickness	Cumulative thickness in excess of 20 m; individual coal seams 2-5 m thick	Cumulative thickness up to 10 m
Gas content	6-12 m^3/t (Bulli Seam); in Appin and West Cliff mining area 12-14m^3/t	2-10 m^3/t; average 5.33 m^3/t
Coal permeability	Low permeability (1-10 millidarcy)	High permeability (up to 500 millidarcy), considered as aquifer
Seams	Thick and laterally extended continuous coal seams	Discontinuous lenses of coal seams
Productive aquifers	Coal seams overlain by low permeability rocks; lack of productive aquifers (except Alluvial and Hawkesbury Sandstone)	Several beneficial aquifers present above and below coal seams (Alluvial, Mooga, Bungil, Gubberamunda Sandstone, Hutton and Precipice Sandstone)
Produced water quantity (average)	~ 0.05 ML/year/well	~25 ML/year/well
Water to energy ratio	<0.8	~100

5.6 GEOLOGICAL MODELLING

Geological modelling involves the development of computerised representations of sections of the Earth's crust based on geophysical and geological observations. Software developers have built several packages for geologic modelling purposes. Such software can display, edit, digitise and automatically calculate the parameters required by engineers, geologists and surveyors (Ward & Kelly, 2013). Current software is mainly developed and commercialised by oil and gas or mining industry software vendors.

For most major mine, oil and gas projects a 3D geological model is built to represent the conceptual understanding of the geological structure (strata tops and fault surfaces) and the distribution of changes in physical properties (porosity, permeability, water quality, etc.). 3D geological models are built by integrating information from geophysical surveys (e.g. seismic, electrical, gravity and magnetics), geological maps, borehole lithological logs and borehole geophysical logs.

Geological structural and property models can be useful for highlighting data gaps and where new exploration wells should be targeted.

New directions for geological modelling include data fusion and machine learning techniques that use a data-driven approach and provide for improvement and refinement of the system as more data becomes available, and an understanding of the uncertainties and confidence levels of the information (Ward & Kelly, 2013).

When added to digital reservoir modelling techniques and advanced software, a sophisticated underground model can be developed to predict the behaviour of coal seams and the surrounding sediment, including the potential impact on groundwater. With the additional inclusion of geomechanical, geochemical and permeability data, the stress fields and the gas volume can be predicted with an increased level of accuracy.

If the exploration program indicates the potential for economical and technically viable extraction of CSG, a full assessment of all or the most promising areas may be undertaken. This will enable the project to move from having speculative values of the amount of CSG in the coal seam that was explored, to a more meaningful figure of how much can be extracted. The level of understanding of the resource or reserve is described in Section 5.2 (Resource Assessment) of the report.

5.7 COMMENTS FROM THE REVIEW

The general geological structure and tectonic history of the basins in NSW is relatively well understood at the large basin-wide scale. Fine-scale features such as the locations of faults and dykes, as well as mechanical, physical and chemical characteristics of the rocks, are less well understood. The groundwater characteristics are also not well understood. It is the development of this fine-scale knowledge that is the focus of prospecting and exploration stages of CSG projects through drilling programs, core sampling, *in situ* hydraulic conductivity measurements, geophysical mapping etc.

Efforts to improve our overall understanding of the geology (and groundwater) system through improved monitoring, measurement, modelling and data analytics, and broader access for companies, regulators and researchers to this data through repositories, will make a considerable difference to our understanding of the geological system and potential impacts (including cumulative impacts) from CSG and other developments. These factors are also critical in the design infrastructure associated with CSG (drilling technologies, holding ponds, etc.).

Although Queensland has the majority of CSG resources, NSW's CSG resources are still considerable and the estimates of these resources are still being determined.

There are major differences between the various basins in NSW and between those and basins in Queensland. These differences, and differences within a particular basin, will influence well locations, and energy and water production levels.

5.8 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- "The geology of NSW- The geological characteristics and history of NSW with a focus on coal seam gas (CSG) resources", Professor Craig O'Neill and Dr Cara Danis of Access Macquarie at Macquarie University
- "Background Paper on New South Wales Geology: With a focus on basins containing coal seam gas resources", Professor Colin Ward and Professor Bryce Kelly of UNSW Global Pty Ltd
- "Subsidence: An overview of causes, risks and future developments for coal seam gas production", Dr Jubert Pineda and Professor Daichao Sheng, ARC Centre of Excellence for Geotechnical Science and Engineering, The University of Newcastle,
- "Life cycle of Coal Seam Gas Projects: Technologies and Potential Impacts", Professor Peter J Cook CBE, FTSE,

6 UNCONVENTIONAL GAS EXTRACTION PROCESSES AND TECHNOLOGIES

This chapter outlines CSG extraction stages and processes, as well as the research and development breakthroughs made over time that have helped make the extraction of CSG and other unconventional gases (shale and tight gas) a commercial reality.

6.1 CSG EXTRACTION STAGES

Companies that want to explore, assess or produce CSG need to apply for a title under the *Petroleum (Onshore) Act* 1991. The licences are applied for through the Division of Resources and Energy, within DTIRIS. The titles include: Petroleum Special Prospecting Authorities (PSPA), Petroleum Exploration Licences (PEL), Petroleum Assessment Leases (PAL) and Petroleum Production Leases (PPL). The features of these different titles are in Table 6.1.

Other licences and approvals are required from different State and Commonwealth Government Agencies, depending on the size of the proposal, at either the exploration, assessment or production phase. For example: water licences through the NSW Office of Water, an Environmental Protection Licence (EPL) through the NSW Environmental Protection Authority; planning approval/development consent through the NSW Department of Planning and Infrastructure; approvals for matters of national environmental significance through the Commonwealth Department of Sustainability, Environment, Water Population and Communities.

This section of the report provides a general overview of the exploration, assessment, production and abandonment process in CSG production, as well as discussing best practice.

Table 6.1: Licences granted by NSW Minister for Resources & Energy through the NSW Division of Resources & Energy (DTIRIS) for CSG activities under the NSW *Petroleum (Onshore) Act 1991.*

Name	Rights/Classes	Requirements	Duration/ Renewal	Notes
Petroleum Special Prospecting Authority (PSPA)	• Provides the titleholder the exclusive right to conduct speculative surveys or low-impact scientific investigations • Classes include standard PSPA and low-impact PSPA	• Applicants must submit a proposed exploration program • Qualified technical personnel must undertake exploration • Applicants must demonstrate ample financial resources • Advertising and public comment must be undertaken • An access agreement must be obtained prior to any activities with certain restrictions • Landholders are entitled to compensation for 'compensable loss'	• Maximum duration of 12 months • Generally not extended or renewed	• Low-impact PSPA is excluded from 'right to negotiate' under Commonwealth Native Title Act 1993; limits range of allowable activities • Standard PSPA allows exploration on non-Native Title land; exploration on Native Title land would require Minister's consent and 'right to negotiate' process • Environmental assessment and approvals also required under the *Environmental Planning and Assessment Act 1979*
Petroleum Exploration Licence (PEL)	• Provides the titleholder the exclusive right to explore for petroleum within an exploration licence area • Classes include Low-Impact; Standard Licence – Native Title option 1 – Minister's consent; and Standard Licence – Native Title option 2 – 'right to negotiate'	• Applicants must submit a proposed exploration program and expenditure over first two years • Qualified technical personnel must undertake CSG activities • Applicants must demonstrate ample financial resources • Advertising and public comment must be undertaken • An access agreement must be obtained prior to any activities with certain restrictions • Landholders are entitled to compensation for 'compensable loss'	• Periods up to 6 years • Renewals granted in periods up to 6 years (area of renewal generally not to exceed 75% original area)	• PELs are granted in graticular blocks (5 minutes latitude by 5 minutes longitude, approx. 75 km^2); minimum 1 block and maximum 140 blocks; exclusions apply for specified public lands & water supplies • Low-impact limits range of exploration activities; excluded from 'right to negotiate' under CNTA • Standard Class 1 allows exploration on non-Native Title land; exploration on Native Title land requires Minister's consent and 'right to negotiate' process • Environmental assessment and approvals also required under the *Environmental Planning and Assessment Act 1979*
Petroleum Assessment Lease (PAL)	• Provides titleholder the exclusive right to explore and further evaluate specific resources, as well as carry out feasibility studies within the licence area • Allows the holder to maintain a title over a potential project area between exploration and production	• Must meet specific requirements around resource data and certainty, conceptual production plan, pre-feasibility or evaluation study, appropriateness of production area, and assessment program • Advertising must be undertaken • An access agreement must be obtained prior to any activities with certain restrictions • Landholders are entitled to compensation for 'compensable loss'	• Periods up to 6 years • Renewal can be granted on one occasion for a period up to 6 years, subject to more stringent criteria	• PALs are granted in blocks (approximately 75 km^2) with maximum 4 blocks for PALs; some exclusions apply for specified public lands and water supplies • Environmental assessment and approvals also required under the *Environmental Planning and Assessment Act 1979*
Petroleum Production Lease (PPL)	• Provides the titleholder the exclusive right to extract petroleum within the production lease area (commercial extraction)	• Applicants must have verifiable evidence of an economic reserve of petroleum and present a conceptual project development plan • Applicants must demonstrate ample financial resources • Advertising must be undertaken • An access agreement must be obtained prior to any activities with certain restrictions • Landholders are entitled to compensation for 'compensable loss'	• Periods up to 21 years or determined by the Minister • Renewals granted for periods up to 21 years	• PPLs are granted in blocks (approximately 75 km^2) with maximum 4 blocks for PPLs; some exclusions apply for specified public lands and water supplies • Environmental assessment and approvals also required under the *Environmental Planning and Assessment Act 1979* • PPLs are considered State Significant Developments and require consent from NSW Planning & Infrastructure

Note: All licences are subject to conditions that provide for protection of the environment; protection of public and private interests; rehabilitation of the land; planning, expenditure and reporting requirements; lodgement of a security deposit; payment of royalty fees (as applicable to the licence). Petroleum licences cannot be granted over potential Native Title Land prior to going through the 'right to negotiate' process under the *Commonwealth Native Title Act 1993.*

6.1.1 Exploration and assessment activities and technologies

6.1.1.1 Exploration

The aim of the exploration stage is to determine whether gas resources are economical to extract and whether to proceed with CSG production. Activities during this stage range from geological mapping to drilling exploration and production pilot wells (requirements for well drilling, including ensuring well integrity are discussed in Table 6.2).

Exploration for CSG resources requires the development of an understanding of the geology, the location, depths and thicknesses of coal seams and the surrounding strata. The term 'brownfields exploration' describes activities in an area where there are already known economic CSG deposits, and the term 'greenfields' is used to describe an area where there are no known economic deposits.

Many areas in the basins may not be explored for a range of reasons, such as urban development or environmental sensitivities or regional Petroleum Moratorium Areas.

Field exploration, including techniques discussed below, is used to develop exploration targets, which are tested by drilling. Exploration for, and evaluation of, gas content in coal deposits are an extension of the methodology used in coal exploration, and include mapping; geophysics; geochemistry and gas content; and down hole cores, exploration wells and bores (Cook, 2013a).

6.1.1.1.1 Mapping

- conventional geological mapping and measurement of the coal seam or seams and determining the volume of coal within the seam making up the CSG reservoir
- geological mapping based on outcropping strata, aerial photographs and/or remotely-sensed imagery

6.1.1.1.2 Geophysics

- evaluation of basin or field structure, and possibly the location of igneous bodies, using ground-based or airborne measurement of gravity, radiometric, magnetic, electro-magnetic fields and other geophysics techniques
- geological investigation of subsurface structure, such as faulting and dykes and strata, using seismic reflection techniques
- geophysical surveys (gravity or magnetic)

6.1.1.1.3 Geochemistry and gas content

- determining the coal's gas content and the gas composition, and also the gas holding capacity and gas saturation, and mapping the distribution of these variables within each seam, ultimately leading to estimation of the volume of gas in place
- evaluating the permeability of the coal beds containing the gas resources
- geochemical surveys (detect natural surface leaks of methane, or methane in water bores to indicate potential subsurface accumulations of CSG)

6.1.1.1.4 Down hole cores, exploration wells and bores

- measure physical and chemical properties of the subsurface coal and non-coal strata that intersect with the well, including coal volume, level of gas saturation, and permeability of the coal, as well as information about the acoustic, electrical resistivity, thermal properties, and natural radioactivity of the rocks; the stress and fracture patterns; and the stability of the well
- estimate the amount of gas present and determine the 'sweet spots' identified through the modelling

- assess the permeability of the coal seam; evaluate subsurface stress patterns; measure the level and fluctuations of the water table; identify and evaluate water-bearing strata within the sequence; and obtain samples of the groundwater from different horizons for chemical analysis
- sample and measure the groundwater to determine its composition and the flow rate; evaluate the groundwater system associated with the coal, including the potential impact of groundwater withdrawal on the surrounding surface and subsurface environment
- drill cores to determine subsurface geology; description of subsurface strata based on lithological properties, recovery of coal samples for determination of gas content and gas-holding characteristics; recovery of rock samples for geomechanical testing
- in more advanced stages of the project, an array of bore holes may be drilled to evaluate permeability, water and gas flow characteristics on a larger scale (Cook, 2013a).

Information from drilling and other geological studies are typically integrated using geological information and modelling systems. These techniques are more fully discussed in Table 6.2. These are well-established in the coal mining industry, where they are used to store, evaluate and display different types of geological information (including 3D geometric models) to evaluate resources and reserves and develop complex production plans and production schedules. A similar approach is also used in the conventional oil and gas industry (Cook, 2013a).

6.1.1.2 Assessment

For assessment, pilot wells are drilled to assess gas production rates and they are put into operation for a period of time to determine the likely production behaviour. The assessment phase of the project usually involves the drilling of a cluster of 3-6 wells, depending on the anticipated production scheme. After the wells are drilled and cased (see 6.1.2), the CSG is produced by decreasing the pressure in the coal, usually by dewatering, which desorbs the gas from the seam. The amount of gas produced is measured and used for the basis of reserve estimates (Cook, 2013a) (see Section 5.2).

6.1.2 Production activities and technologies

If the exploration and pilot testing lead to a commercial production stage, a series of activities is undertaken to design, construct and complete the well, and build gas collection systems, pipelines, processing and storage facilities.

Production (as well as exploration and assessment) wells need to be drilled and completed to specific standards to allow production and protect the environment. Therefore the integrity of the well is a key issue. The various components including processes, testing and monitoring for the different stages up to abandonment are described in Table 6.2.

After a well has been successfully drilled, cased, perforated and, if required, fracked (discussed below), it is necessary to bring it into production. As discussed in Chapter 5, Geology, it is necessary to decrease the pressure in the seam through dewatering so that the gas desorbs from the coal surface. In some CSG wells, water production is a major component of gas production.

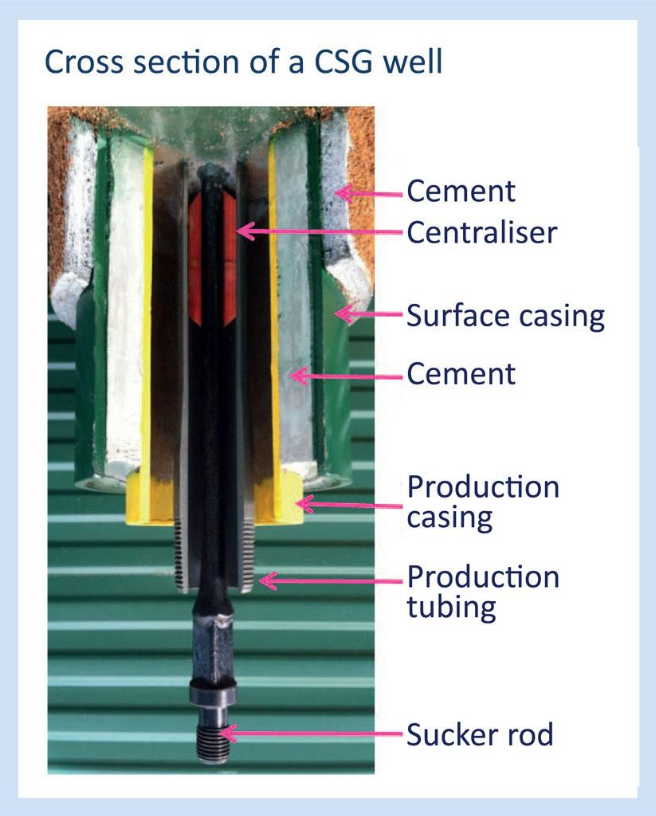


Figure 6.1: Cross section of a CSG well
Source: AGL

Because of the nature of CSG deposits, and the limited volume of coal and therefore gas that can be accessed from a single vertical well, it is necessary to drill many production wells at potentially close spacing (1-2 km apart, or less). However, horizontal drilling can be used in some situations to maximise the production zone within a coal seam and reduce surface requirements.

The production of CSG has a steep initial increase to a peak, following dewatering operations. As gas flow continues, the amount of water tends to decrease (see Chapter 7). The lifetime of a production well is usually 20-30 years. And the amount of water produced depends on the geology of the coal seam. However, in each case the produced water needs to be dealt with. Produced water is commonly saline and can contain other chemicals either naturally from the seam or as a result of the hydraulic fracturing process. Produced water can be 'cleaned' using reverse osmosis (desalination) and used for irrigation or discharged into rivers and streams, left in surface ponds to evaporate, reinjected into the subsurface, and others. This topic and the potential issues associated are discussed in Chapter 7 and Table 6.3. The handling of water in an effective manner is an integral part of the gas production process.

6.1.3 Suspension and abandonment

CSG production in a well may be suspended for a period of time; this may be due to need for remediation to fix issues with cementing and casing, or to clean the well if it has become clogged. This requires a workover rig to be bought to the site for a day or two. When a well is suspended it is sealed to prevent leakage and to facilitate safe recommencement of activities.

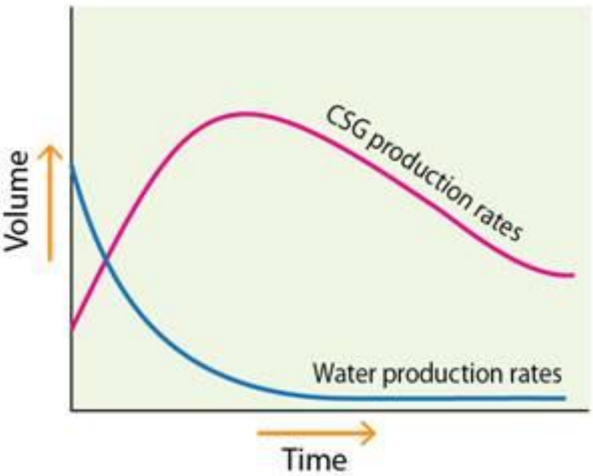


Figure 6.2: Schematic production profile for a typical CSG well (DPI, 2013)

At well abandonment, the operator must ensure environmentally sound and safe isolation of the well, protection of groundwater and isolation of productive aquifers from other formations and seams. Operators are responsible for the well until the NSW Government regulatory bodies are satisfied the well is safe and non-polluting.

6.2 CRITICAL CSG TECHNOLOGIES

6.2.1 Well drilling and completions

Table 6.2 discusses the key components for well construction and integrity.

Table 6.2: Well construction and integrity

Feature/ Component	Description	Why is it done? / What does it prevent?	Further Information
Drilling			
Vertical Drilling	Drilling a well vertically down from the surface using conventional drilling techniques until the target reservoir or formation is reached	Used alone to access and produce CSG or used in combination with horizontal and directional drilling	Vertical drilling is used for a range of applications, including water bores
Horizontal and Directional Drilling	Well drilling, usually by rotary techniques, is deviated onto a horizontal plane to run along coal seam; occurs after vertical well is drilled and casings are installed	Increases contact with reservoir and production rates; decreases surface footprint with fewer wells required; easier monitoring of fewer wells Sophisticated guidance techniques (e.g. gamma ray, neutron logging) reduce potential to deviate from target seam	Horizontal and directional drilling are used for a range of applications, including sewers, utilities, etc. Horizontal wells can be drilled to 4 km or more
Drilling Fluids	Water-based fluid circulated down borehole during drilling before returning to surface; primarily uses two additives – potassium chloride and biodegradable polymer	Lubricates and cools the drill bit, removes drill cuttings from wellbore, maintains pressure control and stabilises the hole	Loss circulation material (LCM) made of cellulose can be placed into the hole with the drilling fluid if drilling fluid isn't being fully recovered. It prevents fluid loss by blocking the pores in the host rock with cellulose particles.
Casings	Series of holes of decreasing diameter and increasing depth are drilled and lined with steel to form a string of casings in the well	Seals the well from the formation, preventing radial leaks - movement of contaminated or saline water or methane horizontally through casing into reservoir; prevents collapse of the well	Generally, only vertical wells are steel cased; horizontal sections of wells are seldom cased, and never with steel Design and selection of casing is important, as they must withstand compressive, tensional and bending forces
Conductor Casing	First casing installed and set into a ground to a depth of approximately 30 metres	Serves as a foundation for the well; prevents caving in of surface soils and isolates shallow groundwater aquifers	
Surface Casing	Second casing installed and runs past bottom of freshwater bearing zones extending back to surface	Set at a depth to prevent groundwater/aquifer protection	Should be drilled using air, freshwater or freshwater-based drilling fluid and cemented from bottom to top to isolate groundwater aquifers
Intermediate Casing	If required, this casing is drilled, installed and cemented either to the base of surface casing or up to surface	Isolates well from non-freshwater zones that could make the well unstable or abnormally pressured subsurface formations	The intermediate casing is not always required
Production Casing	Final casing drilled, installed and cemented either to a safe height above target reservoir or to surface	Allows flow of gas from reservoir to surface through sealed casing; provides isolation of producing zone and subsurface formations	A metal string, called production tubing, is often used without cement in the production casing to transport production fluids to the surface from the reservoir.

Cementing	Cement is pumped down the middle of casing tube and flows back up through void between casing or rock for each casing string installed	Seals the wellbore from surrounding subsurface formation to prevent leakages and contamination	Important to displace all mud, centralise the casing strings, achieve sufficient cement height, avoid gas migration as cement sets to assure proper seal
Cements and Cement additives	Cement properties and additives (non-toxic additives based on cellulose developed) to mix with cements	Additives help protect against gas migration; high temperatures; mineral acids, etc. to improve longevity and application of cement seals	Cement and additive mixtures should be tested in a laboratory prior to use to assure they meet design specifications
Well Logging – Testing and Monitoring			
Open Holed Logging	After drilling but before casing and cementing, electrical and other instruments are run down hole	Produce information about geological formations to optimise well design and construction	Common open holed logging tools for formation evaluation include gamma ray, resistivity, density, and caliper
Pressure testing	Pressurising the well bore with water	Tests integrity after each string of casing is cemented to check for leaks in cement seals	Should be performed after each string of casing is installed and cemented to assure integrity of the job
Cased Hole Logs	Logging that occurs after casings are installed – run inside the casings	Tests integrity of various components of drilling and well construction, including casings and cementing (e.g. bond strength)	Common logging tools include gamma rays, magnetic collar locator, cement bond log (CBL) acoustic device
Wellhead/ Blow Out Preventer	Connected to the casing at the surface	Controls pressure while drilling; prevents blow outs (uncontrolled escape of fluids at surface)	Pressure control equipment run above the wellhead can consist of a wellhead connection, the blowout preventer (BOP), the riser and the control head.
Perforating the Casing	Hole created between casing and reservoir through which CSG is produced, mostly using jet perforating guns	Creates a flow communication, isolated by the cement, from the well to the production zone	
Notes: The NSW Code of Practice for Coal Seam Gas: Well Integrity and the API Guidance Document HF1 – Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines outline best practice well design, construction and maintenance of wells to maintain well integrity. The NSW Code of Practice for Well Integrity covers principles; mandatory requirements; good industry practices; and standards and specifications for most of the components discussed above.			

6.2.2 Hydraulic fracturing

Hydraulic fracturing (hydraulic fracture stimulation, fracking or fraccing) may be undertaken in a well (either vertical or horizontal) to allow gas to move more readily through and from the coal seam. The decision by a company to use hydraulic fracturing is highly dependent on the nature of the coals (thickness, permeability, 'gasiness'), the general geological setting (prevailing stress field, depositional environment), the adjacent rock types, the proximity of major aquifers and the regulatory regime. Not all CSG wells require fracturing; if there is adequate natural permeability, or if it has been horizontally drilled, then it may not be necessary – fracking is expensive – and if it can be, it will be avoided (Cook, 2013a).

Much higher production rates can be achieved after hydraulic fracturing. Production rate increases of a factor of two to five for vertical wells and by a factor larger than five for multiple fracture stimulations along horizontal wells, are typical (Jeffrey, 2012). Wells that are drilled into low permeability reservoirs, which would otherwise be uneconomic, can be produced after fracturing, which allows resources that would otherwise be uneconomic to be recovered.

The fracking process involves high pressure injection of the fracking fluid (mainly water, but with various chemical additives) with sand or glass beads (as the proppant). This hydraulic fracturing induces fractures in the preferred lateral direction whilst the proppant serves to keep the fractures open and transmissive. The process must be carefully monitored because it is important to ensure that fractures do not extend into aquifers, which can make it difficult or even impossible to depressurise the seam (by pumping water out) to enable the methane to desorb. Once the fracture pattern has been established and adequate permeability developed, the fracking fluids are flowed back to the wellbore where they are pumped to the surface and stored ready for reuse or are disposed of at an approved site. This procedure can be undertaken in a single step of a few days in duration or incrementally over several days to a maximum of a couple of weeks (Cook, 2013b).

Hydraulic fracturing can occur at any stage during production. It may be done at the beginning to initiate production or later in the process to improve the level of production. The hydraulic fracturing process is usually undertaken by specialised service companies, as it requires a range of specialised equipment and materials including fluid storage tanks, proppant transport equipment, blending equipment, pumping equipment, and other equipment such as hoses, piping, valves, and manifolds.

Issues related to hydraulic fracturing including potential for contamination, ‘connectivity’, induced seismicity, subsidence and health impacts, are discussed in the various technical issues sections in the report.

6.2.3 Application of codes and best practice to reduce risks for well integrity and fracture stimulation

Literature on the topic of CSG technologies indicates that with application of best practice technologies and processes outlined in codes of practice, operators can minimise the risk of well failure and reduce environmental effects of CSG production (Carter, 2013; Cook, 2013a; Cook et al., 2013; King, 2012).

Best practice dictates to use science and technology early in the process to understand baselines and manage risks (King, 2012). Use of advanced technology to design and monitor activities during completions, stimulations and flowback provides continual industry learning and understanding about how to improve.

Various industry standards have been developed through years of operator experience and technological development and improvement in the more mature CSG and shale gas industries in the US. While they acknowledge that there is some variability in the details of well construction due to geological, environmental and operational settings, the basic practices of constructing reliable wells are similar (American Petroleum Institute, 2009).

In September 2012, NSW Resources and Energy published two codes of practice in relation to CSG activities in NSW: a Code of Practice for Coal Seam Gas for Fracture Stimulation Activities and a Code of Practice for Well Integrity (NSW Resources & Energy, 2012a, 2012b). The codes were developed in consultation with the CSG industry and provide practical guidelines for CSG titleholders about how to comply with applicable restrictions and regulations and how to ensure best practice operations and application of CSG technology. These codes are to be regularly reviewed. CSG titleholders are required to comply with both NSW Codes to assure CSG activities are compliant with the *Petroleum (Onshore) Act 1991*.

It should be noted that the Chief Scientist & Engineer provided peer reviewed comments and recommendations on the draft codes in an April 2012 report. The key outcomes of this work highlighted the need to strengthen mandatory requirements for CSG activities, including provisions related to training and accreditation, risk management plans and monitoring and reporting requirements. In addition, the work highlighted the need for NSW to have the infrastructure and capabilities to characterise the geology and hydrogeology in NSW, to monitor impacts and effectively utilise large data arising from CSG activities to inform future codes of practice.

6.2.4 Processing and gas transport

Gas is transported to the processing plant from the well through polyvinyl gathering lines that are buried to a depth of around one metre. Gas transport lines are carefully monitored between the well head and the plant. Rapid changes in pressure can be detected and can lead to automatic cut off at the well head. The wells and lines can also be shut off in case of bush fires.

The processing plant for CSG is relatively simple due to the small volume of gas processed and the low levels of other gas containments. The AGL Rosalind Park Gas Plant near Camden covers an area of 5-10 hectares and the installations have an average height of 3-4 m. The main plant comprises of gas fuelled engines, a reciprocating compressor with four stage compression and inter-stage cooling, and treatment facilities for dehydration. There is also a gas odorant injection system (methane naturally has no odour, so odours are added to the gas for detection and safety). There is a flare system at the plant as a safety measure in case of over pressurisation of the gas. The plant is monitored for gas, smoke, fire, noise and water removal. The gas is delivered to the market through high pressure steel pipelines.

Gas storage facilities are needed to be able to respond to increases and decreases in gas demand or supply. Some storage of gas occurs because of gas already in the pipeline but the main storage facility for AGL is through a mini Liquefied Natural Gas (LNG) plant near Newcastle. Subsurface storage methane is used in other states and is widely used overseas, but there is currently no underground storage in NSW.

6.3 DEVELOPMENT AND APPLICATION OF TECHNOLOGY IN UNCONVENTIONAL GAS EXTRACTION

The technologies used in unconventional gas extraction, including coal seam, shale and tight gas, were developed through targeted research and development primarily driven by the US Department of Energy (DoE) in the 1970s, ‘80s and ‘90s. Partnerships between government, industry and academia led to significant technological breakthroughs in reservoir characterisation, hydraulic fracturing and directional drilling that made extraction of unconventional gas commercially viable. See Table 6.3 for a description of the technologies developed over time.

The US Government subsidised research and development in the 1980s and ‘90s, when gas prices were low, through directly funded research and an unconventional gas tax credit. When gas prices rose in the late 1990s, unconventional gas production began to take off commercially. Industry in the US, benefitting from the technological advances developed previously, responded to the high prices and heavily invested capital into the industry.

The US Government during the Bush Administration (2000–2008) factored natural gas, including CSG and shale gas, highly in their energy policy. With demand for gas in the US projected to grow 50% from the early 2000s to 2020, the Government aimed to reduce dependency on imports and keep domestic supply high to avoid price increases (ALL Consulting, 2004). These policies encouraged opening new lands for exploration, streamlining permitting, reducing regulatory burdens and expanding infrastructure (ALL Consulting, 2004).

It is also important to note that during this period the US Government has been criticised for several policies that were perceived to favour the industry and reduce safeguards to protect the environment, including the ‘Halliburton Loophole’, passed in 2005 through the Congress, which exempts hydraulic fracturing operations from requirements in the *Safe Drinking Water Act*.

The associated developments shifted the balance for the US from being a gas importer to, projected by the end of 2015, that of a LNG exporter and has dramatically reduced US domestic energy prices through this transition toward abundant gas.

The seemingly sudden arrival of the unconventional gas industry in Australia is the product of decades of research, innovation and experimentation on the part of the US Government and private industry internationally to develop the technologies to make extraction of unconventional gas commercially viable.

The major challenge is in transferring this extensive industry experience and knowledge and applying it to Australia's unique geological and regulatory environment (discussed in more detail in Chapter 12, Safety). This would allow Australia to benefit from the vast research undertaken by the DoE, public companies, and research institutes.

6.3.1 History of technology development in unconventional gas extraction in US

In the 1970s, the DoE invested $92 million in the Unconventional Gas Research Program for the development of advanced exploration and production technology for both shale and CSG resources in the US (Burwen & Flegal, 2013). DoE's National Energy Technology Laboratory (NETL) employed a detailed resource characterisation and technology development approach that geologically partitioned each natural gas resource and matched technology to geology to chart a path for resource development (National Energy Technology Laboratory, 2 February 2011).

During the 1980s and into the '90s, the USDOE was actively field testing technology and processes to convert the science of unconventional gas extraction into viable technologies. DoE tested numerous 'proof of concept' experiments at the Hydraulic Fracturing Test Site in the Rocky Mountains. They coordinated and complemented efforts with industry partners to achieve several significant milestones in unconventional gas development.

Several technological breakthroughs are credited with advancing what has become known as the 'shale gas revolution' in the US. The first, in the mid-1990s, was the successful extraction of gas from the Barnett Shale in Texas by Mitchell Energy in partnership with GTI. A novel well drilled at an angle (not a vertical well) was stimulated with new technology (slick water fracturing) to produce three times more gas than previous wells (GTI, 2013). In the early 2000s, Devon Energy, again in partnership with GTI, combined hydraulic fracturing with horizontal drilling to further improve producible volumes of gas.

The DoE-led research and development programs, in partnership with industry, became a catalyst for experimentation of new technologies to unlock the potential of unconventional gas, beginning with CSG and leading into tight sands and shale (GTI, 2013). These technologies and decades of government and industry learning from the US laid the foundations for the technology used in Australia today.

The types of technologies, their development, importance and potential impacts are described in Table 6.3.

Table 6.3: Technological developments, their importance and potential impacts

Date	Technology	Description/Milestone	Importance	Contemporary developments	Issues and Needs
Late 1970s-2000s	**Hydraulic fracturing**	• Successful massive (large amounts of proppant) hydraulic fracturing in shale where rock fractured with pressurised liquid to access shale gas (US DOE) • Process monitored with fracture diagnostic tools (US DOE) • First used in petroleum fields beginning in late 1940s (Halliburton)	• Increased gas production in low permeability reservoirs, particularly in shale rock • Beginning of real-time sensing to optimise and control fracture stimulation process	• Advances in hydraulic fracture mapping and monitoring to control fracture direction and length, including microseismic sensors; tiltmeters; pressure sensors; temperature and flow logging; proppant tagging; chemical tracers; fibre-optic sensors; 3D Seismic • Advances in fracturing fluids (e.g.CO2, NO2 foams, etc.) making them safer and more effective	• Need for improved methods to manage produced water/ flowback fluid and improve fluid recovery rates – estimates between 85% and 50% of fracturing fluids stay underground as potential groundwater contaminant if connection with aquifer is made (Cook et al., 2013) • Need for baseline air and groundwater measuring and understanding of site specific geology and hydrogeology (through 3D modelling) to more accurately determine effects of hydraulic fracturing and overall CSG operations Note: NICTA is undertaking 3D groundwater modelling research to improve understanding of hydrogeology (See Water Chapter)
1980s	**Horizontal Drilling**	• First 610m air-drilled horizontal shale well using guiding equipment • First successful use of external casing seals in air-filled wellbore to isolate well from the reservoir (US DOE and industry)	• Unconventional gas production commercially viable • Drilling with air rather than fluids decreased drilling time • Casings improved seal between well and reservoir to protect aquifers • Drilling accuracy improved with downhole telemetry equipment and allowed drilling longer distances	• Rotary steerable systems and semi-continuous monitoring improve speed and accuracy • Slimhole drilling, coiled tubing drilling, drilling multilateral wells and multiple wells from a single pad allow faster drilling, reduce costs and/or reduced surface footprint • Advances in drilling, casing, cementing and testing (well integrity) reduce potential gas migration and contamination	• Need to assure stringent application of best practice codes during drilling and well construction, including NSW Codes of Practice for Coal Seam Gas for Well Integrity and Hydraulic Fracturing, to reduce potential for contamination and incidents • Possible site specific worst case scenarios with drilling and overall CSG operations include fracturing the coal seam unintentionally causing connection between seam and aquifers; microseismicity from hydraulic fracturing affecting well integrity; leakages due to poor well casings; well blow out • Additional issues include surface disturbance through site equipment, traffic, air pollution, noise
Late 1980s-early 2000s	**Combined Technologies** Horizontal drilling with hydraulic fracturing	• First multi-fractured horizontal well drilled and demonstrated using microseismic imaging data (late 1980s by US DOE) • First commercial extraction of shale through horizontal drilling paired with hydraulic fracturing (late 1990s by GTI, Mitchell, Devon Energy)	• Produced more gas than previous wells and resulted in commercial extraction of shale gas • Combination leads to US shale gas boom	• Slick-water fracturing most common well stimulation for highly pressurised deeper shales - uses more water/sand and fewer chemicals • Multi-stage allows multiple zones to be fractured continuously, reducing time and fluids • Open-hole multi-stage in use from 2001 • Fracturing fluids using nitrogen foam used more in shallow shales and low pressure reservoirs	• Worst case scenarios (described above) could result if best practice equipment and techniques are not properly employed. • Need to improve methods for technology adaptation for different sites, field validation, technology transfer/ integration and support Note: Hydraulic fracturing in NSW is primarily used on vertical wells; horizontal wells and new technologies are reducing the need to fracture; the decision to hydraulically fracture CSG wells in NSW is based on geology, with conservative estimates that less than 30% will require fracturing, primarily in Sydney, Gunnedah and Bowen basins
1980s-early 2000s	**Diagnostic/ Monitoring** 2D and 3D seismic techniques and tools	• Technologies and software developed for imaging and mapping systems for natural fractures, permeability, reservoir characterisation and seismic profiles for better placement and spacing of wells (GTI)	• Provided accurate picture of subsurface geology to lower economic and environmental uncertainty and more precisely and efficiently pursue shale formations	**Reservoir Characterisation**: • Advances in multicomponent seismic and microseismic techniques; digital modelling software; geophysical (e.g. magnetic and gravity surveys) techniques; geomechanical and geochemical data **Hydraulic Fracturing Monitoring** (see above)	• Worst case scenarios (described above) could result if best practice equipment and techniques not properly employed. • Need for better data collection tools and methods
Note: The US Department of Energy (US DOE) began working on multi-well CSG experiments and hydraulic fracturing, along with Gas Technology Institute (GTI, part of US DOE) in the early 1980s to enable economic production of low-permeability gas sand in the western US. Microseismic mapping, directional drilling, fracturing, etc., verified in field experiments, laid the foundation for many current technologies.					

6.3.2 Advances in technology

Technologies for CSG extraction continue to advance as the industry grows rapidly in Australia and overseas. These technological innovations continue to reduce risks as operations become more precise and materials more advanced, as well as provide a better understanding of the potential impacts of unconventional gas production on environment systems and human health.

Both the Australian Government and the US Government, in partnership with industry, research and environmental organisations, continue to promote and fund research and development to better quantify risks associated with unconventional gas extraction and to further advance the technology to manage those risks.

The USDOE is working to fill future R&D needs, including enhanced treatments for hydraulic fracturing; better data management; air quality, noise, truck traffic, solid waste generation, surface disturbance and induced seismicity challenges; management of produced water; and evaluation and validation of new technologies and technology transfer and support (Gas Technology Institute 2013).

Examples of current or new technologies that are advancing to increase understanding and control, reduce the risk and improve the production of CSG include:

- proprietary fibres as proppants to replace sand for drilling and fracking
- UV light in fracturing processes instead of biocides in fracking fluids
- electric rigs and pumps to reduce use of diesel (in compressors and equipment)
- sliding sleeves and mechanical isolation devices to replace cement seals
- alternative methods to fracture, including electric pulses, waterless fracturing (gels, CO_2, NO_2 foams)
- improved polymers and more benign additives like fertilizer-based fluids for drilling muds

6.4 COMMENTS FROM THE REVIEW

Coal mine methane has been a cause of concern for centuries, and efforts to detect gas (including use of canaries) and remove gas have been underway for many years. It is only recently that the value of the gas as an energy resource has been tapped and economically viable to extract due to technological advances, which have enabled the extraction of the methane that is dispersed over large, deep geological coal seams or shale deposits.

These advances have enabled the rapid expansion of the CSG and shale industries in North America, Australia and other locations. However, it is not only drilling and extraction technologies that have improved, but also technologies that minimise risks and impacts to the environment, human health and safety – these include environmental monitoring technologies for emissions and water; process monitoring; computer modelling and data analytics to understand and predict geology, hydrogeology and geomechanics; down-hole well logging sensors to test the integrity of gas wells; new drilling and fracking fluids to minimise toxic contamination of aquifers.

Australia is poised to take advantage of evolving technological advances and lessons learned here and overseas, with a key challenge in finding ways to transfer effectively the vast industry experience from North America to Australia. An important aspect is to ensure that technologies specific to Australia's unique geology and hydrogeology are applied appropriately to inform proper well design, process methods, and best use of technology.

Risks to CSG projects are significantly reduced through the correct application of industry best practice. Codes of practice and regulations need regular review so that improvements in practice are captured and reflected in the legislation and regulations.

6.5 INFORMATION SOURCE

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- “Life cycle of Coal Seam Gas Projects: Technologies and Potential Impacts” , Professor Peter J Cook CBE, FTSE

7 WATER

The availability of sufficient quantities of high quality water for domestic use, agriculture and stock use, as well as for maintaining environmental flows, is a high priority for people living in Australia. As a community, we have concerns about groundwater and surface water which have arisen due to issues such as deforestation, rising water tables, drought impacts, and agricultural run-off and chemicals. Against this background, the possible additional impacts that CSG extraction activities could have on water resources has been the major concern raised during the Review to date (see Section 2.2).

Issues surrounding water in the CSG debate naturally group into four:

1. concerns about flowback and produced water
2. concerns about impacts on groundwater quantity
3. concerns about contamination of groundwater
4. concerns about possible long term or irreversible changes to the artesian basins and water resources.

The following section provides a background and context for concerns with water, with the issues discussed in sections 7.2 to 7.5.

7.1 BACKGROUND INFORMATION ON WATER

Deep groundwater, shallow groundwater, surface water, precipitation and evapotranspiration interact and can be conceptualised as a single hydrological system (Council of Australian Governments, 2010) (Winter, Harvey, Franke, & Alley, 1998). A better understanding of the interrelationships has led to a global move since the 2000s to manage various connected water bodies as a single resource (Council of Australian Governments, 2010) (Rassam, 2011).

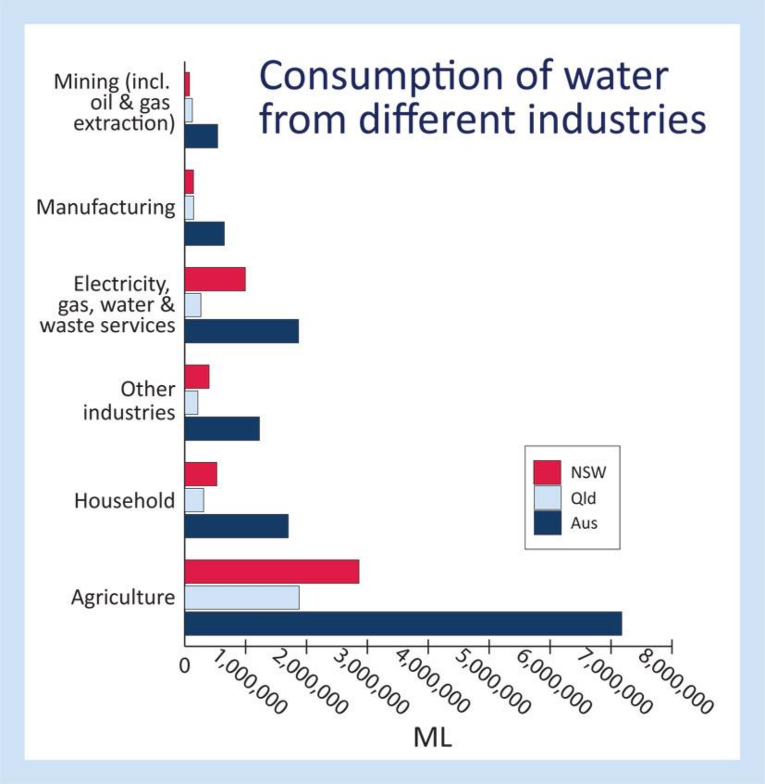


Figure 7.1: Consumption of water (Megalitres, ML) from different industries, in Australia, NSW and Queensland in 2010-11. Gas extraction is included in the mining industry (ABS, 2010-11)

7.1.1 Water resources

New South Wales has extensive, and environmentally sensitive, water resources. These include the well-known Murray Darling Basin and Great Artesian Basin. Within the State the biggest user of water is the agriculture sector, accounting for 44% of water consumption. In contrast, the mining sector (which includes CSG extraction) accounts for about 1.5%. Australia-wide, these figures are approximately 54% and 4%, respectively. Figure 7.1 shows the consumption of water by different industries in

NSW, Queensland and all of Australia.

7.1.2 Surface water

Water that is on the land surface is termed 'surface water'. This includes creeks, rivers, lakes, reservoirs, wetlands and oceans. Surface water is one component of the hydrological cycle, and interacts with other components via the processes of precipitation, evapotranspiration and seepage.

Aside from Antarctica, Australia has the lowest rainfall of any continent, and vast regions have a semi-arid climate. Runoff is generally low, and some rivers do not flow continually: 'losing rivers' can lose water to shallow groundwater, while 'gaining rivers' gain water from shallow groundwater, while other rivers are termed 'gaining/losing rivers' that can be gaining at one reach and losing at another (Rushton, 2007).

7.1.3 Groundwater

Australia-wide groundwater makes up 17% of accessible water resources and accounts for more than 30% of water consumption (National Water Commission, 2008).

Beneath the land surface are two zones: the 'unsaturated' and the 'saturated' zones. Water in the unsaturated zone is termed 'vadoze water' while water in the saturated zone is termed 'groundwater', with the top surface of the saturated zone termed the 'water table'.

A common misconception of groundwater is that it is akin to underground lakes or oceans. While in some instances groundwater does occur in large voids such as caves, groundwater is most commonly the water which saturates the pores, fractures, and faults of sediments and rocks below the ground surface.

Groundwater can occur in a variety of environments, from unconsolidated sedimentary deposits to rock strata of different types (i.e. sedimentary, igneous, and metamorphic).

Those strata that contain pores and fractures and through which high volumes of water can move are often called aquifers, of which there are two types:

- **unconfined aquifers** where the upper aquifer surface (i.e. the water table) is at atmospheric pressure
- **confined aquifers** where the upper aquifer surface (i.e. the bottom of the confining layer, e.g., a shale bed) is at a pressure greater than atmospheric.

Aquitards are geological strata that are characterised by having a low rate of water flow in the horizontal and vertical directions compared with aquifers.

Flow of water in a groundwater system, including aquifers and aquitards, is controlled by two factors:

- **hydraulic conductivity -** the ease by which water moves through the pores/fractures in the strata, where an aquifer is a zone of high conductivity and aquitards have relatively low conductivity. All natural porous media, from unconsolidated sediments to unfractured rock, fall on a spectrum of high to low hydraulic conductivity
- **pressures - hydraulic head** is a measure of the potential for flow, and water moves from areas of high to low hydraulic head. At a point of measurement, hydraulic head is the water pressure plus the elevation of the point.

The transient flow conditions are in addition controlled by the **hydraulic diffusivity**. When the hydraulic diffusivity is high, there is the potential for rapid dissipation of water pressures; when the hydraulic diffusivity is low, there is only the potential for slow dissipation of water pressures, and this dictates the velocity at which the pressure effects travel through the overlying aquifers, and laterally along the aquifer/coal seam. This may be faster than the velocity of the flow of water itself.

7.1.4 Flowback and produced water

During the process of hydraulic fracture stimulation, fracking fluid is pumped into the coal seam and pressurised, which results in the opening up of fractures in the coal seam. The chemicals and materials in fracturing fluid as well as the formation water in the seam are then returned to the surface as 'flowback' water, which must be collected, stored, disposed of or recycled to recover the fracking fluid constituents.

Flowback water emerges if fracture stimulation activities are used by the title holder, and is composed of a combination of the fracking fluid that is pumped underground and the water that was naturally present in the seam (formation water).

Produced water differs from flowback water in that it is primarily made up of the formation water from the seam, with minimal if any fracking fluid, brought to the land surface during the process of depressuring the coal seams and recovering CSG. Produced water will emerge from CSG wells whether or not they have been fracture stimulated.

7.2 CONCERNS ABOUT FLOWBACK AND PRODUCED WATER

The community is divided on the potential of produced water. Some see it as a significant environmental issue, with the potential for irreversible environmental degradation. Others see produced water as a resource that could be harnessed for the benefit of the local or regional community (e.g. use of water for crop irrigation or environmental river flows).

Once the coal seam has been depressurised for production, or hydraulically fractured to stimulate production, the water extracted and brought to the surface has to be managed. This can be by way of:

- storage ponds
- evaporation ponds (now banned in NSW)
- cleaned for reuse (environment, irrigation, etc.), using techniques such as reverse osmosis (RO) and solid waste removed, and
- reinjection.

Produced water can be high in salts and organic and hydrocarbon chemicals (see Table 7.1) that were naturally occurring in the seam, while flowback water will also include the chemical constituents of the fracking fluid.

Water composition of the formation water is region specific, since the local geology will largely determine the water quality parameters. Generally speaking, produced water will have concentrations of total dissolved solids of up to 40,000 mg/L, which is the typical upper limit for sea water.

The location of the seam or aquifer in the vicinity of certain geologies also impacts the constituents of produced water; for instance water associated with strata that were formed by volcanic structures may have higher levels of trace metals, while water associated with granite may have higher levels of naturally occurring radioactive materials. The nature and abundance of hydrocarbon content in the produced water will also vary, with lower rank coals having a greater concentration of solubilised organic molecules compared with higher rank coals (CSIRO, 2011).

Table 7.1: Potential constituents and chemicals in produced water

Category	Constituents
Dissolved Solids	• sodium cations, and anions of chloride and bicarbonate (Sodium chloride or salt at concentrations of 200 to more than 10,000 milligrams per litre) • total dissolved solids concentrations up to 40,000 mg/L (typical upper limit reported for seawater)
Oil and grease	Organic chemicals that collectively lend an 'oily' property to the water
Organic and inorganic chemicals	• found naturally in the formation • trace elements such as mercury, arsenic and lead • organic acids and polyaromatic hydrocarbons • semi-volatile organic chemicals, benzene, toluene, ethylbenzene, and xylenes (collectively known as 'BTEX')
Naturally occurring radioactive material	Low levels of radioisotopes such as radium, thorium and uranium
Chemical constituents of drilling and fracking fluids	A wide range of chemical constituents used in the processes: e.g. mineral oil, isopropanol, borate salts, citric acid, hydrochloric acid, N,N-dimethylformamide, Gluteraldehyde

Issues related to the management of produced water have been highlighted in NSW recently through incidents such as:

- the Pilliga Forest spill in June 2011 due to untreated saline water leaking 10,000 litres of brine from a pipe at the Bibblewindi site
- the Metgasco CSG activities near Casino of processing produced water in the local sewage treatment plant.

7.2.1 Produced water or flowback water spills and release

There is potential for unregulated releases of produced water or flowback water to surface waters or groundwater bodies, or for leaks from storage ponds or tanks onto land and also potentially to water bodies.

Discharge of produced water onto land and soil may occur inadvertently through an accidental spill, or by design for purposes such as dust suppression on roadways, or as an irrigation processor for disposal by infiltration. Over time, discharge onto land can result in salts present in the water accumulating in the soil, which in turn can lead to physical and mechanism changes to the properties of soil. Osmotic effects and specific ion toxicity can also be a problem in soils.

Discharge of produced waters into freshwater environments such as streams and rivers can potentially cause damage. The level of impact depends on factors including the salinity level of the produced water (compared with the receiving environment), the sensitivity of the biota in the receiving environment to increased salinity, and the volume and timeframe over which the produced water enters the water body.

A particular factor leading to accidental release may derive from an inaccurate calculation of the volume and rate of water to be brought up and managed. The volume or rate of flow of produced water varies between regions and will typically depend on the water content of the coal seam and the adjacent geological structures, and also the isolation of the seam.

Newer, shallow coals tend to be wetter (e.g. Jurassic basins – Clarence Moreton and Surat basin), compared with deeper and older coals (e.g. Permian basins - Sydney, Gunnedah, Gloucester basins), see Table 7.2. Figure 7.2 illustrates the differences in water production to date between the NSW and Queensland production areas. Regardless of the absolute volumes involved, the water production is generally higher earlier in the CSG well life and declines with time (see Figure 6.2).

It is important that planning for infrastructure design and scale takes into account risks from unplanned natural events such as floods or storms which can greatly affect the volume of waters to be managed and result in potential overflows.

Table 7.2: Estimated potential water co-production from proved and probable (2P) CSG reserves over the entire resource (Table adapted from the National Water Commission 2011, Waterlines report: Onshore co-produced water: extent and management (RPS, 2011))

Basin	**Estimated total water production**		
	GL	%	GL/yr**
Bowen Basin (Qld)	2,360	30.7	94.4
Surat Basin (Qld)	5,290	68.7	211.6
Gunnedah	1.7 – 36.0	0.6*	1.9*
Clarence-Moreton	0.7		
Gloucester	3.0 – 10.0		
Sydney	0.15		
Total	7,696	100	308

Note: Due to the infancy of this industry in NSW, there are few estimates of resource life and the period over which this water may be produced. * Assuming upper limit for basins in NSW.
** Average annual rate of water produced assuming a resource life of 25 years.

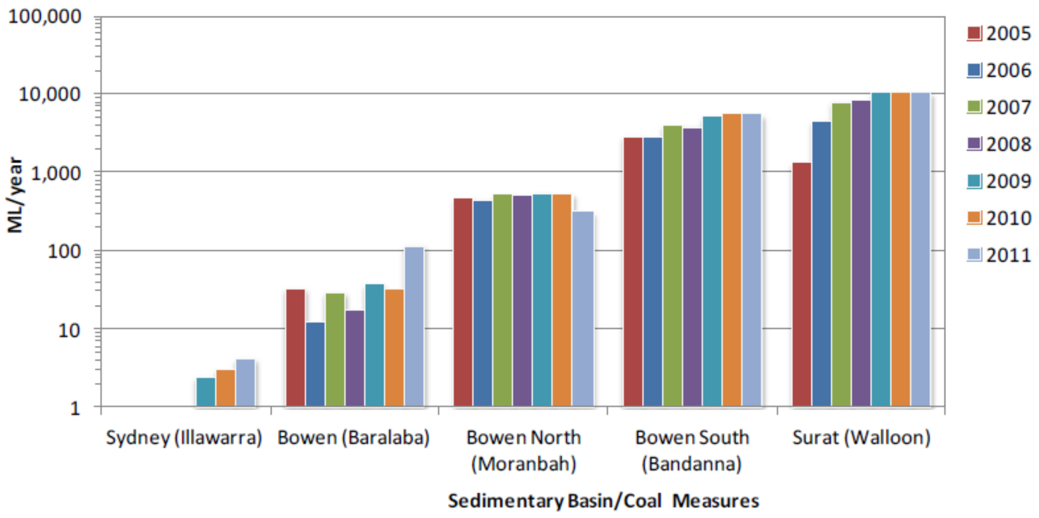


Figure 7.2: Estimated volume of water from Queensland and NSW commercially producing CSG fields (Sydney Catchment Authority, 2012a). Note: Y axis is a logarithmic scale

Release of untreated produced water of concentrated brines or solids can have a detrimental effect on potable groundwater or surface drinking water sources. Disposing of produced waters directly to surface water bodies can potentially cause contamination of the surface water and shallow drinking water aquifers, although it is a common approach to managing the water. If it is undertaken it should be done under regulation from the state, e.g. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000).

A thorough scientific analysis of reuse/disposal is required for each case, comprising hydrodynamic modelling, effluent toxicity testing, and salinity tolerance analysis of aquatic species.

7.2.2 Disposal of solids wastes

Produced water typically contains substantial amounts of dissolved chemicals, which can be separated out and concentrated as solids. This contaminant solid residue must also be disposed of or used. This can be done offsite in a properly designed and managed containment facility, but will require transport and truck movements. There is a risk that environmental contamination will occur through these handling, transport and disposal activities.

7.2.3 Release of purified waters into natural water bodies

Most produced waters need to be treated before they can be disposed of or reused. The levels of specific constituents and the type of reuse determine the water treatment adopted. The most commonly used technologies are nanofiltration and reverse osmosis (RO).

Although treated and separated from the brines and solids, the 'cleaned' water may be used in an environmentally unsafe manner. Following treatment through RO or other techniques, water is produced that is extremely pure. By comparison, water in the natural environment contains dissolved salts, nutrients, organic matter, microorganisms etc. If not undertaken properly, releasing highly pure water into a natural water body can also cause significant harm to the receiving body, so it may be necessary to add impurities to the pure water component prior to introducing it to the stream or river to ensure the water matches as closely as possible the environment it is being released into.

7.2.4 Pipes and holding tank scale

Scale from pipes and sludge from tanks holding produced water can concentrate naturally occurring radioactive materials. These need to be monitored and disposed of in an appropriate way. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has regulations around the management of radionuclide-bearing materials.

7.2.5 Volatile organic compounds released from produced water

Produced water brought up from the hydrocarbon-bearing coal seam will likely contain hydrocarbons in the form of volatile organic compounds (VOCs). Concern has been expressed about these compounds, such as benzene toluene, ethylbenzene and xylene (BTEX) chemicals, being volatilised from the liquid phase into the gas phase as an air emission.

7.2.6 Effects on surface water bodies and connected shallow aquifers

The release of produced water into a surface water body can increase the volume and flow of a river or stream, which can result in physical alterations such as sedimentation and potential clogging, or alternatively increased erosion.

However, an increased volume of water in a losing stream could also potentially work to increase the groundwater volume in the subsurface connected aquifers. Modelling these effects would be required to understand whether an increased salinity issue would arise from an increased water volume in such unconfined aquifers. This is probably a small problem and it would require further consideration against modelled discharges at particular sites.

Chemical impacts of produced water on receiving water bodies include sodicity, salinisation, turbidity, and potential toxicity due to chemical component.

7.2.7 Reinjection of produced water into aquifers

The process of reinjection needs to be well thought out, as it can potentially have ongoing effects on the aquifer quality, and also potentially cause induced seismic events (see Chapter 9). Efforts to monitor seismicity during injection would assist to track these occurrences and alert authorities to alter or stop reinjection if seismic effects were indeed induced.

7.2.8 Engineering and scientific approaches to reduce risks from produced water

The potential impacts from produced water are all related to the way CSG operations are planned and managed. Thus, the impacts from produced water should be negligible provided best practice is followed, which includes: undertaking exploratory measurements to determine the quantity of produced water that would be produced over time, as well as the chemical constituents of the produced and flowback waters; accurate calculation of the depth of the coal seam so that fracture stimulation occurs within the seam; best practice drilling, of either horizontal of vertical wells, to make sure that the drill bit remains within the coal horizon and does not enter surrounding aquifers.

7.3 CONCERNS ABOUT GROUNDWATER QUANTITY

Worry about how groundwater extraction during CSG activities will affect the water table is one of the most often raised concerns due to the possible impacts on the availability of groundwater for regional communities, farmers and the environment. Groundwater is accessed for stock, irrigation and other bore water use for regional areas, and is also critical for providing base flow to some rivers, streams and lakes as well as ecosystems dependent on groundwater-fed springs.

7.3.1 Potential impacts of CSG activities on the water table and the quantity of groundwater

Some of the potential impacts on groundwater quantity that have been identified as possible concerns from CSG relate to a reduction in groundwater quantity and a decline in the water table.

Coal seams in some cases are considered aquifers themselves, as they contain water and can have a relatively high hydraulic conductivity. This factor has in some cases resulted in landholders drilling artesian wells into coal seams and extracting water for domestic use (methane in water bores is discussed in Chapter 10).

7.3.1.1 Depressurising aquifers and drawing down water levels

Given water present in coal seams, the first impact to be considered when CSG wells are drilled and de-watered is that the coal seam itself will be depressurised, its water extracted and the seam depleted. This is undertaken for the express purpose of reducing the pressure that holds the methane to the coal surface, and allowing it and the formation water to flow up the well to be separated, captured, processed and transported away.

When a well is drilled into a confined coal seam and water is extracted, a zone of depressurisation is established, the size and extent of which is important and reliant on factors including the size of the seam, its storage capacity, the pumping rate, initial pressure, recharge rates, geology and the flow of water through the seam.

Initially, the extracted water from the CSG seam will be sourced from confined groundwater storage, largely within the coal seam. Given time, the extracted water may be sourced from the groundwater in the surrounding strata, shallow groundwater and surface water.

The depressurisation of the CSG seam induces a pressure gradient towards the well and seam, which means that a potential is created for water flow towards this area, from other areas of the seam, or neighbouring strata.

Depending on the connectivity between the coal seam being dewatered and higher strata, the dewatering process may cause a drawdown in water levels in the upper groundwater layers and possibly a decline in the water table. This will particularly be the case where aquitards are 'leaky'.

Reduction in the quantity of groundwater and/or a reduction in the height of the water table will be dependent on the volume of water removed during the CSG processes; the geological characteristics of the strata, aquifers and aquitards, including how 'leaky' the aquitards are, and the hydrogeological characteristics including hydraulic conductivity, hydraulic head and diffusivity and what impact these factors may have on pressure gradients and volume and direction of water flows underground. Water flow direction is further discussed in section 7.5.

7.3.1.2 Repressurisation

After the CSG operations, when the seam is no longer being depressurised, the seam will repressurise naturally with water, again ultimately sourced from shallow groundwater and surface water or natural recharge zones, or it may be repressurised artificially (through water reinjection).

The total volume of water that flows into the coal seam aquifer to replenish the depleted aquifer will be the volume of water that was there pre-CSG extraction and also part of the pore space volume that was occupied by the now extracted gas including methane.

7.3.1.3 Using best practice for mitigation

Given these factors, it is important that monitoring and modelling is used to develop a good understanding of the groundwater system and the potential impacts on water quantity and potential drawdown of the water table. The hydrogeology and geology should be studied and modelled and analysed, so that the likelihood of impacts or worst case scenarios, and measures to assess and manage risk, are established.

Within these potential impacts, there are direct operational risks and indirect risks to the hydrological system. Operational issues can be managed by industry best practice and government regulation (e.g. good well construction; controlled fracking). However, risks related to changes that occur to the hydrological system are not well understood nor easily quantified, and need to be studied further through data collection (pressure and pumping tests, water age, etc.), research, modelling and data analytics approaches. This is particularly the case with respect to the timing of the quantity reduction impacts.

Efforts have been underway in Queensland and other locations to develop approaches to assessing the cumulative impact of multiple extractive takes on groundwater, with the Queensland approach aiming to examine the effect on water table drawdown over time. Further discussion of cumulative impacts is in Chapter 13.

7.4 POTENTIAL GROUNDWATER CONTAMINATION

Particular concerns have been raised in submissions and discussions about potential contamination of water with chemicals through the CSG processes. Discussion of contamination of surface water and alluvial aquifers from produced water spills is in Section 7.2.1, however other concerns have related to contamination due to underground activities such as drilling and hydraulic fracturing.

There are several mechanisms for potential contamination of water resources from CSG activities. Contamination of a groundwater body with foreign chemicals could potentially occur from:

- the introduction of chemicals in fracking fluid or the drilling fluids and muds

- mobilisation of chemicals located within the coal seam
- transport of chemicals between strata
- spillage at the surface with leaching into surface aquifers.

7.4.1 Use of chemical additives during drilling

Chemical additives can include drilling water from a different water source and muds which contain bentonite stabilisers. These can potentially mix with water from surrounding aquifers during the drilling process. It should be noted that there is a long history of drilling wells for different purposes in the state (e.g. water bores for drinking water and irrigation; monitoring wells). Furthermore, it is also the case that the types of drilling muds being used are also changing. Methods and codes for drilling and installation of wells and bores are well established (NSW Resources & Energy, 2012a, 2012b).

7.4.2 Use of chemical additives during fracking

Chemicals are deliberately introduced into coal seams during hydraulic fracturing of the seam. The fate of these chemicals is of particular interest, either those that remain in the seam following the completion of depressurising, or those that may leave the seam if a connection to another aquifer is opened up. Efforts to model the exposure pathway of these chemicals would assist in understanding what amount and concentration could potentially reach other water bodies and over what timeframe. Exposure pathways are further discussed in Chapter 11.

The fluids that remain in the seam can potentially mix with water from surrounding aquifers. Furthermore, following the fracturing, the water that had been pumped in is allowed to flow back to the land surface, and is called 'flowback water'. Flowback water is a mixture of hydraulic fracturing fluid and formation water, which makes it physically and chemically different from the water in the formations. This water has to be treated and recycled, or disposed of in a manner similar to produced water.

The use of hydraulic fracturing chemicals in NSW is regulated through the Code of Practice for Hydraulic Fracture Stimulation, which bans the use of BTEX chemicals in NSW, and requires the licensee to disclose:

- identity and Chemical Abstracts Service (CAS) numbers of the chemicals
- the volume and concentrations
- potential risks to human health arising from exposure to the chemicals
- the risk, likelihood and consequence of surface spills of the chemicals
- the risk, likelihood and consequence of the injected chemicals affecting the beneficial use class of the target aquifer or any other aquifer.

7.4.3 Accidental contamination of shallow aquifers from spills and leaks

As with many industries, there is a risk of spills or leaks at the land surface during construction and production activities. This could cause contamination of soils, surface waters or shallow groundwater systems. The issues around the storage, handling and treatment of produced water, as discussed in section 7.2.1, are applicable to this issue also.

7.4.4 'Cross-contamination' of aquifers due to CSG extraction

As seen above in section 7.2.6, there is the possibility that preferential flow paths may be created from CSG activities, thereby allowing for enhanced flows of water between aquifers. Studies in the USA (Jackson et al., 2013; Osborn, Vengosh, Warner, & Jackson, 2011; Warner et al., 2012), in relation to reported contamination of drinking water aquifers from well activities, appear to demonstrate that poorly constructed wells and bores can act as a pathway for the movement of chemicals, including methane, between aquifers, including the gas-bearing aquifer, to a higher quality drinking water aquifer.

7.4.5 Mixing of different waters following depressurisation of a coal seam

When a coal seam is depressurised, there is little risk of mixing of water from the coal seam with surrounding aquifers, due to the hydraulic gradients towards the seam. However, as seen in section 7.3, the depressurisation could potentially induce changes to the hydrological system, with consequent water quality impacts (e.g. inducing mixing of shallow groundwater with deeper groundwater).

7.4.6 Assessing the impacts

The potential contamination impacts can be divided into direct operational risks and indirect risks to the hydrological system.

Many of the issues and mechanisms for water contamination are directly associated with the CSG operations and practice. As such, these are influenced by the standards, practice and professionalism of the organisations undertaking CSG activities. Various contamination risks could potentially affect the hydrological system and these need to be assessed on a scientific basis.

Current work through the Commonwealth Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Developments (IESC) process is looking at the chemical and hazard characteristics of fracking fluid constituents and also the identity of chemicals in formation waters.

A key factor in assessing whether, or to what extent, CSG extraction has contaminated groundwater aquifers is the background level of chemicals in the groundwater. Aquifers in their natural state, before CSG activities have occurred, will naturally contain a range of chemicals that derive from both surface and geological entities. For instance, organic matter from streams and lakes can be washed into aquifers, and be broken down to methane by the action of bacteria. Metal ions, radionuclides, salts, and methane from geological structures such as volcanic rocks, granite, coal seams, can be found in aquifers from natural groundwater flow processes, again without necessarily being driven by CSG activities.

7.5 CONCERNS ABOUT POSSIBLE LONG-TERM OR IRREVERSIBLE CHANGES TO THE ARTESIAN BASINS AND WATER RESOURCES

The Australian continent today has a very different landscape to before European settlement, and this is reflected in our surface water ways and rivers, and also the groundwater and artesian systems that the rivers are connected to. Drying rivers, rising and falling water tables, salinity, disappearing marshlands are part of the story that we are familiar with.

7.5.1 Concerns about effects on groundwater connectivity

In discussion of how CSG activities at depth may impact surface water and groundwater resources, ‘connectivity’ is a key concern. Connectivity in hydrogeology can be either ‘static’ or ‘dynamic’ with static connectivity referring to the physical connections that exist between the different zones of the aquifer(s). These connections may be natural or enhanced due to human activities (e.g. drilling, fracking). Dynamic connectivity refers to the flow of water between one aquifer unit and another unit. Again, these flows may be natural or enhanced.

The concept of dynamic connectivity considers the hydraulic conductivity, and pressure, and allows for an understanding of whether a potential flow path exists for water, and how the pressure distribution also influence flow.

7.5.2 Changing the conductivity

In many cases, the coal seam is located below aquitard strata and thick layers of various types of rock that helps reduce the vertical flow of water into the coal seam. On depressurising the coal seams, due to the induced pressure gradients, there is the potential of the amount of water that flows through aquitards to increase. The flow of water vertically through an aquitard may be increased if the aquitard is 'leaky' due to cracks or fractures in aquitard; discontinuities in the aquitard conductivity; or poorly installed bores or wells that could allow leakage between aquifers.

The presence of preferential flow paths in aquifers, whether natural (e.g. faults, fractures, joints) or enhanced (e.g. along poorly constructed wells or fractures induced by fracking), can dominate the flow of water from one area to another. Process monitoring technologies at the drilling, fracturing and production phases, including pressure monitoring assist the operator to track and understand whether unplanned connectivities have been established with surrounding aquifers.

7.5.3 Impacts on surface water connectivity and quantity

As discussed in section 7.1, surface water and groundwater are connected through the hydrological cycle, with shallow aquifers sometimes providing baseflow to surface water bodies, or losing streams in turn able to supply unconfined aquifers.

This connectivity can have implications for CSG extraction activities and de-watering potentially impacting connected surface water bodies. This can arise when the surface water recharges the CSG seam (such as where the seam extends to shallow depths and near surface water features), or when the surface water recharges shallow groundwater.

Impacting surface water quantities has implications not only for the quantities of water available to other users, but also for the environment. A river is continuously interacting with the underlying aquifer, and the magnitude and direction of the exchange of surface and groundwater is determined by the hydraulic gradient and conductivity between the river and the aquifer (Rassam, 2011).

Pumping from shallow groundwater resources leads to changes in the pressure distribution within aquifers. Worldwide, this has led to the phenomena of 'captured discharge' and 'induced recharge' whereby water that would have discharged from an aquifer to river is captured thus reducing baseflow, or flow of water from a river to the aquifer is induced. The time from initial pumping until these phenomena depends on the geological context but can be decades.

Many streams and springs are fed by groundwater (i.e. gaining river). However, if the pressures are changed such that the surface water now feeds the groundwater (i.e. losing river), less water is available for the riparian zone (the interface between land and rivers). Therefore, CSG activities that lead to a lowering of the water table could impact the health of the river.

This has implications for any ecosystems which are depending on the steady influx of groundwater (i.e. 'groundwater dependent ecosystems'). As discussed in Rassam, factors that may affect river depletion include diffusivity, riverbed clogging, aquifer heterogeneity, distance between the extraction well and the river and other factors.

Developing groundwater models and undertaking measurements of pressure, head, conductivity etc. allows estimates of factors related to groundwater flow such as:

- the time until impact on overlying strata or the water table from dewatering deeper aquifers or coal seams

- the volume of water which is required to be removed for pressure dissipation to occur and how much the aquifer is depressurised, and
- any changes to the direction of groundwater movement with changes in pressure. This could mean that where groundwater previously fed surface water features, such as perennial creeks and springs, the surface water will now recharge the aquifer.

7.5.4 Changing the direction of groundwater flow

In a similar way to the connections between surface water and groundwater, pumping from deep aquifers, such as a coal seam, may potentially cause pressure gradients with the aquifer system. There is thus potential for water that previously discharged at the surface and sustained groundwater dependent ecosystems or baseflow will reverse direction, and instead flow towards the depressurised coal seam.

In relation to concerns about connectivity, there is a potential that extraction of water and subsequent depressurisation of an aquifer (including a coal seam) may change the pressure gradient between groundwater bodies. Water will flow from a zone of high hydraulic head to a zone of low hydraulic head, at a rate that depends on the hydraulic head difference and the hydraulic conductivity. The situation could arise whereby the reduction in pressure with water extraction could result in a reversal of the pressure gradient such that the zone that was higher pressure becomes the lower pressure zone, which could then change the direction of flow of water. The hydraulic diffusivity will impact the rate that this relative pressure change would occur, meaning that there is the potential that the change in pressure may occur more quickly than the velocity of the water flow.

7.5.5 Cumulative impacts

Given the connectivity between hydrogeological zones, both in terms of depth and lateral linkages, the development of techniques and approaches to estimating the cumulative impacts from numerous wells, numerous developments, and multiple industries and resource users drawing from the groundwater is important. Efforts to understand cumulative impacts in regions which have altered geological conditions, such as may occur from subsidence above longwall mines are also important. Many locations of potential CSG extraction activity are likewise locations of current or potential coal mining (Southern Coal Fields, Gloucester basin, Hunter Basin). Therefore understanding these overlaying activities, potentially with co-located agriculture and potential seasonal effects are realistically possible to occur. This is further discussed in Chapter 13.

7.5.6 Sydney water catchment

Particular concern has been raised by the community, including through Review Submissions, about CSG activities within water catchment areas. The effect of CSG and management of risk on water catchments is a particular focus of the Term of Reference 2 of this Review.

Much of the concern expressed by community and in submissions relating to water catchments centres on extractive industry activities within Sydney's drinking water catchment areas in the vicinity of the Southern Coal fields. These catchments include Warragamba Dam and the surrounding Warragamba Special Area, the Woronora Dam and the surrounding Woronora Special Area, as well as the Cataract Dam, Cordeaux Dam, the Avon Dam and the Nepean Dam and the Metropolitan Special Area that surrounds these four dams.

7.5.6.1 Special Areas

The Special Areas were established for the purposes of excluding industrial and development activity in the vicinity of the potable water sources to prevent the contamination of the water supply, particularly by microorganisms. Following the 1998 cryptosporidium contamination of drinking water in Sydney, the responsibility for the management of the Sydney Catchment was transferred to the newly created Sydney Catchment Authority (SCA). The Nepean and Metropolitan Special Areas are both Schedule 1 Special Areas, while the Warragamba Dam is surrounded by a Schedule 1 Special Area close to the water and a more extensive Schedule 2 Special Area, in which is permitted a wider range of activities and access by the public. Special Areas have been in place around the dams for over 100 years (Sydney Catchment Authority, 2007).

The responsibility for the management of the Special Areas sits with the SCA under the Sydney Water Catchment Management Act 1998. Various rules and regulations apply for the management of the Special Areas and the types of activities that can take place, and the mechanisms for their assessment and approval including the *Sydney Water Catchment Management Regulation 2008* and others (Sydney Catchment Authority, 2007, 2011) (DP&I, 2011).

7.5.6.2 Mining in the Catchment

Mining has occurred historically to the east of the Warragamba Dam including within the Schedule 1 Special Area. Historically and currently, mining has been and is occurring near or underneath the Woronora Dam and the surrounding Woronora Special Area, as well as the Cataract Dam, Cordeaux Dam, and the Avon Dam in the Metropolitan Special Area.

The most significant coal seams in the Southern Coal Fields are Permian age, including, from shallowest to deepest, the Bulli Seam, the Balgownie Seam, the American Seam, the Wongawilli Seam, Tongarra Seam and the Woonona Seam.

The Southern Coal Fields have been the site of underground coal mining activities since the nineteenth century, largely in the earlier years by bord and pillar mining. From the 1960s, the longwall mining approach to coal extraction has been increasingly used given the greater economic return and availability of equipment.

7.5.6.3 Subsidence and effects on geology and hydrogeology

Subsidence issues have been evident over a long period, and the Mine Subsidence Board has established several Mine Subsidence Districts in the region. Both bord and pillar mining and longwall mining practices have been used in the area.

Subsidence effects and strata with bord and pillar mining are usually negligible, typically 5 mm of vertical displacement (Hebblewhite, Galvin, Mackie, West, & Collins, 2008). Subsidence at the surface following longwall mining can be in the order of 1–2 m, or more than half the thickness of the coal seam extracted (see Section 8.1.3).

The extensive history of underground mining in the region has meant that alterations have occurred to local geology. In some locations two overlying seams have been extracted, and more recently some plans have been conceptualised toward extracting three overlying seams of coal.

Longwall mining and the subsequent subsidence effects above the mining have the potential to alter the groundwater characteristics of strata. The collapse of the mine roof results in various zones (caved zone, fractured zone, constrained zone etc.) above the mine workings which have a range of altered hydrogeological characteristics (GHD Geotechnics, 2007). Given the structural alterations that occur following longwall mining (collapse of ceiling structures and upper rock), the alterations to geology, groundwater bodies, and connectivity are of particular interest. Efforts to understand and model the hydrogeology after mining will help to develop a picture of whether there has been an effect on the groundwater regime, pressure gradients and connection to surface water.

7.5.6.4 CSG extraction and cumulative effects on water catchments

Of concern to some in the community is the cumulative impact of undertaking additional CSG extractive activities where mining has already been undertaken. Extraction for CSG involves drilling wells into intact coal seams, as well as extracting gas from goafs. Goafs can be dry or water-filled depending on the connectivities to local aquifers.

The SCA has raised concern that the opening of the Special Areas to CSG activities will exacerbate the pressures already felt from longwall coal mining, and are concerned with cumulative environmental consequences (PAC, 2013). Major concerns listed by the SCA with CSG exploration and production/extraction:

- risks to water quality are inadequately understood
- potential for dewatering flooded mine workings to increase gas production
- extent of surface impacts associated with drilling and construction of gas gathering systems
- extraction of gas from un-mined coal seams below existing mine workings would require depressurisation of the seam, which could enhance connectivity between the mine voids and seam
- use of hydraulic fracturing in intact seams underneath existing mine workings
- contamination from produced water and flowback water, its storage and risk of spillage or release into the drinking water supply.
- impact on terrestrial, aquatic and subsurface ecosystems from clearing

The SCA has developed six principles for managing the impacts of (mining) and CSG activities (Sydney Catchment Authority, 2012b).

As discussed previously in Section 7.5 on long-term impacts on water, there is the potential for changes in hydraulic connectivity and conductivity to impact connected groundwater bodies and as well as surface water bodies, and great care needs to be taken in developing groundwater models informed by data collection, and an assessment of the risks involved with water extraction and management during CSG activities. The importance of this modelling and risk assessment, including its statistical confidence, is further heightened in the case where cumulative effects of other industries are in play, in particular where the actions of those industries can potentially alter the basic geological and hydrogeological characteristics of the system. This is even further heightened in importance when the activities are occurring adjacent to, and underneath, a drinking water catchment. Further discussion on cumulative impacts is located in Chapter 13.

7.5.7 Water regulation

Given the very large number of water bores throughout NSW used for irrigation, monitoring and bore water, coupled with systems to collate water information such as in the NSW Office of Water, there is a relatively good understanding of the nature of the alluvial, artesian and shallow groundwater system. The Water Sharing Plans, Water Licences and more recent Aquifer Interference Policy, have provided further impetus to better understand the groundwater system. However, further work on regulation to address cumulative impacts is warranted (see Section 13.2). It should be noted that the level of knowledge and data available for the deeper groundwater bodies and aquifers is not as good, largely because the majority of water bores are in the shallower aquifers.

The Commonwealth Government has amended the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) to require any CSG development or large coal mining development that has, will have, or is likely to have a significant impact on a water resource. These actions will require approval under the EPBC Act once the changes commence (the Bill was assented to in June 2013). This development gives the Federal government an enhanced environmental assessment role in relation to mining and CSG projects.

7.6 DATA, MODELLING AND TECHNOLOGIES

7.6.1 Required data

Given the potential for significant impacts on water resources, it is important that “(T)he starting point for effective water management is to obtain a comprehensive understanding of the hydrogeology of the CSG basin” (Cook, 2013a). This understanding is built upon data collected before, during and after the CSG activities.

Understanding hydrological systems requires that baseline data are collected. Under natural conditions, water levels and quality are not static due to variations in the climatic drivers of the system (i.e. precipitation and evapotranspiration). In addition, surface waters are often regulated, and aquifers are already being used for stock, domestic and irrigation water demands. Thus, before any CSG activities, the hydrological system is already in a state of flux. Baseline data enables an understanding of the current system to be built up.

Collecting data to develop an understanding of initial conditions (baseline data) should be initiated before pilot or production phases of a CSG project. Baseline data helps to compare future impacts of CSG activities, including the hydrological system, and helps one to understand the surface water and groundwater system in the pre-production condition in order to be in a position to confidently predict and monitor the impacts of CSG activities.

To enable a comprehensive understanding of the hydrological system, the datasets should have a sufficient duration and spatial coverage. For this, there are no simple rules that can be followed. Data should be collected or accessed to establish at least seasonal and inter-annual variability. In regions subject to patterns of flooding and drought, there may be a need for longer data sets. Similarly, the number and location of monitoring points is particular to the system being studied. For groundwater studies, in general, monitoring points are required vertically above and below as well as within the aquifer unit of interest (see Figure 7.3), and at a minimum of three points (to define a surface) laterally also. Monitoring networks that have been developed by experts and independently reviewed would assist to grow the available data.

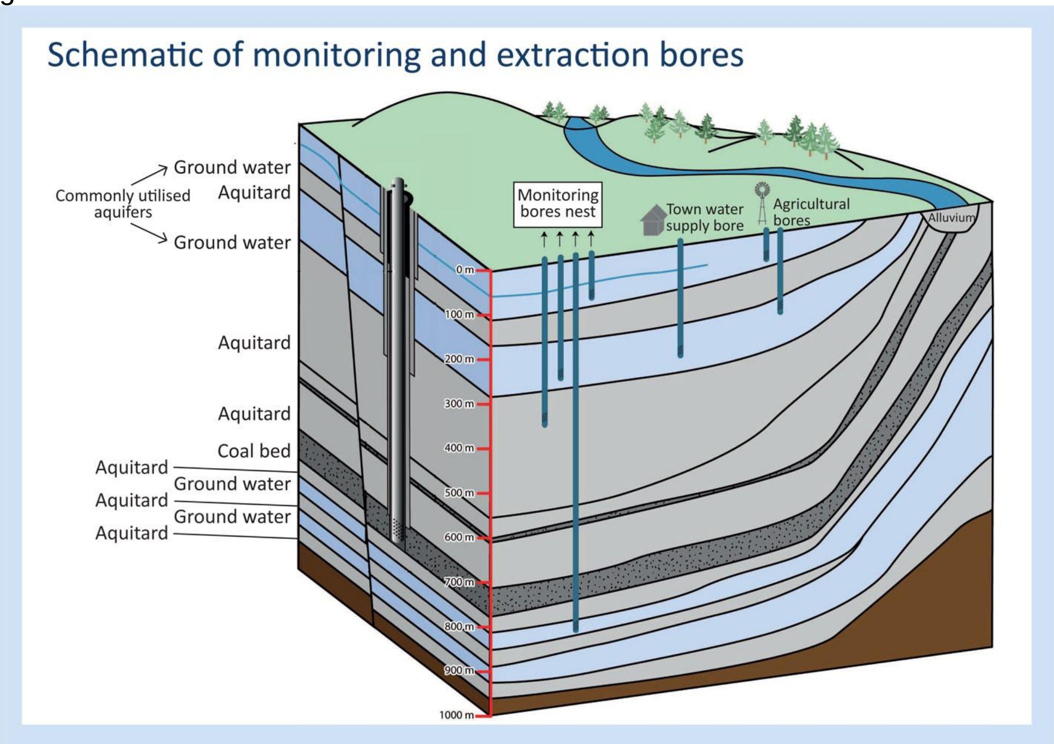


Figure 7.3: Schematic of monitoring and extraction bores Source: Water Research Laboratory, UNSW (Anderson, Rahman, Davey, Miller, & Glamore, 2013)

Ongoing monitoring of surface water and groundwater levels and quality parameters is essential during the production phase of the CSG project. Furthermore, the monitoring "*must* continue for many years well after the completion of the activity" (emphasis in original Anderson et al., 2013). Without these data, it will not be possible to assess the impacts of CSG activities on the hydrological system.

7.6.2 Existing data

In many cases, other data sets owned or collected by industry, government, a neighbouring tenure holder or farmer could be available that would provide valuable added information to a CSG extraction licensee. The practice of data-sharing should be encouraged, both at the planning and application stage, and also maintained throughout the development. This sharing of knowledge, helps a CSG (or mining) licence holder to build the understanding of their own development; as well as the regional cumulative impacts of their combined developments (such as a mine and a CSG field in the same area); and it also is a mechanism better to understand the long-term impacts of their proposed development by analysing the effect of their neighbouring mine. Some data are considered commercial-in-confidence by coal mining and CSG companies. Chapter 14 of the report discusses data issues.

The NSW Office of Water (NOW) manages the largest network of surface water and groundwater monitoring sites in the state. There are over 2000 surface water sites and more than 9000 groundwater sites (NSW Office of Water, 2013). Of the surface water sites, about 95% are digitally monitored and 77% telemetered. In contrast, of the groundwater sites, about 10% are digitally monitored and 10% telemetered. Some of these data can be assessed online.

The NSW Strategic Water Information and Monitoring Plan (NSW Office of Water, 2012) notes that "in some catchments, the groundwater network coverage is not fully meeting water information requirements". This review also found "insufficient hydrogeological classification of groundwater sources". These data gaps impact on "planning for future sharing of the resource" including "sustainability of water users and the environment" as well as the compliance auditing of "groundwater use – pumping drawdown, interference, trading". Given that the groundwater monitoring sites that were the subject of this study are focussed on the shallow alluvial sediments, there would seem to be opportunity to improve the information through the development of deeper groundwater monitoring bores and piezometers.

7.6.3 Modelling

Increased monitoring capabilities, particularly in the deep aquifers and sophisticated modelling approaches will enable better understanding of the hydrological system related to CSG, including potential impacts on the ground water and surface water. Much work, most notably by CSIRO, the Bureau of Meteorology (BoM) and many universities, has been done over many years building complex numerical models of aspects of Australia's groundwater system. Given the challenges involved, the introduction of new and powerful computational techniques such as the work being carried out in this area by NICTA provides useful further insights into the issue.

An example of work being conducted in NSW by NICTA is a project, in partnership with the NSW Office of Water, on hydrogeological models. This project is using data fusion techniques and machine learning to develop probabilistic models of groundwater systems. This research is being funding through the National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development. Further information on the project is at www.water.nsw.gov.au/Water-management/Modelling/Modelling/default.aspx. A parallel project has also been commissioned at NICTA by Geoscience Australia.

7.7 COMMENTS FROM THE REVIEW

Concern about produced water, the drawdown of groundwater and the water table, contamination of water sources, and the risk of irreversible damage to the water system is one of the most common set of issues raised by community and submissions to the review.

The issue of potential contamination from flow-back water and produced water through release or spills into surface water, soil or shallow aquifers should be able to be addressed through appropriate planning and characterisation, and by utilising and maintaining appropriate infrastructure (treatment facilities, holding ponds and transport), and having available well-skilled industry employees and compliance officers.

In relation to concern with water table and groundwater drawdown and quantity issues, NSW water use is regulated in such a way that any activity (e.g. CSG extraction, irrigation, mining, etc.) that has impacts on groundwater or surface water through an aquifer must be licensed. This means that if there is no available groundwater that can be taken, the activity cannot proceed.

Reducing the risk of groundwater contamination can occur through using best practice in well drilling and completions to avoid cross-contamination between aquifers and the surface water. Undertaking fracture stimulation, where it is required, using best practice and process monitoring will reduce the risk of fractures creating connections between the coal seam and other aquifers.

The connectivity issue is more of a challenge as we do not know how to characterise it fully at this stage. A lot is known but for a dry continent such as Australia more knowledge will be necessary. Further research is required to build our understanding of the hydraulic connectivity between groundwater bodies (including between shallow and deep aquifers) and also between shallow aquifers and connected surface water bodies. This will require access to large quantities of data, so efforts to open up access to existing data sets and to expand the number of monitoring bores will be welcome.

Further research is also required on cumulative impacts on groundwater and connected surface water where there are numerous wells and plays, and where there are other industries also drawing on the water (such as agriculture) or changing the geological structures such as long-wall mining.

7.8 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- “Background paper on groundwater resources in relation to coal seam production”, Water Research Laboratory, The University of New South Wales
- “Background Paper on New South Wales Geology: With a focus on basins containing coal seam gas resources”, Professor Colin Ward and Professor Bryce Kelly of UNSW Global Pty Ltd
- “Coal Seam Gas: Produced Water and Solids”, Dr Stuart Khan, The University of New South Wales
- “Interim report: Background paper on produced water and solids in relation to coal seam gas (CSG) production”, Dr Damian Gore and Dr Peter Davies, Macquarie University.

8 SUBSIDENCE

Subsidence is a general term usually applied to downward movements in the ground surface. The occurrence of subsidence, either by natural or anthropogenic factors, is a concern in engineering practice due to the potential impacts on infrastructure, natural resources, and the environment. The study of subsidence draws on a range of discipline areas including geology, hydrogeology, geomechanical engineering and environmental engineering.

8.1 HOW SUBSIDENCE MAY OCCUR

There are four basic origins of subsidence:

- reduction in the volume (shrinkage) of subsurface soils and rocks
- compression of subsurface soils and rocks due to a change in stress
- filling of a subsurface void by overlying materials
- movements in the earth's crust.

Subsidence occurs naturally as a result of:

- relative movements of geological structures (tectonic actions)
- induced consolidation caused by seismic actions
- dissolutions of geological structures – erosion by water flow
- cyclic swelling-shrinkage of clayey materials by changes in the water table (seasonal subsidence).

Subsidence may also occur as a result of anthropogenic (manmade) causes, including through:

- excavation
- mining subsidence (e.g. longwall mining for coal)
- subsurface erosion and karst collapse (creation of sinkholes or caverns)
- withdrawal of ground pore fluid - geothermal water or steam, groundwater (as in agriculture and CSG extraction) and oil and gas.

The growing interest in CSG as an energy source in Australia means that it is now necessary to evaluate the potential subsidence, as well as the possible mitigation measures that are available to minimise and/or control subsidence during gas extraction (Pineda & Sheng, 2013).

8.1.1 Coal seam gas

Subsidence is caused by the compression of the coal seam as a consequence of the reduction in the pore fluid pressure (due to dewatering) that increases the effective stress. The magnitude of the subsidence seen at the ground surface will depend on the compressibility of the strata from which the water is extracted, the thickness and strength of the overlying formation and other factors such as the natural stress within the rocks (see Figure 8.1). Compressibility is typically low (but variable) for coals and very low for hard rock, sedimentary rocks such as sandstones and mudstone which dominate coal basin rocks.

Subsidence can be further complicated by the influence of a stimulation procedure or hydraulic fracturing (see Figure 8.1). Uncontrolled fracturing, caused by excessively high applied fluid pressures during hydraulic fracturing, could induce fractures in the coal seam as well as the adjacent strata (hence degrading their strength). The hydraulic connectivity between different strata could possibly lead to an acceleration of subsidence (Pineda & Sheng, 2013).

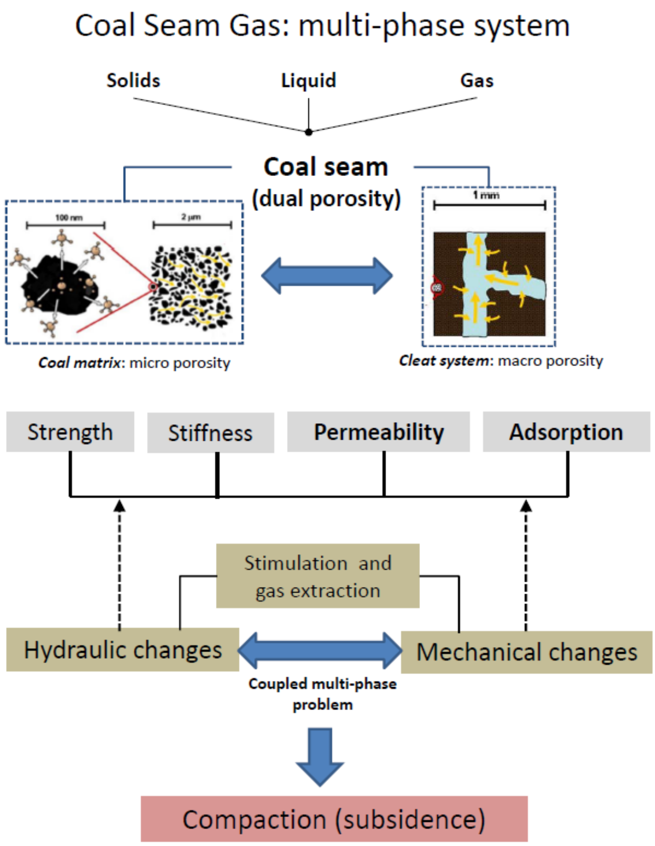


Figure 8.1: Coal seam gas: Multi-phase system
Source: (Pineda & Sheng, 2013)

Subsidence associated with CSG extraction is a coupled hydro-mechanical phenomenon caused by the reduction of the pore fluid pressure when extracting the methane from the coal seam. As represented in Figure 8.1, the unique characteristics of coal, in combination with the techniques used to extract the gas (dewatering and potentially fracture stimulation), make subsidence a multifaceted and site dependent problem.

Different subsidence bowls (areas of subsidence around the activity) are expected if vertical or horizontal well configurations are used for gas extraction. However the magnitude of the induced-subsidence may not be compared easily as different volumes of coal and different gas production rates are involved in each case. It is expected that multiple wells will enhance the subsidence bowl in both cases. The overlapping of the subsidence bowls will depend not only on the separation length between wells, but also on the effectiveness of the stimulation and extraction techniques.

Estimates by CSG proponents of subsidence across CSG areas range between 0.06 m and 0.2 m over 2 km lateral distance. The resultant 0.003% to 0.1% differential subsidence is small and is not expected to have a significant impact on buildings. Local responses to subsidence are difficult to predict but could have impact on:

- infrastructure – the well itself, access roads, houses, buildings, pipelines, water supply, sewage systems, dams, connection to nearby underground workings
- natural resources – aquifers, streams, rivers, lakes, cliff lines, rock formations, archaeological sites, micro-tremors in fault systems.

The impacts and severity of subsidence in CSG production depends mostly on proximity to the well, but also on the vulnerability of the infrastructure under study.

The potential for subsidence depends greatly on the geology and hydrogeological conditions of the region. Figure 8.2 shows the geological profile at the AGL Camden Gas Project where the Bulli and Balgownie coal seams – at about a depth of 770 m – are targeted. The maximum subsidence in this area should be the result of the compression or compaction of the two coal seams plus any additional compaction due to the dewatering in the overlying strata. There are currently no published estimates of subsidence for CSG development in the Sydney Basin, however the geology and hydrogeology suggests that any subsidence from CSG would likely be small to insignificant.

The highest potential for subsidence is in localised areas of CSG basins that have loose, unconsolidated and unconfined alluvial aquifer systems that are in direct hydraulic connection with the underlying coal seams. A potential example could be the potential dewatering of surface alluvial deposits in the Namoi Valley (Gunnedah Basin). However it also must be noted that water extraction for agriculture in these areas also can lead to subsidence.

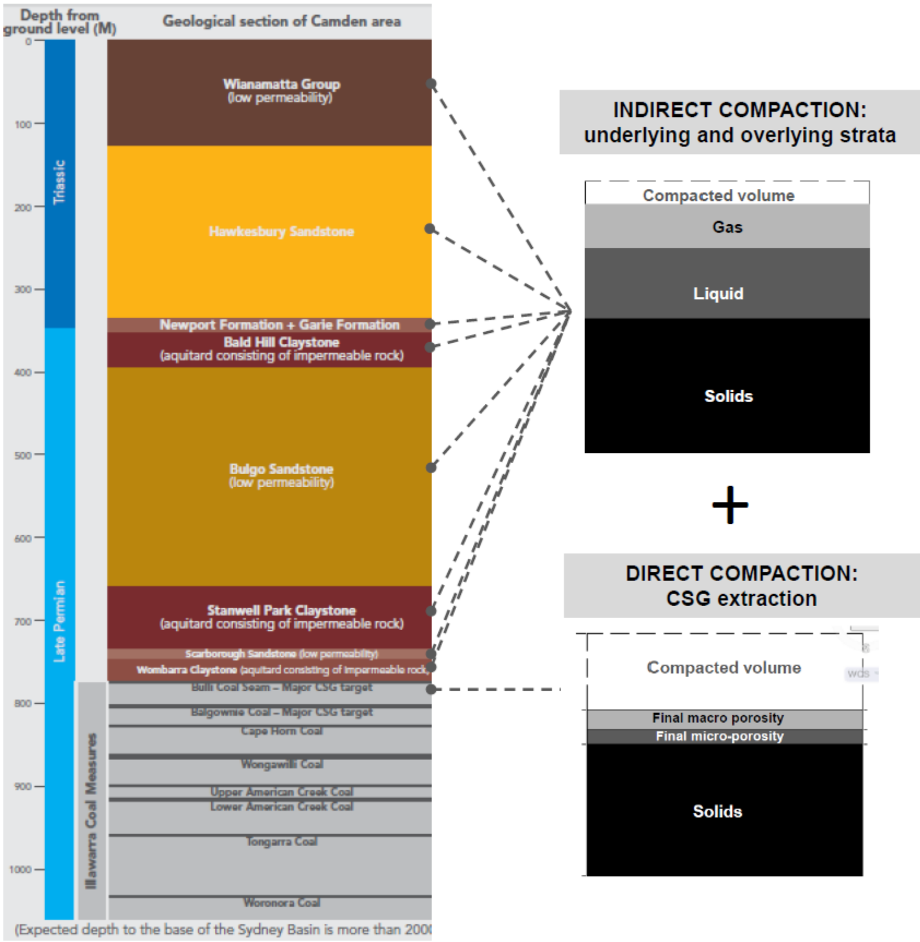


Figure 8.2: Geological profile at the AGL Camden Gas Project and the compaction process
Courtesy of Professor Daichao Sheng and Dr Jubert Pineda, ARC Centre of Excellence for Geotechnical Science and Engineering, The University of Newcastle (Pineda & Sheng, 2013)

Queensland currently has a much larger CSG industry than NSW, with their coal seams producing larger volumes of water (see Chapter 5, Geology). Predicted subsidence from modelling the Walloon Coal Measures in the Surat Basin in South East Queensland varies between 50 mm and 200 mm. A project is currently underway in Queensland to study historical and current levels of subsidence in CSG fields; it will also continue with ongoing monitoring. Given the early stages of the project, there is no definitive confirmation of actual subsidence in the field related to CSG in Australia to date.

The Powder River Basin, Wyoming, USA, has been producing CSG for over a decade, and currently has over 20,000 wells producing gas. Preliminary estimates of subsidence due to aquifer drawdown were found to be about 12 mm (Evans, Rosin, Andrew, & Spies, 2013).

8.1.2 Tunnels

The ground subsidence for infrastructure for urban development such as transport and utility tunnels are usually very small due to restrictions in urban areas. The subsidence varies in accordance with ground conditions and methods used, but usually range between 10 to 30 mm. The subsidence is generally restricted to an area around the construction areas.

8.1.3 Mining

Mining activities, such as longwall mining, are another excavation process that causes subsidence problems. This is of major interest in Australia due to our long history of large scale coal mining. In 2020 about 88% of NSW underground coal was produced by longwall mining (DTI, 2010 as cited in Evans et al., 2013).

Longwall coal mining involves cutting panels 150-400 m wide, 1,000-4,000 m and 2-5 m thick. The roof of the excavation front is temporarily supported but is then allowed to collapse once temporary support is removed. This is defined as the 'goaf'.

Additional factors causing subsidence in longwall operations are:

- the presence of adjacent panels
- multiple seams
- disordered movements (buckling and cracking of rock bars may occur when the longwall passes under drainage courses
- subsurface model (the local hydro-geological model).

The maximum vertical subsidence extending to the surface is typically 1–2 m, or more than half the thickness of the coal seam extracted. Table 8.1 provides examples of maximum subsidence reported in the literature for longwall mining operations in NSW coalfields. The number of longwall mines is expected to rise significantly over the next 20 years.

Table 8.1: Published data of maximum subsidence in NSW coal fields

Location	Panel	Thickness of seam (m)	Width (m)	Cover depth (m)	Subsidence max (m)	Source
Newstan Colliery	LW 6	3.4	155	60	2.03	(Holla & Thompson, 1992 as cited in Pineda & Sheng, 2013)
	LW 8	3.2	210	75	3.03	
Liddell Colliery	LW 1	2.4	180	160	1.55	(Li et al., 2007 as cited in Pineda & Sheng, 2013)
	LW 3	2.0	180	200	2.10	
Cummock Colliery	LW 17	2.2	210	90	1.72	
	LW 3	2.5	205	133	1.25	

The large magnitude of subsidence above longwall panels imposes significant fracturing of the overlying strata which tends to permanently alter its hydrogeological properties. Also with the large magnitudes of surface subsidence there is much greater risk of damage to infrastructure, stream flows and surface hydrology.

Due to the subsidence caused by coal mining activities in NSW the Mine Subsidence Board (NSW Trade and Investment) was set up to ensure compensation for those affected and to control the types of buildings in mine subsidence areas. This authority is enabled through the *Mine Subsidence Compensation Act 1961*.

Further to this, in 2008, an independent inquiry was conducted due to concerns over both past and potential future impacts of mine subsidence on significant natural features (such as cracking of the bed of the Cataract River) in the Southern Coalfield. These impacts were published in the final report, *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield,* available at http://www.planning.nsw.gov.au/planningsystem/pdf/report_southern_coalfields_final_jul08.pdf. The report provided a series of recommendations related to subsidence impact management, better prediction of subsidence effects and impact and the need for environmental baseline data. After the inquiry there was a shift toward greater obligation on the proponents to demonstrate the project would not have unacceptable impacts on natural features (Alderman, Price, & Binder, 2011).

8.1.4 Groundwater extraction

Subsidence caused by groundwater extraction can affect large areas. Subsidence occurs as a result of two mechanisms during groundwater withdrawal:

- local compaction due to the reduction of pore pressure that increases the effective stress
- lateral shrinkage of strata where the water table is lowered.

Excessive groundwater drawdown in poorly consolidated alluvial aquifers can cause widespread subsidence. An example of this in NSW is in the Lower Namoi Valley, in northern NSW, an alluvial valley in an area of 5,100 km^2 (Ross & Jeffrey, 1991 as cited in Evans et al., 2013). The valley has the most developed groundwater system in NSW, with a history of more than 30 years of irrigated agriculture e.g. cotton production. Over-utilisation of the groundwater resources has resulted in between 80-210 mm of subsidence over the 10 year period between 1981 and 1990. No further estimates have been made since this time. A major concern is that previous excessive use may have impacts much further into the future.

8.1.5 Oil

Extraction of oil from underground deposits in sedimentary basins (such as from sandstone, shale, mudstone or coal) can result in subsidence. The magnitude and extent depend on the characteristics of the reservoir and the overlying strata.

The Wilmington Oil Field located near Long Beach California, USA, the third largest oil field in the country, has experienced significant subsidence due to oil extraction (Mayuga & Allen, 1969 as cited in Evans et al., 2013). The subsidence bowl covered an area of about 50 km^2. The centre of the subsidence bowl experienced over 9 m of vertical subsidence which was evaluated between 1926 and 1968. There was also horizontal movement of about 3 m recorded. The subsidence caused major damage to wharves, pipelines, buildings, streets and bridges. The rate of subsidence was reduced, beginning in 1958, through the injection of sea water into the producing strata.

8.1.6 Cumulative subsidence

There is also the possibility of cumulative subsidence in areas where multiple activities that draw on underground resources are occurring, such as mining, agriculture and CSG. Subsidence from one activity alone can have impacts on the geological and hydrological conditions surrounding the activity, including altering the geological structure, permeability, and surface hydrology.

Monitoring of the region would be required to determine the impact and magnitude of subsidence in these areas. Monitoring techniques are discussed below.

This potential cumulative subsidence needs to be considered during planning and proposal stages for any activity and needs to consider past activities in the region. The issue of cumulative impacts is discussed in Chapter 13 of the Report.

8.2 MONITORING SUBSIDENCE IN CSG

A detailed monitoring through the entire profile is crucial for a better understanding of the subsidence phenomenon in CSG extraction. Since the amount of subsidence from CSG is estimated to be in the range of millimetres to centimetres, surveying methods designed to monitor ground deformation associated with CSG extraction must be able to measure a high degree of vertical accuracy (1-2 cm) over very large areas for long time frames (10+ years).

The most appropriate measuring technique for any particular CSG activity monitoring will depend upon the spatial extent of the expected deformation and the likely magnitude. Crude techniques can be used to detect large (i.e. > 0.5 m) deformation signals, while more sophisticated – and more expensive – techniques are required to detect small (i.e. < 1 cm) deformation signals.

All require repeat measurements in order to derive estimates of change (i.e. subsidence). The more frequently the observing program is repeated, the greater the insights will be into how the subsidence pattern evolves over time.

Since subsidence is a measure of change in the Earth's surface, a baseline measurement of where the Earth's surface was prior to CSG activities – or would have been without any CSG activity – is needed. This requires defining the topography of the surface prior to any activity, which in effect means commencing an observing program in advance of CSG activity. This monitoring should continue throughout production and after production is completed to ensure the impacts are fully understood over time.

Interferometry Synthetic Aperture Radar (InSAR) is a satellite based remote sensing technique that could be used to monitor subsidence caused by activities such as CSG. The technique uses radar signals to measure changes in the land surface elevation over time. This technique can be cost effective and allow the measuring of land surface deformation on a regional scale with a high degree of resolution. This technique has successfully been demonstrated in Australia and internationally to monitor subsidence from longwall mining (Ge et al., 2007a, 2007b as cited in Evans et al., 2013); earthquake studies to measure better than 3 mm (Dawson, 2008 as cited in Evans et al., 2013), and aquifer response to groundwater pumping (Bell et al., 2008 as cited in Evans et al., 2013). A weakness of this data is that the satellite missions do not always operate continuously, leading to gaps in the data.

SAR supported by ground Global Navigation Satellite Systems (GNSS) could enable the measurement of horizontal and vertical movement at discrete points to accuracies of 5 mm and measurement of vertical movements of large areas to accuracies in the order of 10 mm at horizontal resolutions of 3 mm (Lemon, Spies, Tickle, & Dawson, 2013).

Airborne LiDAR (Light Detection and Ranging) is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light (McClusky & Tregoning, 2013). Airborne LiDAR mapping can produce high-resolution topographic maps of high accuracy. LiDAR could be used to develop baseline measurements, by taking a survey prior to the commencement of CSG activities. This technique could bridge the above-mentioned gaps in satellite mission data (McClusky & Tregoning, 2013).

An extensive subsidence monitoring program is currently being undertaken in Queensland. Four CSG companies have commissioned a regional satellite InSAR study to look at historical and current earth surface movements (Lemon et al., 2013).

Broad area monitoring of subsidence in NSW could be accomplished through analysis of data from a variety of sources including InSAR, LiDAR and historical photographic images of the State.

8.3 COMMENTS FROM THE REVIEW

Possible subsidence needs to be considered when planning, managing and monitoring CSG activities. The level of potential subsidence from CSG projects depends on the geological and hydrogeological conditions as well as any existing subsidence from prior activities in a region such as mining and agriculture.

The extent of potential subsidence from CSG activities is expected to be considerably less than longwall mining and somewhat less than water extraction for irrigation from alluvial aquifers. However, even though subsidence due to CSG is estimated to be low, the causal mechanisms are not completely understood and further study is required.

Data collected from monitoring activities as part of the CSG extraction process can lead to development and improvement of models to enable a better understanding of subsidence. The early understanding of subsidence, not only related to CSG, will require the development of baselines and ongoing monitoring strategies, such as through the use of remote sensing technologies. See Recommendation 3.

8.4 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- "Subsidence: An overview of causes, risks and future developments for Coal Seam Gas Production", Dr Jubert Pineda and Professor Daichao Sheng, ARC Centre of Excellence for Geotechnical Science and Engineering, the University of Newcastle
- "Background paper on subsidence monitoring and measurement with a focus on coal seam gas activities", Dr Simon McClusky and Dr Paul Tregoning, Research School of Earth Sciences, the Australian National University
- "Subsidence Causes Related to Coal Seam Gas Production", CRC for Spatial Information
- "Subsidence Monitoring", CRC for Spatial Information.

9 EARTHQUAKES AND INDUCED SEISMICITY

The seismicity or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time (Earthquakes, 2013). Earthquakes are the motion produced when stress within the Earth exceeds the strength of rocks at its weakest points. These are some regions of the Earth that experience earthquakes more frequently, but no part of the Earth's surface is free from earthquakes (Geoscience Australia, 2013).

Earthquakes are most common at tectonic plate boundaries, with some of the largest events occurring where the plates collide, or slide past each other, particularly around the edge of the Pacific Plate (New Zealand, Papua New Guinea, Japan and the Americas) and where the Indo-Australian Plate collides with the Eurasian Plate (Indonesia).

Earthquake magnitude is a measure of the 'size' on a scale, usually determined from a measure of ground motion as recorded by seismometers then corrected for distance. The Richter scale, M_L, is a logarithmic scale, with 1 magnitude unit increase corresponding to an increase of displacement by a factor of 10, and two units a factor of 100.

There is a huge range in earthquake sizes from the smallest events recorded in mines with magnitude -3.0 M_L to the largest known earthquake in Chile during 1960 9.5 M_L (Gibson & Sandiford, 2013).

Earthquakes smaller than 3.0 M_L are often called microearthquakes, with the associated seismicity called microseismicity. Normal tectonic earthquakes in this range may be felt or heard, but rarely cause any damage, and never produce serious structural damage. However, because of the short distances involved, induced earthquakes in mines with magnitudes of less than 1.0 M_L may cause local safety problems, and larger than 2.0 M_L may cause serious damage (Gibson & Sandiford, 2013).

Several different magnitude scales are used, using different seismic waves (P, S or surface waves) and motion of different frequencies. The original Richter Local magnitude, M_L, is suitable for smaller earthquakes within 600 km of the seismometer and is best up to M 5.0. Two newer scales are moment magnitude, M_W, which is based on low frequency spectral displacement (best from 6.0 M_W to 9.0 M_W), and energy magnitude, M_e, which depends more on high frequency motion (Gibson & Sandiford, 2013).

The Australian continent has a low level of seismic activity, but with occasional damaging earthquakes. In a typical region a seismic event is only felt on average every 5-10 years. The Australian continent experiences about 600 recorded events each year with typically only 2 events with magnitudes greater than 5 M_L. In the last year (4/7/2012–4/7/2013) (Geoscience Australia Earthquake database http://www.ga.gov.au/earthquakes/searchQuake.do) there were 591 recorded earthquakes in Australia, with 587 of these less than 4 M_L (507 less than 3 M_L). Only 4 events were greater than 4 M_L, with the largest being 5.7 M_L on 9 June 2013 near Pukatja (formally Ernabella), South Australia (1,400 km by road from Adelaide). According to Geoscience Australia, earthquakes above 5.5 M_L, such as at Newcastle in 1989, occur on average every two years (Geoscience Australia, 2013).

The record of seismicity in continental Australia is quite heterogeneous, with a number of distinct seismic zones being defined. Almost all Australian earthquakes are in the upper crust, from the surface to a depth of about 20km.

9.1 INDUCED SEISMICITY

There are two broad mechanisms for triggered earthquake activity. The first involves changing the stress within the earth; the second involves reducing the strength of faults. Earthquakes are commonly 'triggered' in an entirely natural way. The term 'induced' is used to indicate possible anthropogenic impact on the event. Earthquakes can be triggered by human activities, including the filling of large water reservoirs, mining and activities involving pumping fluids into and out of the crust, such as required in hydrocarbon extraction, geothermal energy and some water resource activities. These types of earthquakes are called 'induced'. Some notable induced earthquakes are included in Table 9.1.

Table 9.1: Some significant Australian earthquakes including notable 'induced' earthquakes

Year	**Location**	**State**	**Magnitude** (M_L)	**Effects/notes**
1892	Flinders Island	TAS	~ 6.9	Offshore sequence, felt widely across SE Australia.
1897	Beachport	SA	~6.5	Felt widely. Significant damage in vicinity.
1906	Newcastle	NSW	n.a.	Believed to be mining-induced 'creep'; buildings rocked, walls cracked, gas mains burst.
1929	Broome	WA	~6.6	Felt in Perth.
1941	Meeberrie	WA	~7.1	Australia's largest onshore earthquake. Felt over much of WA including Port Hedland and Albany.
1954	Adelaide	SA	5.4	Centred 15 km south of Adelaide. Some building damage in Adelaide
1959	Jindabyne	NSW	5.0	Induced by Eucumbene Reservoir filling
1968	Meckering	WA	6.8	Significant building and infrastructure damage (millions of dollars)
1970	Lake Mackay	WA	6.7	Significant subsequent aftershocks
1973	Warragamba	NSW	5.5	Induced by Warragamba Reservoir filling
1989	Newcastle	NSW	5.6	12 deaths; very significant building and infrastructure damage (billions of dollars)
1996	Thomson Dam	VIC	5.0	Induced by Thomson Reservoir filling
(Leonard, 2008; McCue, 1990; Gibson, 1997; and McCue 2012 as cited in Gibson & Sandiford, 2013)				

Induced earthquakes differ from normal earthquakes in that they can be caused by an external trigger. The type of faulting of an induced earthquake is not different from a normal earthquake at this location. Failures in faults that trigger induced earthquakes can occur through increasing shear stress, reducing normal stress, and/or elevating the pore pressure (Brodsky & Lajoie, 2013).

As with normal tectonic earthquakes, the magnitude of the induced earthquake depends on the stress level about the fault. If the stress is high over a long segment of the fault, the magnitude may be large. However, since induced events usually occur at shallow depths, they tend to have small magnitudes similar to those in normal shallow earthquakes (Gibson & Sandiford, 2013).

A site that is susceptible to induced earthquakes generally has a pre-existing susceptibility to natural earthquakes. This means that the worst-case scenario for a site is the same maximum credible magnitude earthquake that would have occurred eventually without any artificial trigger mechanism (without being induced) (Gibson & Sandiford, 2013).

In the central and eastern US, there has been a dramatic increase in the earthquake count, with more than 300 earthquakes $M_L \geq 3$ in 3 years from 2010 to 2012, compared with an average rate of 21 events per year between 1967 to 2000 (Brodsky & Lajoie, 2013). The possibility that these events were induced has been raised since many occurred close to different industrial activities. However it is difficult to determine the actual cause of the increase.

The current seismological methods do not allow the discrimination between human induced and natural tectonic earthquakes (Brodsky & Lajoie, 2013). This is because induced earthquakes can occur at the source of the activity or a distance away; they also can happen a long time after an activity has ceased.

9.1.1 Coal seam gas

CSG gas extraction occurs at shallow depths usually less than 1 km, compared with shale gas extraction at depths to 3 km and geothermal energy production at depths of 3 to 5 km. Shallow rocks and especially shallow sedimentary rocks tend to be weaker than those at greater depth, and can support a lower stress limiting the magnitude of earthquakes that can occur within them, and limiting the chance of inducing a larger earthquake at depth.

In Australia, to date, there have been no reported incidents of induced seismicity associated with hydraulic fracturing, either in coal seam gas or tight gas operations (Case, 2000 as cited in Cook et al., 2013). Overall the likelihood of fracking resulting in induced seismicity is judged to be low in both shale and coal seam gas production.

Induced seismicity is more likely to arise from deep disposal of fluids than from hydraulic fracturing in CSG activities (Gibson & Sandiford, 2013). Also hydraulic fracturing is not always required. Wastewater reinjection may be applied to CSG projects due to concerns about surface storage. Worst-case scenarios with CSG activities are likely to be involved with wastewater injection, rather than hydraulic fracturing and water and gas extraction.

9.1.2 Hydraulic fracturing in other unconventional gas and geothermal energy

The extraction of shale gas and the production of geothermal energy require the use of hydraulic fracturing. There have been recent reports of earthquakes associated with fracking activities; however their magnitudes were too small to cause any structural damage to infrastructure (Brodsky & Lajoie, 2013). In its review of shale gas in the UK, The Royal Society and the Royal Academy of Engineering (2012) states, “There is an emerging consensus that the magnitude of seismicity induced by hydraulic fracturing would be no greater than 3 ML (felt by few people) and resulting in negligible, if any surface impacts” (Mair et al., 2012).

Some potential induced seismic events, to date, include:

- South central Oklahoma, USA - sequence of events with a maximum 2.9 M_L that were temporally correlated with fracking activities
- Near Blackpool, UK – in April and May 2012, a series of earthquakes (maximum 2.3 M_L) during fracking of a shale reserve
- Basel, Switzerland – injection of water under high pressure into impermeable basement rock to develop EGS induced four 3 M_W earthquakes in 2006 and 2007 (this led to the project being abandoned) (Brodsky & Lajoie, 2013).

Microseismicity is associated with hydraulic fracturing and can be used to measure fracture growth (orientation and extent). The fracking process causes shear slip along natural fractures in the reservoir and the surrounding rock, and this produces a microseismic signal that can be monitored by a long array (60-120 m) of accelerometers/geophones (which convert ground movement into voltage so it can be recorded) located in an offset monitoring well. Other measuring devices can be used to monitor the fracking process. This monitoring is generally only relevant during the fracking operations.

9.1.3 Fluid and wastewater injection

Fluid injection into geological basins is used in solution mining, EGS, hydrocarbon recovery, and storage of gases, contaminants and waste fluids. This could also be applied to CSG activities if produced water is reinjected (Gibson & Sandiford, 2013).

In a high proportion of cases where fluids are injected into well-consolidated rock, earthquakes will be triggered, especially if the rock is fractured or jointed. The total volume of fluid injection into rocks seems to be a key determinant for increasing the size of an induced earthquake. Most of the larger earthquakes experienced as a result of fluid injection are from depths from about 3 to 5 kilometres, where less weathering and fracturing allows higher strain energy density (Gibson & Sandiford, 2013).

The largest event associated with wastewater reinjection occurred near Prague, Oklahoma, USA, with a magnitude 5.7 M_W earthquake on 5 November 2011 (Gibson & Sandiford, 2013). No unusual seismic activity had occurred in this region in the past, with waste water reinjection beginning 18 years previously. Then in 2010 a 4.1 M_W earthquake occurred near injection wells with aftershocks after this initial event occurring sporadically though 2010 and into 2011. Then on 5 November 2011 a 5.0 M_W earthquake occurred which was followed 20 hours later by the 5.7 M_W mainshock. These large events occurred within 1.5 km of the injection wells (Brodsky & Lajoie, 2013). Previous to this the largest event was near Denver, Colorado, USA with a 4.8 M_W event on 9 August 1967 (Brodsky & Lajoie, 2013).

9.1.4 Reservoir trigged seismicity

Large reservoirs are known to trigger or induce earthquakes. Most water reservoirs trigger only small earthquakes, a few have triggered magnitudes exceeding 5.0 M_L and a couple of large reservoirs have triggered magnitudes larger than 6.0 M_L. Groundwater pore pressure is increased by compression under the weight of the reservoir, which will increase as the reservoir fills, and can trigger earthquakes almost immediately (Gibson & Sandiford, 2013).

The earthquakes triggered by this mechanism are delayed after reservoir filling because of the low permeability. Thomson (5 M_L) and Warragamba (5.5 M_L) Dams both experienced earthquakes exceeding magnitude 5.0 M_L more than ten years from commencement of filling. In most cases the rate of reservoir triggered activity reduces after about 20 years, and the probability of earthquake activity reverts to the levels that existed prior (Gibson & Sandiford, 2013).

9.1.5 Mining-triggered seismicity

A relatively high proportion of underground mines trigger earthquakes compared with the proportion of water reservoirs that trigger earthquakes. Mines that trigger events of magnitude 4.0 M_L or above are usually large mines (open-cut or underground) and maximum magnitudes experienced are about 5.5 M_L.

Large open-cut mines in hard rock reduce the vertical principal stress under the mine, and so tend to trigger earthquakes in reverse faulting environments. The most significant example of this in Australia was the shallow magnitude 5.0 M_L event a couple of kilometres southwest and under the Kalgoorlie Super Pit open-cut mine on 20 April 2010.

Underground hard-rock mining-triggered earthquakes are mainly caused by changes in the stress field due to mining. They are often affected by blasting in mines, and many earthquakes occur seconds or minutes after large blasts. The mining causes many small-scale changes that produce large numbers of very small microearthquakes. Magnitudes from -3 up to 0 M_L are common. Events up to 2 M_L are not unusual in some mines, and larger events are sometimes triggered with magnitudes to 4 M_L or more.

9.2 MONITORING, MEASURING AND EARLY WARNING SYSTEMS

Earthquake monitoring is conducted over a wide range of scales, including global, regional, local and micro earthquake using surface instruments or widely spaced borehole instruments. The seismometer arrays concerned cover thousands of kilometres down to kilometres or metres for microseismic monitoring.

In each case the normal practice is to surround the study area by a sufficient number of instruments to allow accurate event locations and determination of focal mechanisms. Events outside the array can be recorded, but with lower accuracies in the analysis.

The cost of monitoring seismicity depends on the resolution, with the relative cost reducing dramatically with increasing scale, with deep borehole monitoring being very expensive, shallow boreholes being expensive, and surface monitoring being relatively inexpensive. Such costs explain why just 3% of hydraulic fracturing operations have been monitored for microseismicity in the US (Zoback, 2010 as cited in Gibson & Sandiford, 2013). In hydraulic fracturing, the hardware cost of a small seismic array for a site is modest, but the expertise to operate the array and process and interpret the data is the real expense.

Geoscience Australia (GA) monitors, analyses and reports on significant earthquakes to alert the Government and the public about earthquakes both here and overseas. GA monitors seismic data from more than 60 stations on the Australian National Seismograph Network and in excess of 300 stations worldwide in near real time. Data is also provided through other international government national seismic networks such as New Zealand, Indonesia, Malaysia, Singapore and China, with access to data from global networks provided by USA, Japan, Germany and France.

The Joint Australian Tsunami Warning Centre (JATWC), operated by GA and the Australian Bureau of Meteorology (BoM), monitors, detects, verifies and warns the Australian community of potential tsunami impacts. The principle objective of the JATWC is to provide emergency managers with at least 90 minutes warning of a potential impact on Australia's coastline from tsunami that are generated from earthquakes occurring on plate boundaries in the Indian, Pacific and Southern Oceans.

9.3 MITIGATION

Appropriate best practice in hydraulic fracturing will mitigate the potential risk of induced seismic events associated with both CSG and shale gas. The Fracture Stimulation Management Plan (FSMP), as required by the NSW Government Code of Practice for Coal Seam Gas Fracture stimulation activities, has a mandatory requirement for a risk assessment that needs to consider induced seismicity.

According to the Australian Council of Learned Academies report, *Engineering Energy: Unconventional Gas Production* (2013),best practice mitigation for hydraulic fracturing involves:

- mapping local fault structures with 3D seismic (and avoiding them);
- near-real-time monitoring of the fracturing by microseismic (and pressure) sensing and
- a plan to cease operation if fracturing impinges on fault structures resulting in prescribed threshold levels in the microseismic signal, so-called ‘cease operation’ trigger levels.

Ellsworth (Brodsky & Lajoie, 2013) suggests that an approach to managing the risk of water injection induced earthquakes would involve ‘setting seismic activity thresholds that prompt a reduction in injection rate or pressure or, if seismic activity increases, further suspension of injection.’

9.4 COMMENTS FROM THE REVIEW

Induced seismic events are unlikely to occur due to activities directly related to CSG, such as hydraulic fracturing, since the extraction activities occur within shallow sedimentary rocks that limit these seismic events from occurring. However, any reinjection of produced water does pose risks of causing induced seismicity. Reinjection of water in the USA has been associated with seismic events up to a magnitude 5.7 M_L.

CSG processes such as hydraulic fracturing should be monitored to ensure that no adverse impacts from induced seismicity or other environmental impacts occur. Advanced microseismic source monitoring is required to help further understand and model the mechanisms involved in hydraulic fracturing.

Characterisation of the geology, in particular the presence of faults that may be associated with seismic events, would potentially influence the choices made around location of activities and the technologies used for CSG processes.

In cases where activities that have the potential to induce a seismic event are occurring, such as reinjecting produced water from CSG, seismicity can be monitored during the injection process. If a seismic event is detected, then the approach to injection needs to be adjusted (e.g. pressures and quantities reduced) or abandoned.

Measurement of seismic events to better understand and mitigate the risk of induced seismicity will require site, local and regional monitoring of earthquakes at high resolution. This may require building up the scale of seismic monitoring that is currently undertaken in Australia. Programs such as Seismometers in Schools (http://www.ausis.edu.au/), through AuScope (http://auscope.org.au/site/geophysical_education_observatory.php), can both increase the amount and resolution of seismic data and teach school children and teachers about earthquakes and geology.

9.5 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- “Seismicity and induced earthquakes”, by Gary Gibson and Professor Mike Sandiford, Melbourne Energy Institute, University of Melbourne.

An additional background paper has been commissioned to obtain more information on seismicity by Dr Barry Drummond.

10 FUGITIVE EMISSIONS AND AIR QUALITY

Fugitive emissions are 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 (http://en.wikipedia.org/wiki/Fugitive_emissions). Submissions to the Review highlighted concerns over fugitive emissions arising from CSG activities, in particular how these may impact human health and the environment. Further discussion of human health impacts from air emissions is in Chapter 11.

Fugitive emissions from CSG activities can include methane, carbon dioxide and other air pollutants (e.g. other volatile organic compounds like benzene, toluene, etc.), which can have impacts as greenhouse gases and on the health and safety of CSG operators and the community. Methane is the primary fugitive emission emitted, as most of the CSG produced in NSW is naturally low in carbon dioxide and averages 95% pure methane.

As explained in Section 5.3, methane is a colourless gas that may be generated as a by-product of metabolic decomposition of organic molecules by bacteria, with major sources of methane being agriculture and farming, particularly industries such as livestock and cattle. Other non-exhaustive sources of methane can include coal mines, wetlands and swamps, forests, garbage dumps, and even cemeteries. Methane has a global warming potential, defined by the Intergovernmental Panel on Climate Change (IPCC), as 21 times that of carbon dioxide.

Fugitive emissions from CSG projects can arise during a number of stages, including production, processing and transport from vented emissions and flaring gas, and gas leakages in pipes, valves and other equipment. Most of the carbon dioxide and other air pollutants emitted during CSG operations arise from diesel trucks and the use of fossil fuels to operate pumps, compressors, generators and other equipment.

It is worthy to note that fugitive methane emissions for the CSG industry result in lost product and revenue, so it is in the industry's interest to minimise methane lost.

10.1 HEALTH AND SAFETY

Health and safety issues related to CSG emissions stem from potential exposure to methane and other air toxins or pollutants that are emitted either as fugitive emissions or during the combustion of fossil fuels to run equipment. The concentration and the pathway of the exposure are critical factors in determining the potential health and safety impacts.

Methane is considered a low toxicity gas with no impacts on human health at low or normal environmental concentrations. However, at mixtures between 5% (Lower Explosive Limit) and 15% (Upper Explosive Limit) in air, it is explosive and can pose a safety risk to people within the high concentration area. At higher concentrations in air, methane can reduce oxygen levels and lead to asphyxiation.

Further discussion of potential health impacts from fugitive emissions and safety issues are in Chapters 11 and 12.

10.2 GREENHOUSE GASES

Natural gas is widely being discussed as a transitional fuel to a lower carbon economy due to natural gas producing around 40% of the carbon dioxide of coal for comparable electricity generation (Day et al., 2012). There is widespread debate, however, that uncertainties in accurately measuring fugitive emissions from CSG operations and the high greenhouse gas effects from methane may negate its benefit over coal in reducing greenhouse gas impacts. The ACOLA study on shale gas (Cook et al., 2013) considered this issue and concluded that, for shale gas at least, it is not correct provided best practice including green completions is followed. Accurately estimating or measuring fugitive emissions from CSG activities in Australia is central to inform the debate over whether CSG has lower overall greenhouse gas impacts than coal use for electricity generation.

In the United States, where the unconventional gas industry has grown rapidly, per capital greenhouse gas emissions fell 16% from 2000 to 2009 (Cox, 2010). This figure has been largely attributed to increased use of gas over coal for electricity generation and other domestic and industrial purposes.

Fugitive emissions created by various industries, including agriculture, manufacturing, electricity production, mining, waste and transport, are measured or estimated annually and reported under the National Greenhouse Gas Emissions Reporting Scheme (NGERS). Figure 10.1 provides a breakdown of the total Australia-wide fugitive emissions by sector for 2012 as reported under NGERS.

The fugitive emissions reported from natural gas industries, which combines conventional and unconventional gas, make up around 2.3% of Australia's total greenhouse gas emissions (DIICCSRTE, Dec 2012). The contribution of fugitive emissions from CSG has been estimated at 0.3% of the total national inventory in 2012, using the assumptions that CSG accounted for approximately 10% of the total natural gas produced and that CSG

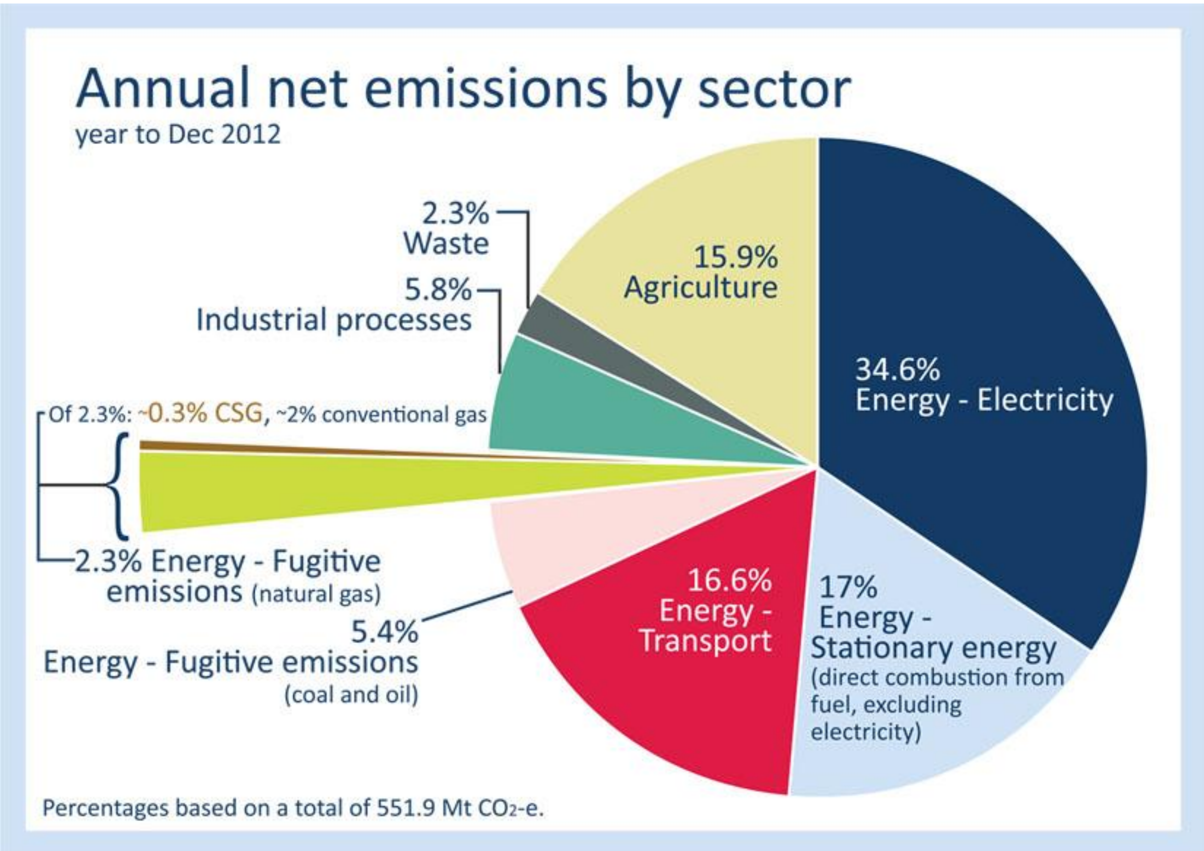


Figure 10.1: Annual net emissions by sector, 2012

Note: For the purposes of National Greenhouse Emissions Reporting, fugitive emissions from conventional and unconventional gas are combined. To separate fugitive emissions from CSG and unconventional gas, the following rough assumptions were made: that CSG currently makes up approximately 10% of total natural gas production, and that CSG emissions are 50% higher than conventional gas emissions per unit of gas produced due to greater number of wellheads and hydraulic fracturing processes. Therefore, the breakdown of 2.3% would be CSG ~.3% and conventional gas ~2.0%
Source: (DIICCSRTE, 2013a, 2013b)

emissions per unit of gas produced are 50% higher for CSG than conventional gas due to more wellheads and use of hydraulic fracturing and flowback techniques.

10.2.1 Reporting and estimates of fugitive emissions

Estimates and/or measurements of fugitive emissions from CSG extraction (leakages, venting, and flaring during pre-production, processing and post-production) are based on facility level data submitted by industry under NGERS.

The Commonwealth, through the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE), is working to address numerous criticisms related to the application of methods for the CSG industry to estimate and measure fugitive emissions, as current estimates are made using methods for the conventional gas industry and do not take account of factors in the CSG industry such as increased well density and potential for hydraulic fracturing.

The process has included the release of a discussion paper (*Coal Seam Gas: Enhanced Estimation and Reporting of Fugitive Greenhouse Gas Emissions under the NGER Measurement Determination)* and the consultation draft *National Greenhouse and Energy Reporting (Measurement) Amendment Determination 2013*. Both of these processes have now been completed. Further to this, DIICCSRTE is partnering with CSIRO's Energy Technology Division on a project to provide preliminary data based on field measurements and modelling of methane emissions from a sample of production facilities in New South Wales and Queensland (DIICCSRTE, 2013c). A report on the research findings, available to the public, is anticipated around December 2013.

10.3 NATURAL AND WATER BORE EMISSIONS

Some areas of CSG bearing coals are characterised by natural venting of methane that migrates upwards into shallow aquifers or to the atmosphere through existing faults, fractures or other permeable zones, including groundwater bores. This occurrence makes measuring fugitive emissions directly from CSG activities more complex.

The NSW Division of Resources and Energy collected water bore geochemistry data between 1995 and 2004, across the NSW Great Artisan Basin, prior to and away from current CSG activities. The results are available in *NSW Bore Water Geochemistry Sampling and Analysis (1994 – 2004)* (NSW Division of Resources and Energy, 2004). The data collected showed that of almost 300 bores sampled, over 90% emitted methane, around 60% and 30% emitted ethane and propane, respectively, and around 85% carbon dioxide. The methane emitted ranged from 3 ppm to more than 600,000 ppm, with the concentration varying according to localised geology and the shallowness of the coal. The emissions could have come from natural fractures or the intersection of the bores through coal seams and natural gas sands.

The occurrence of natural methane leaks through fault lines raises the importance of both obtaining baseline measurements of methane over a period of time (to account for seasonal variations) and using sophisticated techniques to monitor an area, to be able to distinguish between natural sources of methane, methane being emitted through other bores, and CSG fugitive emissions.

10.4 MEASURING AND MONITORING

To understand the potential impacts of fugitive emissions and other air pollutants from CSG processes, there is a need to identify the type of emission, the volume and/or concentration of the emission, and the source and/or origin of the emission. Measured or calculated emissions rates (emissions/time period) can be used for many applications, including compliance, assessing health risks, and monitoring long-term air quality issues.

Factors such as the degree of accuracy required, the timeframe for measuring, prior estimates of emission rates, the complexity of the source (e.g. from single or multiple well, through soil, etc.), and the area over which the emissions occur will influence the techniques and technologies used in a particular case. A challenge is to determine the appropriate use of the technology and modelling techniques to assure consistent and reliable results.

Bottom-up methods of measuring and monitoring emissions are those that examine emissions from the individual source, like a piece of equipment or a plant, and aggregate up to determine full facility or industry emissions. They can be measured directly in the field or samples taken that are analysed in a laboratory. Bottom-up approaches to examine emissions provide the advantage of measuring leakage rates from specific items of equipment or processes that can help in developing emissions factors for better estimation of emissions (see 10.2.1) or mitigation strategies to fix leaks. The main disadvantage is that a large number of individual measurements are required to adequately characterise a full process or the entire CSG industry (Day et al., 2012).

Top-down methods examine emissions across larger areas and measure emissions from combined sources. Top-down atmospheric techniques can be used for continuous monitoring, which is important when emission rates and locations are changing over time (Day et al., 2012). However, given that methane gas is emitted from a wide range of environmental processes, both biological and geological, identifying the source of the methane is an important challenge and goal of monitoring approaches to methane emissions.

A variety of technologies is available to measure and monitor emissions from a bottom-up or top-down perspective. Accurate and more affordable field equipment is developing rapidly, reducing the need to capture gas samples for laboratory analysis.

The PICARRO G-2031-i Cavity Ring Down Spectrometer (Picarro) instrument can be used to measure concentrations (ppm) of methane and other gases that may arise from local sources. It utilises an isotopic analysis of methane to indicate whether the source is likely to be derived from biological sources such as from cattle, alluvial aquifers or wetlands (with a comparatively low level of high atomic weight of carbon atoms in the methane) or from geological sources (heat and pressure conversion in a coal seam with a relatively high ratio of high atomic weight carbon). The instrument is useful for getting precise baseline data, however continuous monitoring is required and it can miss large diffuse sources (e.g. soil sources) (Rayner & Utembe, 2013). This instrument was used in the controversial study by researchers at Southern Cross University looking at fugitive air emissions levels associated with Coal Seam Gas extraction, in particular in the region of Tara in Queensland (Tait, Santos, Maher, Cyronak, & Davis, 2013).

Enclosures (flux chambers) can be used to determine emissions from point sources, including rigid flow-through chambers that can be used to measure emissions from the soil. The chambers are a widely used, straightforward technology that can provide direct emissions measurements for sources of gas concentration, the flow rate and the surface emissions area at the point prior to the gas being dispersed into the atmosphere. They offer potential for long-term monitoring of point sources of emissions from CSG activities.

Additional point source technologies include sensitive and portable infrared cameras for optical gas imaging which pinpoint methane leaks from surface equipment.

An important component of a sound air monitoring program includes taking a systems based approach, which can include using a network of linked monitoring sites, rather than single instruments, to record methane levels, wind speeds and directions, meteorological and barometric conditions, etc. This information can be fed into appropriate models to predict the movement of chemicals. The program should provide adequate instrumentation to cover baseline measurements over the area under consideration.

An identification and analysis of the risks associated with a particular site will impact on the purpose and the design of a monitoring regime. The program should be designed with the specific purpose in mind; it should consider the timeframe required and how the data may be used to feed into a modelling program, as well as the full scale of equipment and operations in an area.

10.5 MODELLING

Modelling is an important tool to help predict the movement of emissions through the air. It can be used to inform a community about whether an emission is coming from a nearby CSG well or an operator or a regulator to know the volume and concentration of a particular emission that will reach a community. With appropriate choice of model and inputs, modelling can help determine these to a degree of accuracy.

There are different approaches to modelling emissions through the air, usually termed chemical transport modelling (CTM). Forward modelling simulates the dispersion of pollutants to the atmosphere from a source to help determine where pollutants will spread and at what concentration. Forward models are classified as either Legrangian or Eulerian, depending upon the frame of reference. Inverse modelling measures changes in concentration of a gas and aims to identify the source of the emission from a remote location. The approaches can be used independently or through a hybrid.

The applicability of a model depends upon a range of variables, including the time and area scale required. They also require a range of inputs, including information about emissions, topography, meteorology, and boundary data.

Models need to be validated either directly against empirical data from an appropriately designed measuring or monitoring system or indirectly against a second established model. As such, they can be a valuable tool when combined with a direct monitoring program. A monitoring network should be undertaken with a view to consideration of how the data will be used as an input into the modelling regime.

Expertise is required to make correct choices about which model is most applicable for the circumstances and the means to provide the model with high quality input data. As different models can provide different results, comparing approaches and obtaining external or expert advice on model design can assist with dealing with this.

10.6 OTHER AIR QUALITY ISSUES

In addition to the fugitive emissions concerns raised in relation to the exploration and production of CSG, there are also broader air quality concerns that are of significance. In particular these concerns are:

- diesel emissions from equipment
- dust emissions.

Diesel emissions relate to the exhaust gases emitted from the engines of vehicles (onsite and transport), drills, pumps, compressors and generators required in the exploration, production, processing and transportation phases of CSG. Diesel emissions are composed of a complex mixture of gases and fine particles. The emissions vary depending on engine type, operating conditions, fuel composition, lubricating oil, additives, and emission control system (Technology Planning and Management Corp, 2001).

Gases from diesel emissions include: nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), and water vapour (H_2O), carbon monoxide (CO), sulfur oxides (SOx), nitrogen oxides (NOx), volatile hydrocarbons, and low molecular weight PAH and their derivatives. Some of the other elements that should be noted about diesel emission health impacts are volatile organic compounds (VOCs). VOCs are emitted as gases from certain solids or liquids. They include a variety of chemicals, some of which may have short- and long-term adverse health effects. Some of the most common VOCs found in the atmosphere are benzene, toluene, ethylbenzene and xylenes (BTEX), particularly in areas connected with heavy traffic and industrial activity.

The human and environmental health effects for an individual exposed to the air emissions will depend on factors including the toxic hazard level of the chemicals or particles (how hazardous it is), the exposure level or concentration of material that the individual is exposed to (how much of the chemical is breathed in, digested or absorbed), and dose response to the material (change in effect on a person caused by differing levels of exposure to a stressor over a time period).

Dust emissions may potentially arise from the associated construction activities and vehicle movements that are necessary for CSG projects. Dust is referred to as 'particulate matter' to describe the particles that exist in the air we breathe. Particulate matter exists naturally in the atmosphere but can be increased as a result of human activities.

The factors that influence the health effects of dust are the size of the dust particles, the composition of the dust particles, the concentration of the dust particles in the air, and the duration of exposure to the dust particles.

Possible health symptoms arising from exposure to coarse particles are likely to be:

- cough
- wheeze, or worsening of asthma
- increased need for medications
- increased breathlessness
- high levels of total suspended particulates may also cause coughing, sneezing or sore eyes (NSW Minerals Council & NSW Health, 2011).

Some research has addressed the dust emission effects from mining activities, but little has been done on dust emissions from CSG activities. It is possible that the research into mining is relevant but this is unproven. Concern has also been raised about flow-back or produced water being used to spray on roadways and pads for dust suppression. It is possible that this produced water may dry out resulting in produced water constituents as dust.

It is important to note that neither diesel emissions nor dust are exclusive to the CSG industry, as they are similar to those from many commercial and industrial operations. Further discussion on the health impacts from air emissions is in Chapter 11.

10.7 COMMENTS FROM THE REVIEW

Fugitive emissions and other air pollutants emitted during CSG activities are of concern to the community in regards to health and safety, air quality and greenhouse gas impacts. There are economic reasons for companies to monitor and prevent emissions, to avoid loss of gas, and also for a social licence to operate.

There is currently an absence of fugitive emissions data for CSG activities in Australia. Therefore there is a requirement for further research, baseline and ongoing monitoring to understand the level of fugitive emissions from the industry.

Fugitive and other air emissions can be mitigated through the application of best practice technology, operations and maintenance of wells and pipelines. Should mitigation measures fail, and emissions occur, then a well-planned and integrated monitoring and modelling system to detect, warn and potentially isolate the cause of the leak is required. Compliance with fugitive and air emissions standards should be enforced by regulators.

Many of the emissions regarded as fugitives are naturally occurring chemicals, or readily available in the ambient environment from other human activities and infrastructure, including housing and traffic transport. These factors demonstrate the importance of measuring background and baseline emissions levels prior to CSG activities commencing

Measuring, monitoring and modelling to assess emission rates are also important in determining whether the source was a CSG well nearby or the garbage dump across the valley. This will benefit both community and industry and enable risk management and mitigation strategies to be developed to deal with fugitive leaks.

The availability of instruments to determine the isotopic characteristics of methane to identify the source, forward modelling to predict the concentration of gas from a point source, inverse modelling to backtrack the path of a molecule through the air, and other remote sensing technologies that allow the operator to measure and monitor substances from a distance, make it possible to determine the emissions with a level of accuracy at both the equipment (point) level and the broader area level.

As the physical, chemical and biological characteristics of CSG sites will vary, a one-size-fits-all approach will be unlikely to work for monitoring. However, providing some level of consistency to the methodologies used by the CSG industry can also help provide transparency to the public and lead to data that is consistent across the industry.

Data from monitoring and modelling should be made available through data repositories to enable understanding of the level of emissions and further research. Issues surrounding data are discussed in Chapter 14 of the report.

Bringing together information on hazard levels of fugitive and other air emissions, with exposure pathway information and concentration, can give estimates of the risk to human and environmental health.

10.8 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- “Modelling the airborne dispersion of pollutants from coal seam gas extraction”, by Peter J Rayner and Steven Utembe from the School of Earth Sciences at the University of Melbourne.

11 HEALTH

Human health and environmental health impacts from CSG activities are of major concern to the public. This was highlighted in submissions to the Review (Figure 6.1), with the most common concerns being about contamination of drinking water from fracturing fluids and naturally occurring chemicals in coal seams; exposure to fugitive gas emissions; concern about noise and dust; and concern about effects on mental health and well-being.

Health as related to a particular activity is difficult to study as there are many influencing factors. The infancy of the unconventional gas industry also means that there are very few peer-reviewed academic publications or industry and government reports available to help understand health risks and potential impacts.

Those studies which have been undertaken are often inconclusive and do not provide firm evidence of correlations and causality with CSG activities. Many are focused on the impacts of shale gas in North America, which have some relevance to CSG. However, great care is required when comparing the shale gas situation in North America with the Australian and NSW experience with CSG, due to geological differences (e.g. more liquid hydrocarbons with shale gas than with CSG) as well as differences in regulatory regimes.

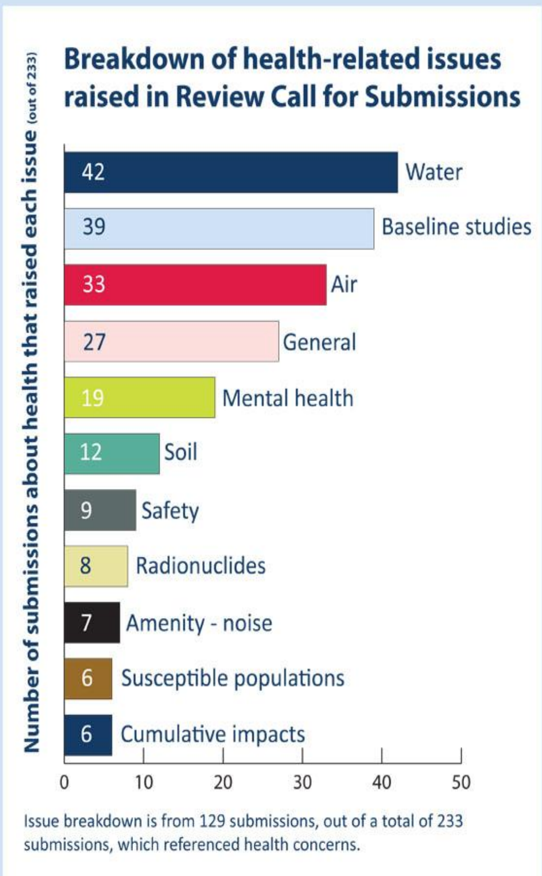


Figure 11.1: Breakdown of health-related issues submitted to Review, received between 26 March and 11 July 2013.

This Chapter provides a brief overview of the main health issues identified during the Review, and summarises in table form the most relevant Australian and international published studies on unconventional gas and health.

Table 6.1 provides examples from these studies. Considerable work and research still needs to be conducted by researchers, government and industry to determine the potential risks to health from activities related to CSG extraction. The Review commissioned a study on community concerns and psychosocial wellbeing, and its findings are summarised in 11.4 below. In future work, the Review will consider further the issues of exposure pathways. The Review has also commissioned a paper on design options for baseline epidemiological health studies to better understand what data and information sources could be drawn from baseline health studies related to possible impacts from CSG and identified risks, including mental health.

Table 11.1: Summary of studies on physical human health and conventional gas extraction

Author(s)	Title	Date/ *Journal* or Type/ Location of Study	Methodology	Results	Comments
Human Health Risk Assessment					
Queensland Health (Q. H. Queensland Government, 2013)	Health effects of coal seam gas – Tara Summary risk assessment of health complaints and environmental monitoring data	2012 Government report Tara, Qld	The report reviewed a range of studies undertaken in the Tara region of Queensland. This included 2 health assessments (Hutchinson 2013) (Adam 2013), and various air, water and soil monitoring studies aimed to identify the presence and level of chemical hazard.	The paper found that noise and vibration were common complaints. The paper in its examination of health complaints and exposure levels from various studies around Tara couldn't find evidence that excessive exposure to emissions from the CSG activities is the cause of the symptoms residents have reported. The paper notes that available data from the Hutchinson study (see below) were insufficient to properly characterise any cumulative impacts on air quality in the region, particularly given the anticipated growth of the industry. It is necessary to assess those impacts according to health-based standards which are relevant to long-term exposure.	The Queensland Health report raises some questions about one section of one of the papers it examined. The results of a Queensland Gas Company air water and soil sampling study by Environmental Resources Management Australia (ERM). Some qualifications are required for the air data of ERM due to detection limits for some chemicals being above the reference criteria for the concentration levels. This is further discussed in the Queensland Health paper.
A report of the Fraser Basin Council to the BC Ministry of Health (Fraser Basin Council, 2012)	Identifying health concerns relating to oil & gas development in northeastern BC – human health risk assessment – phase 1 report	2012 Government report BC, Canada	The study undertook a range of discussions with residents to identify concerns that they had relating to the oil and gas extraction industry. This information will inform the development of the human health assessment phase 2.	The study is a multi-phase study to examine long-term human health impacts. Phase 1 reported concerns that reflected a range of exposure pathways including water, air, noise and light and emergency events.	Phase 2 study design is still underway, but once complete will potentially provide valuable information on approach to health impact assessments.
Studies to Identify Stressors and Reported Symptoms					
Hutchinson, Dr Penny (Appendix 1 of Queensland Health Tara study)	The Darling Downs Public Health Unit (DDPHU) investigation into the health complaints relating to	2013 Government report	Study undertook follow up consultations and examination of clinical data of residents of a QLD community who had self-	Exposure via noise, odour, dust was most often reported. Most common symptoms: Headache 34; sore itchy eyes 18, nose bleeds 14, skin rashes 11.	Study described other potential exposures that may have caused health concerns including household factors (pets, open fires, use of generators for electricity supply for off-grid homes). Use of tank water and dam

Author(s)	Title	Date/ *Journal* or Type/ Location of Study	Methodology	Results	Comments
(Hutchinson, 2013)	Coal Seam Gas (CSG) activity from residents residing within the Wieambilla Estates, Tara, Queensland–July to November 2012	Tara, Qld	reported symptoms allegedly related to CSG. Study mapped distances from wells to residences. Study included 11 households (56 individuals) of total population 1257 in the community	Residents lived between 1.0 and 7.2 km from nearest wells Study found a low prevalence of symptoms and low exposure levels.	water for household supply. Use of septic tanks. The paper discussed the issue of solastalgia where residents may feel distress at the environmental changes to their home.
Adam, Dr Keith (Appendix 2 of Queensland Health Tara study) (Adam, 2013)	Health effects of coal seam gas – Tara	2013 Government report Tara, Qld	Author reviewed individuals in Tara region who believed their health to be affected by CSG in Tara. Examinations were undertaken where relevant. The author also reviewed a range of monitoring studies undertaken for the region.	The author was unable to identify objective evidence of clinical conditions that had been reported. Several residents did report feelings of lack of trust, and lack of confidence in state and local health authorities, concern about reports of safety and health risks.	The author noted the low response to the call for participants.
Department of Science, Information Technology, Innovation and the Arts (DSITIA) (Appendix 4 of Queensland Health Tara study) (D. Queensland Government, 2013)	Wieambilla Estates Odour Investigation Results: July-December 2012	2013 Government report for DEHP Tara, Qld	Study used 2 sampling devices for airborne chemicals. A summa canister that residents could activate (1-minute) when they detected an odour; and a passive sampler that collected molecules over a 3-week period. Six canister samples and 4 passive samples (and a control) were analysed.	Canister detection limit was 0.5 – 1.0 ppb, and the passive sampler was <0.17 ppb. Number of volatile organic chemicals (VOCs) detected in canister was 3 to 7, while passive samplers detected 4 to 18 VOCs. The paper indicates that the levels of VOCs were generally below the level that would result in an exceedance over a year (if those levels were maintained for a year).	The samples detected were generally below published health exposure guideline levels.
Ferrar et al (Ferrar et al., 2013)	Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional **shale**	2013 *International Journal of Occupational and*	Thirty-three respondents were interviewed in the first stage May–October 2010, and of these twenty were interviewed in the second stage of interviews between	Bodily systems most commonly reported (in order) as impacted include psychological system, dermal system, digestive system, immune response, central nervous system, upper respiratory system, cardiac system.	The purpose of the work was to serve as an input for a separate study to address questions of whether there were statistically valid causal relationships between health effects and shale gas extraction activities.

Author(s)	Title	Date/ *Journal* or Type/ Location of Study	Methodology	Results	Comments
	gas development in the Marcellus Shale region	*Environmental Health* United States	January–April 2012. Physical symptoms and complaints were recorded as were psychosocial stressors.	Stressors most commonly reported (in order) as impacted include health concerns, denied or provided with false information, corruption concerns/complaints ignored, being taken advantage of, noise pollution, financial damages.	The authors determined the participants were likely to be individuals opposed to shale gas development and represented a biased convenience sample.
McCarron, G (McCarron, 2013)	Symptomatology of a gas field - an independent health survey in the Tara rural residential estates and environs	2013 Individual Study - Not peer reviewed Tara, Queensland	Two part survey undertaken on reported health effects of 113 residents in the Tara region located in the vicinity of a CSG field. For baseline, participants were asked to report how their health had been in the two years prior to CSG activities. Respondents were asked to complete a survey on symptoms	The study reported an increased incidence/prevalence of all symptoms in the various age groups (except seizures in 6-18 y.o.) when comparing resident recognition after (versus before) CSG extraction commenced. In all age groups there were reported increases in cough, chest tightness, rashes, difficulty sleeping, joint pains, muscle pains and spasms, nausea and vomiting. 82.58% of residents surveyed reported that their health was definitely adversely affected by CSG, whilst a further 19% were uncertain.	The study acknowledges the limitations of its design, including the selection of participants and reliance on respondent recall of past symptoms. The report doesn't include an overview of the statistical significance of the data. The paper calls for a number of initiatives including: long term epidemiological studies to track health effects; health impact assessments as part of CSG development approval process; comprehensive air and water monitoring.
Witter and colleagues (University of Colorado) (Roxana Witter et al., 2008)	Potential Exposure-Related Human Health Effects of Oil and Gas Development: A White Paper	2008 White Paper United States	The paper focused on possible health, medical and social issues that faced the community of Garfield County in Colorado USA, with increasing oil and gas industry. The paper reviewed three air sampling studies for the region, two water quality studies and one study on ambient noise prior to gas activities. At the	The paper reported on studies of locations that included domestic wells, water wells, irrigation wells, monitoring wells, springs, ponds and rivers with detectable levels of methane in 75% of samples. These, the paper posited, were due to gas development activities (including leaking abandoned wells), unknown sources and biogenic sources such as methane produced in shallower formations by naturally occurring methanogenic bacteria. Overall the	The paper brings together a range of studies on human health and chemical levels in the region. Examination by the authors of associations between health effects and gas extraction activities appears to be inconclusive in relation to causality between oil and gas industry and human health. There were major gaps identified in both the health and chemicals data. The team from University of Colorado has also published Health Impact Assessment for

Author(s)	Title	Date/ *Journal* or Type/ Location of Study	Methodology	Results	Comments
			time the paper was written, the county had 4,521 active wells.	paper indicates that for the region, there were major data gaps in air and water quality assessments, with many potentially hazardous air emissions not monitored.	Battlement Mesa, Garfield County Colorado Garfield County Colorado (Roxana Witter et al., 2010).
Health Concerns Related to Water Contamination					
US EPA (US EPA Office of Water, 2004)	Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs	2004 Government Report United States	The study reviewed information on 11 major coal basins in the USA, with 10 of them co-located with underground sources of drinking. The study looked at complaints that were provided relating to four basins, which were the most active of the 11, about unpleasant taste and odour; impacts on fish, vegetation and wildlife; and loss of water in wells and aquifers.	Overall, the report could not find confirmed evidence that drinking water wells were contaminated by hydraulic fracturing fluid injection into CSG wells or that water quality degradation in the underground sources was a result of injection of hydraulic fracturing fluids into CSG wells and subsequent underground movement of these fluids. The report noted that hydraulic fracturing may have increased communication between coal seams and adjacent aquifers in two of the basins: the Powder River and Raton Basins likely due to high volume of produced water.	The report suggested other factors as potentially contributing to groundwater problems such as various aspects of resource development, poorly constructed, sealed, or cemented manmade wells; improperly abandoned gas wells, or naturally occurring conditions. Note: The USEPA is currently undertaking a study to better understand potential impacts of hydraulic fracturing on drinking water resources. The scope of the research includes the full lifespan of water in hydraulic fracturing. The progress report was released in December 2012 and a draft report is expected to be released for public comment and peer review in 2014.
Studies addressing contaminant levels, pathways and potential health risks - Air Emissions and Pollutants					
McKenzie and colleagues (University of Colorado)(McKenzie, Witter, Newman, & Adgate, 2012)	Human health risk assessment of air emissions from development of unconventional natural gas resources	2012 *Science of the Total Environment* United States	Study took air samples to measure the level of 78 hydrocarbon chemicals emitted from 4 **tight sands** gas well pads during completion and production stages. Study considered a range of distances from well sites, and stages through the well commissioning. Study used toxicity level	The study found that cumulative cancer risk for people at the closer distances of <800m was 10 in a million over 30 years, compared with the people living >800m having a 6 in a million over 30 years cumulative risk. Study suggests that the greatest potential for health effects from air pollutants occurred from subchronic exposures (less than 2 years 10 months)	Study provides a model for determining risk by bringing together exposure level information and dose response information. Study was undertaken in a tight sands play so care needs to be taken in interpreting risk levels to Australian situation with different levels of hydrocarbons in formation water, and different regulations.

Author(s)	Title	Date/ *Journal* or Type/ Location of Study	Methodology	Results	Comments
			data to determine the predicted excess risk levels of cancer and non-cancer illnesses that could be triggered by the chemicals over chronic and sub-chronic timeframes.	during well completion activities – where flowback water was captured in open tanks.	
Krzyzanowski, J (Krzyzanowski, 2012)	Environmental pathways of potential impacts to human health from oil and gas development in northeast British Columbia, Canada	2012 *Environmental Health* BC, Canada	Paper describes a methodological approach to examining hazard levels, and exposure pathways to determine risk levels. Paper discusses importance of accounting for background health conditions such as smoking rates and other health indicators.	The paper was undertaken to inform the design and development of the British Columbia longitudinal study. Paper considers a range of health concerns arising from air, water, noise, including both contaminant and non-contaminant stressors. Paper also calls for consideration of combined risk or cumulative impact of gas extraction activities on human health.	Paper highlights the importance of understanding the level of baseline or ambient chemicals in the environment so that any additional contribution from gas extraction can be measured. Paper indicates cumulative impact issues are also key to designing health impact assessments.

Studies on movement of chemicals in groundwater and relationship to health impacts

Other studies or approaches that address the issue of chemicals associated with unconventional gas being attributed to water well contamination include:

- Gradient paper undertaken for Halliburton (Gradient Corp, 2013)
- Marcellus shale groundwater methane transport papers, set of three papers (Osborn et al., 2011) (Jackson et al., 2013; Warner et al., 2012)
- US EPA analysis of water in bores in town of Dimock (US EPA, 2012a)
- Rozell and Reaven statistical analysis of likelihoods of methane contamination through five different pathways (Rozell & Reaven, 2012)
- Shallow groundwater and geochemistry in an area of shale gas production (Kresse et al., 2012)

The papers use a range of techniques including conceptualisation, statistical probability assessments, and chemical sampling to determine the likelihood of chemicals entering groundwater drinking supply following fracture stimulation and other activities such as drilling, as well as examining methane and other chemicals' presence from natural pathways. Over all, issues relating to chemical contamination via naturally occurring chemicals in groundwater, poorly completed bores and wells, and spills appear to show through as principal causes of groundwater contamination.

11.1 WATER CONTAMINATION

There is a concern that CSG activities will result in the contamination of drinking water from water bores and surface reservoirs and dams. This is based on concerns that water from drilling, flow back and produced water that is brought to the surface during gas extraction will be spilt and enter waterways, reservoirs and subsequently drinking water. There is also concern that CSG processes, such as poorly constructed wells, drilling and hydraulic fracturing, can lead to the contamination of beneficial aquifers by opening or creating a connection between the coal seams and nearby aquifers. Water issues are discussed in more depth in Chapter 7.

Much public concern has also centred on the particular toxic hazards associated with chemicals and materials that might be transported via water, rather than understanding the level of exposure or dosage that would be required for an acute or chronic health impact.

It is clear that a good understanding of the geological and geochemical characteristics of the target coal seam and the broader region in which gas extraction activities are proposed is a prerequisite to understanding the movement of groundwater and associated chemicals, and thus potential health risks. In particular, more work is required to understand water 'pathways', both above and below ground, and the true nature of the risks involved.

At this stage, it is evident that there has been little peer-reviewed work on the human health impacts from CSG extraction in relation to produced or groundwater.

11.2 AIR EMISSIONS AND POLLUTANTS

The community has expressed major concern about the impacts of air emissions and pollution on people in the vicinity of CSG activities – not just those immediately adjacent to an extraction site but those in the general region. Fugitive emissions and air quality are discussed in more detail in Chapter 10.

We are all constantly exposed to a range of chemicals in the atmosphere, both naturally occurring and pollutants. Some pollutants have raised a level of concern e.g. radon in homes,(ARPANSA, 2011) diesel and petrol and their associated emissions from traffic (Sydbom et al., 2001), hydrocarbon chemicals emitted from everyday objects (Hinwood et al., 2007) and dust from mines.

Possible sources of fugitive air emissions in the CSG context include:

- leaks of methane and other gases from wells and seepage through geological pathways to the surface
- emissions of particles and chemicals from equipment including diesel generators and compressors
- emissions of volatile organic chemicals from produced or flowback water (including BTEX chemicals)
- dust particles that may be mobilised following the spraying of untreated produced water on roads.

Management of some of these issues is well understood because of their occurrence in other industries; others will require solutions directly related to best practice in CSG operations, appropriate regulatory standards and emission limits, and monitoring. Having good baseline data will be essential.

11.3 NOISE, VIBRATION AND LIGHT

Another area of concern, not exclusive to CSG, is noise and vibration, mainly from truck transport and construction activities, and light from illuminated night-time activities. Large trucks are needed to transport CSG well equipment, for drilling and to conduct hydraulic fracturing processes, and these can produce vibration and high-volume noise, creating disturbances not only to people but to wildlife and livestock.

It is apparent that noise impacts will be episodic, with some activities during the construction phase requiring day and night activities. Mechanisms to reduce the impact include setback arrangements between homes and wells, communication between companies and residents about activities, and discussion of possible alternative arrangements including accommodation alternatives.

11.4 PSYCHOSOCIAL WELLBEING AND MENTAL HEALTH

Another common concern was the impact of CSG activities on psychosocial wellbeing. When individuals regard existing or potential CSG activities as an unwanted presence, and therefore a stressor or 'threat', it is clear there can be an impact on their psychosocial wellbeing and mental health which can produce both psychological and physical symptoms (Taylor et al., 2013). The Review commissioned a report specifically to understand more on this issue. We have summarised and reproduced some of the main points of the report below, including references cited in the report.

11.4.1 Concern, fear, anxiety and MUPS

Psychosocial and mental health impacts may be experienced in response to an actual or perceived threat being present, but impacts may also be felt in anticipation or expectation of a threat occurring. Therefore if CSG activities are perceived as threatening/unpleasant impacts to an individual, the feeling related to threat may be experienced not only when such activities occur, but also in anticipation of CSG activities (Taylor et al., 2013).

People facing a range of potential perceived threats may acutely or gradually develop anxiety regarding their possible effects, such as their effects on health, financial security, or other aspects of their life. Such fears and preoccupations may be increased when public concerns are further aroused by circulating rumours, media controversy or an adversarial social context. Everyday symptoms may then become more significant, take on a greater focus, and become attributed to toxic or other uncertain dangers. The symptoms are often described in general patterns including headaches, shortness of breath, chest pain, body pains, sleeping difficulties, chemical sensitivity, and poor appetite(Wessely, Nimnuan, & Sharpe, 1999). These and similar patterns have been described after a wide range of exposures with perceived threats including 'toxic' waste sites, air pollution, irradiation, and other threats (Taylor et al., 2013) (Dunne, Burnett, Lawton, & Raphael, 1990) (van den Berg, Grievink, Yzermans, & Lebret, 2005).

Systematic medical and scientific assessments have been unable to confirm these as physical consequences of the perceived threat and they have been labelled as Medically Unexplained Physical Symptoms (MUPS) – also often referred to as somatisation disorder. It should be noted that, although MUPS are considered here in the context of concerns/anxiety, such symptoms may not always be associated with psychiatric factors(Taylor et al., 2013) (Nimnuan, Hotopf, & Wessely, 2001).

The treatment of MUPS poses challenges for health care providers. Of particular relevance to the situation with the CSG debate in Australia is the potential for 'conflicted causation', where MUPS occurs in the context of a situation that is in the public arena and may involve media controversy, advocacy groups, scientific and political debate and even legal proceedings. The treatment of MUPS is more complex and there is a greater need to maintain a good patient-health care provider relationship to avoid erosion of trust (Taylor et al., 2013).

"Over time, concerns and associated distress may settle or become more severe and entrenched. Accurate and regular information from trusted sources (e.g., local leaders, trusted experts) with opportunities for questions and discussion may be helpful, particularly if communities are engaged and believe their worries are being addressed. However if the sense of uncertainty and threat grows and strong beliefs develop that there are dangers that will cause (or are already causing) harm/disease, local leaders may seek to find proof that there is a significant problem and that 'others' such as politicians or industry, are 'covering up'" (Taylor et al., 2013).

"When these concerns, whether accurate or otherwise, become entrenched they are more difficult to manage. The anxiety states that may result may also add to health vulnerabilities especially when the way of life, the home (often the main resource of the family), and the capacity to work or make a living are threatened. In reality there may be uncertainties for all, so honest and open, ongoing communication as well as engagement of relevant stakeholders (including media) may be relevant" (Taylor et al., 2013).

11.4.2 Uncertainty, anger and frustration

The uncertainties people may experience; perceived potential threats to property, business, and home, disruption of familiar environments, and fears of gas, chemicals, and possible toxic health effects, can all lead to real impacts on health. These impacts can be related to distress about continuing uncertainty, financial insecurity, changed health behaviours, stress effects and mental health issues such as anxiety and depression. Anger may develop over time, due to a sense of injustice, frustration over lack of clarity, perceived inability to help oneself, and no easy solutions being apparent to the individual or their family. This can increase distress and exacerbate existing health problems (Taylor et al., 2013).

11.4.3 Loss of control, helplessness and depression

The media has noted that some people living near CSG activity can feel a sense of loss of control, either in terms of lack of personal choice or being 'surrounded' when neighbours permit CSG activities on their properties. A large body of evidence links loss of control to feelings of helplessness and hopelessness, and then to symptoms of depression. Depression can be experienced at a range of levels, from mild to severe and can be totally debilitating. Depression is also a common factor in suicide (Hawton, van Heeringen, & Lönnqvist, 2008) (Taylor et al., 2013).

The term solastalgia has been developed by some Australian academics to describe the distress produced by environmental change in the environment. Unlike 'nostalgia' which relates to a person feeling a sense of longing when they are separated from home, solastalgia refers to the distress people feel due to environmental changes occurring to people in their home environment, such as could occur in times of drought or increasing mining activity (Albrecht et al., 2007).

These effects on psychosocial wellbeing must be acknowledged, and support must be provided to help people understand them and address them.

11.5 COMMENTS FROM THE REVIEW

There is a significant lack of peer-reviewed publications on health and CSG. Those studies that have examined people reporting symptoms are inconclusive and do not provide evidence of correlations or causality between physical health issues and CSG activities.

Marrying together information and data on the following elements that relate to human health risk should improve our understanding of impacts and assist in putting in place mechanisms to identify and support people who feel impacted:

- our understanding of the toxic hazards of chemicals
- an exposure or dosage level through understanding chemical air and water and soil pathways
- information on dose response for chronic and acute exposures
- well-designed baseline data for both background health status and ambient chemical baselines.

In future work, the Review will consider further the issues of exposure pathways. The Review has also commissioned a paper on design options for baseline epidemiological health studies to better understand what data and information sources could be drawn from baseline health studies related to possible impacts from CSG and identified risks, including mental health.

There is no doubt that industry operators need to engage with communities in more meaningful ways, including through transparent sharing of information on matters such as chemical releases and emissions. Regulators need to make the establishment of robust standards and practice in well drilling and completion a priority, and also explain how these standards will reduce risks in respect of those matters about which the community has expressed such widespread concern.

In addition to ensuring physical triggers and symptoms are avoided or allayed, further work on the psychosocial and mental health aspects of CSG in Australia is warranted with a view to understanding the range of symptoms associated with psychosocial factors that may occur. A strong focus is also required toward developing programs and services to monitor and support individuals and communities under stress. Such services should facilitate information sharing and the development of materials for local healthcare providers. Improving community outreach and focussing attention on GP and health care practitioner training would help enable better handling of patients in the affected regions.

11.6 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- "Community concerns and their potential effects", Dr Melanie Taylor, Natalie Sandy and Professor Beverley Raphael at the University of Western Sydney
- "Approaches to baseline studies of human health in relation to industries with potential environmental impact", Dr Pavla Vaneckova and Associate Professor Hilary Bambrick, University of Western Sydney

12 SAFETY

Worksite safety and community safety are important considerations in the CSG industry. A strong regulatory regime, including industry-specific requirements and national work health and safety requirements applies. However, the nature and culture of the industry, being dispersed and operating in large amounts through layers of subcontracting companies, means that there is a risk of gaps in practice leading to potential safety hazards. On the whole, the oil and gas industry, like the mining industry, does put considerable effort into promoting safe practice, and some of the larger extraction and subcontracting firms utilise high international standards.

However, there is no room for complacency, and the regulatory regime put in place by government needs to ensure that the practices of smaller firms and operators can reach the standards of larger firms. Particular issues can emerge at various stages of CSG development including during well drilling and construction (such as blow outs); production (such as gas ignition and spills); and factors off-site (such as traffic and truck movements).

As well as efforts to promote ongoing safe practice, government and industry will also need to address legacy issues arising from past practices such as abandoned wells and chemical spills.

12.1 COMMUNITY SAFETY

A characteristic of comments from the community, whether expressed in the media or in Review submissions, is concern for health and safety. This concern has emerged in part from media reports about effects of unconventional gas developments on drinking water, air pollution and road and traffic safety, and well blow outs (McCarthy, 2011). Air and water are discussed in more detail in previous chapters.

Key to ongoing viability for the CSG industry in NSW will be increased community trust in the industry's practices and community confidence about the industry's safety.

There was strong community feedback that it is important to investigate all reports provided by residents and the community, and provide a clear, understandable and scientifically rigorous explanation for incidents which do occur, even if it is determined that there is no causal link with CSG activities. Clear and timely communication can assist to identify options for remediation, and reduce community concerns about cover-ups or lack of commitment to community safety.

12.1.1 Company responsibilities

Companies are required to develop Safety Management Plans, such as those required under the NSW Code of Practice for Fracture Stimulation Activities and the Code of Practice for Coal Seam Gas Well Integrity. As stated in the latter:

> The operator has the responsibility for the safety of not only workers and visitors on site but also members of the general public who might be affected by the operations. In this regard the titleholder must provide and maintain, so far as reasonably practicable, a site that is both safe and without risks to the health of employees, visitors and members of the public (NSW Resources & Energy, 2012b).

It is important that companies, when developing safety management plans, monitoring plans, incident response plans and emergency response plans, consider wider impacts on neighbours and the general public and how these will be managed and responded to. Consultation with emergency services and local councils will assist with this.

12.1.1.1 Driver safety

For companies, driver safety and adherence to local traffic regulations and speed limits in the neighbourhood is critical. The Review understands that CSG operators place a high priority on training employees to drive in a cautious and safe manner. Initiatives to minimise traffic impact include preparation and publication of a Traffic Management Plan to NSW Government standards (Transport Management Centre, 2012); installation of road signage; minimising impact with major traffic flows; and informing residents of traffic arrangements. Santos has incorporated driver monitors to track adherence of employees to road safety requirements.

12.1.1.2 Seasonal factors

Companies need to maintain an awareness of how different weather or seasonal factors (including the extremes of flooding, drought and bushfires) may impact on operational risks from various extraction processes. In addition to developing policies and communication initiatives with staff to reinforce good practices, companies can also implement safety monitoring devices and remote cameras to detect and record issues.

12.1.1.3 Communication with community and neighbours

Keeping neighbouring households or communities informed about activities, particularly those that are out of the ordinary, helps to demonstrate a degree of respect and acknowledgement that neighbours may be impacted by CSG activities.

One approach would be to make information and data on wells publicly available, including their type, owner, location, status (operational, abandoned, exploration, production) and safety issues or hazards. Such data could also include real time information on: chemical and pollutant levels in air and water relating to wells; data on safety and accident incidents for wells; information on how regulators have responded to incidents; and activity planning and schedules for works, drilling, fracture stimulation, flaring and any out-of-the ordinary activities.

12.1.2 Government and regulator responsibilities

Government and regulators could consider the radius and scale of potential emergency incidents and events (well head blow outs, leakages of produced water and potential gas leaks) in determining setbacks and buffer zones between residences and gas infrastructure. They also need to consider the level of response required by residents and how emergency services and companies will coordinate it. There are similarities with bushfire responses, with considerations including the route and time to evacuate should an incident occur. Worst case scenarios should also be contemplated when planning, including cumulative impacts or coincident events and how these should be managed.

12.2 ON-SITE SAFETY

12.2.1 Regulatory regime

In New South Wales, most CSG safety regulation sits within:

- *Work Health and Safety Act 2011* (WHS Act) and the *Work Health and Safety Regulation 2011*
- *Schedule of Onshore Petroleum Exploration and Production Safety Requirements (1992)* – compliance is a condition of all petroleum titles
- *NSW CSG Codes of Practice*, which are also a condition of petroleum titles related to CSG, and require the development of Safety Management Plans

The objectives of the *Schedule of Onshore Petroleum Exploration and Production Safety Requirements,* published in 1992, are to ensure that the operator of either a petroleum exploration program or production facility:

a) accepts responsibility for the safety of employees, visitors on site and members of the general public who might be affected by those operations
b) has identified the major hazards on a site or installation and has implemented the appropriate controls in order to ensure that the management, design, construction, operation, and maintenance of each site or installation and its associated services are safe
c) maintains a safety management plan
d) ensures persons are competent for work
e) at shift handover, ensures that vital workplace information is exchanged.

The *Work Health and Safety Act 2011* (WHS Act) and the *Work Health Safety Regulation 2011* place the primary duty of care on the person conducting a business or undertaking to manage risks to health and safety. The duty holder must identify reasonably foreseeable hazards and eliminate or minimise risks to health and safety so far as is reasonably practicable. Contractors and subcontractors must also fulfil health and safety duties in respect of anyone who may be affected by their operations. The Act and Regulation cover factors such as general risk and workplace management requirements, identification of hazards and control measures, emergency plans and protective equipment.

The Code of Practice for Coal Seam Gas Well Integrity (NSW Resources & Energy, 2012b) and the Code of Practice for Coal Seam Gas Fracture Stimulation (NSW Resources & Energy, 2012a) incorporate requirements relating to onsite activities to ensure human and environmental safety.

Key elements of the Well Integrity Code include:

- CSG titleholders are required to apply a rigorous, risk based approach to the safety of operations and possess a comprehensive asset integrity regime to minimise risks associated with their operations
- prior to commencing any operations at a well site, titleholders must ensure that operators and contractors prepare, implement and review as necessary a safety management plan for the site to address the specific safety risks that might arise from well operations, and to ensure that the design and operation of the site and its equipment are safe
- the safety management plan must provide the basis for the identification of hazards, and of the assessment of risks arising from those hazards, for the development of controls for those risks and for the reliable implementation of those controls through a formal safety assessment process
- emergency procedures must be in place that are adequately resourced and equipped, specifying actions to be taken and identifying persons responsible, in the event of an emergency arising.

From the Code of Conduct for Fracture Stimulation Activities, some key elements include:

- worker training and certification is central to good practice and the mitigation of safety and environmental risks. Workers must have the knowledge and skills necessary to perform their work safely and to the highest possible standard. Titleholders must ensure that workers undertaking any activity that requires a qualification or authorisation or in the case of drilling operating plant, a competency identified for their position under the relevant drilling competency standard, have the relevant qualification or authorisation or competency
- the Fracture Stimulation Management Plan must include a risk assessment complying with AS/NZS ISO 31000:2009 Risk management-Principles and Guidelines. At a minimum, the risk assessment must address risks associated with: workplace health and safety; public safety; and other factors
- prior to commencing a fracture stimulation activity, titleholders must ensure that operators and contractors prepare, implement and review as necessary, a Safety

Management Plan to address the specific safety risks that might arise from a fracture stimulation activity, and to ensure that the design and operation of the site and its equipment are safe
- incidents and emergencies must be prepared for and managed appropriately to ensure that risks to health, safety and the environment are minimised.

12.2.2 Case study on workplace accidents

Following the death of a Queensland well driller in February 2003 due to an accident at the end stages of a drilling job, the State Coroner's Inquest delivered a set of findings that included observations and recommendation relating to training and operations for CSG to improve safety (Barnes, 2006). In his findings, the Coroner noted that, despite an apparently comprehensive interlocking system of safety policies and audits, basic and obvious dangers were unaddressed. He found that despite the documentation, checking, auditing and drilling of 11 wells, the workers still did not have a shared understanding of some basic operational aspects of the rig, nor had sufficient attention been given to adequacy of some equipment.

Following the incident, the Queensland Government put in place several requirements including safety management plans with risk assessment and risk management measures; a skills assessment detailing competencies and experience required of operating the equipment; and a training program. The Coroner criticised the focus on 'on the job' training, commenting that drilling rig workers and those supervising them should have formal qualifications that would be recognised Australia wide. He recommended that the training package address the training needs of rig workers, supervisors and senior drilling company personnel. In the case of rig managers and supervisors he recommended that the education package mandate a tertiary education course as a component of the required qualifications.

12.2.3 Well site activities conducted in a safe manner

The safety record of the petroleum and gas industry (onshore and off-shore) is continuing to improve, with the number of lost time injuries per million hours worked in 2011 falling to a 16-year low of 0.8 compared with 1.0 in 2010 and 3.4 in 1996 (APPEA, 2012). The total recordable injury rate (recordable injuries per million hours worked) also fell, recording a level of 4.7 in 2011 compared with 5.1 in 2010 and 13.4 in 1996 (APPEA, 2012). However, the industry in Australia does not have as good a safety performance as in other parts of the world. In 2011, the total recordable injury rate among members of the International Oil and Gas Producers Association was 1.8 injuries per million hours worked (APPEA, 2012).

From consideration of the Queensland Coroner's findings, it appears that on top of the system of policies and audits in place, there is a need for clear communication of information and responsibilities between individuals, work teams, subcontractors, and across organisational hierarchies. A lack of clarity of responsibilities can lead to considerable risk. Appropriate implementation of Safety Management Plans and other plans required in NSW regulations should help address this issue.

The NSW Mine Safety Advisory Council is a body set up to provide advice on critical work health and safety issues of importance to the NSW Government. It has also developed a range of publications and tools for industry to promote safe mine practice. For instance, the Contractor OHS Assessment Tool (NSW Department of Primary Industries, 2008) has been developed to assist a mine manager to ensure that contractors' occupational health and safety practices and systems complement those of a mine site. These and other tools could be adapted for use on CSG sites.

As appears clear from the Queensland case study, appropriately structured and delivered training is fundamental to workplace safety. Required competencies, experience and skill sets for activities, whether drilling, or cementing, fracturing or operating, need to be made clear and be assured through the onsite quality assurance frameworks. Operational systems and competency and compliance checks should be in place that address the issues of new team members. Staff should, where possible, be formally trained and accredited to undertake activities.

When incidents do cause harm to human health, the environment, land or infrastructure, appropriate levels of insurance are required to address, compensate or remediate the issue as appropriate. This issue of coverage, protection and insurance including pre-activity bonds is the topic of an expert paper that the Review has commissioned.

12.3 TRAINING

Efforts to progress the establishment and implementation of competency and training standards for the CSG industry in NSW should continue to completion.

Under the NSW *Schedule of Onshore Petroleum Exploration and Production Safety Requirements (1992), Section 203 Certificate of Competence,* the titleholder must ensure that, where a person is legally required to have a certificate of competence, an authorisation or a qualification to carry out an activity, the person meets that requirement. However, the *Schedule of Onshore Petroleum Exploration and Production Safety Requirements*, does not define a minimum skills competency for safe working practice about a drilling plant. For well integrity, the NSW *Code of Practice for Coal Seam Gas Well Integrity* refers readers to the Queensland Competency Standard for the Petroleum and Gas Drilling Industry.

It is understood that Queensland is currently updating its competency standard for drilling and that the NSW Government through the Office of Coal Seam Gas is working with Queensland to achieve a harmonised approach to training and competency. Such an approach is worthwhile since many drilling companies and operators work on both sides of the border, so having different skills and safety requirements could potentially cause uncertainty.

The NSW competency code for drilling needs to be progressed toward completion. Further work also needs to be undertaken to address other required training, skills and safety competencies for CSG, including rigs not covered by the Code (see Recommendation 4).

12.4 COMMENTS FROM THE REVIEW

Specific industry and work health and safety regulations exist for the petroleum and gas industries, with a good and improving safety record, especially in large companies. However, as evident in the findings of the Queensland Coroner in 2006, the CSG sector is a dispersed industry, in terms of geography and company profile. This can mean that cultural issues can play a part in safety risks, so appropriate systems, training, communication and documentation protocols are required to ensure safety standards are maintained from the company to the contractor to the community.

Better training and competency standards are required. Recommendation 4 addresses this.

A high safety culture, which already exists in the mining industry and some of the larger gas and petroleum firms, is required for all companies, contractors and sub-contractors which operate in the CSG industry, and appropriate compliance and insurance mechanisms must be in place. The Review has commissioned a study on liability and insurance matters related to CSG.

12.5 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- "Skills, Training and On-Site Knowledge Sharing", by Jon Gibson.

13 CUMULATIVE IMPACTS

Cumulative impacts can arise when multiple activities are sharing the same space either at the same or different times. Cumulative impacts include environmental and social impacts. This section of the report will focus on the environmental side.

Our sedimentary basins provide vitally important resources for communities, agriculture, mining and energy and the natural environment. As discussed in Section 5.5, these basins are currently being used and investigated for a variety of activities (e.g. mining, agriculture, water storage, waste disposal, heat extraction, etc.).

Thus our sedimentary basins are being exposed to a wide range of differing impacts, not only from resource development and water needs but also related to urban growth, transport, agriculture, tourism and forestry. These activities affect biodiversity, vegetation, plant and animal species, soils and local water supplies for ecosystems, on people and other industries.

Mining, agriculture and human infrastructure separately and together have already had a significant impact on our environment, through practices such as land clearing, foreign plant and animal introduction, habitat fragmentation and water use (dams, irrigation, etc.).

There are long-term economic and social benefits in ensuring that multiple activities including agriculture and resource developments coexist. However much more attention needs to be paid to cumulative impacts of these activities on our water resources and environment, particularly as new activities are proposed.

The current level of use of our sedimentary basins is unprecedented. This is leading to competition for access to basin resources that is bringing up challenging social, political and regulatory issues (Rawling & Sandiford, 2013). “With potential for conflict over competing access regimes to sedimentary basin resources, there is a case for new approaches to the management of our sedimentary basins to help reduce adverse environmental and social impacts, reduce the potential for unintended resource depletion and/or sterilisation, and reduce economic risk arising from multiple, interacting and competing resource usage scenarios” (Rawling & Sandiford, 2013).

Holistic monitoring regimes and new methods of modelling looking at the range of activities and potential impacts are required. To date monitoring and modelling has focused primarily on the impact of one project or system at a time. This has been because both regulations have required specific monitoring for each project and because modelling and computing technologies have not had the power to manage the scale of monitoring and modelling that is often required.

The Legislative Council Inquiry into CSG (NSW Legislative Council General Purpose Standing Committee No 5, 2012) noted that it is difficult for an individual company adequately to assess cumulative impacts, as it generally cannot access all the necessary data. Data is a key issue in developing comprehensive models for natural systems. Data access and sharing can help with ensuring that government, industry and research have the most comprehensive and up-to-date data. The importance of data is discussed in Chapter 14 of the Report, but its necessity for understanding cumulative impacts cannot be over emphasised.

It is important that cumulative impacts are considered to minimise the future impacts new activities have on the environment as well as communities. An effective and efficient management system that considers the cumulative impacts of all activities at all times is required.

13.1 ACTIVITY IMPACTS

Any activity that is undertaken will have an impact to some degree. Activities such as CSG, mining, agriculture and urban development have cumulative impacts associated with them individually. Figures 13.1 and 13.2 illustrate that in Australia our arable land, water and energy resources are concentrated in the same regions (our sedimentary basins). Table 13.1 provides examples of the types of activities and the potential impacts associated with them.

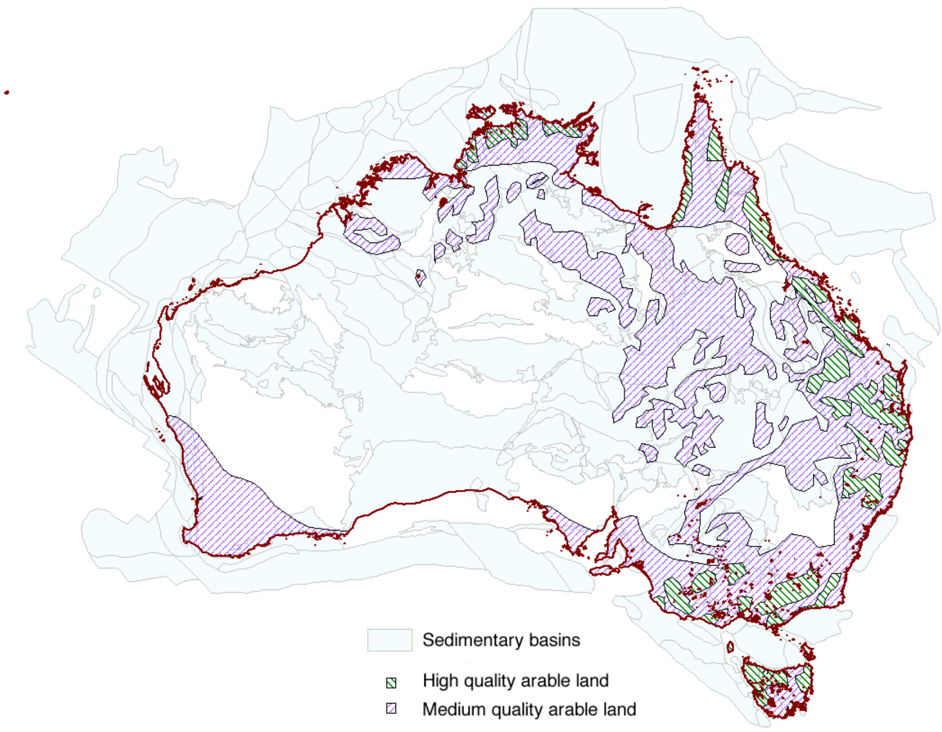


Figure 13.1: Australia's arable lands (hatched) overlayed on sedimentary basins (light blue). Distribution of arable land types (Rawling & Sandiford, 2013)

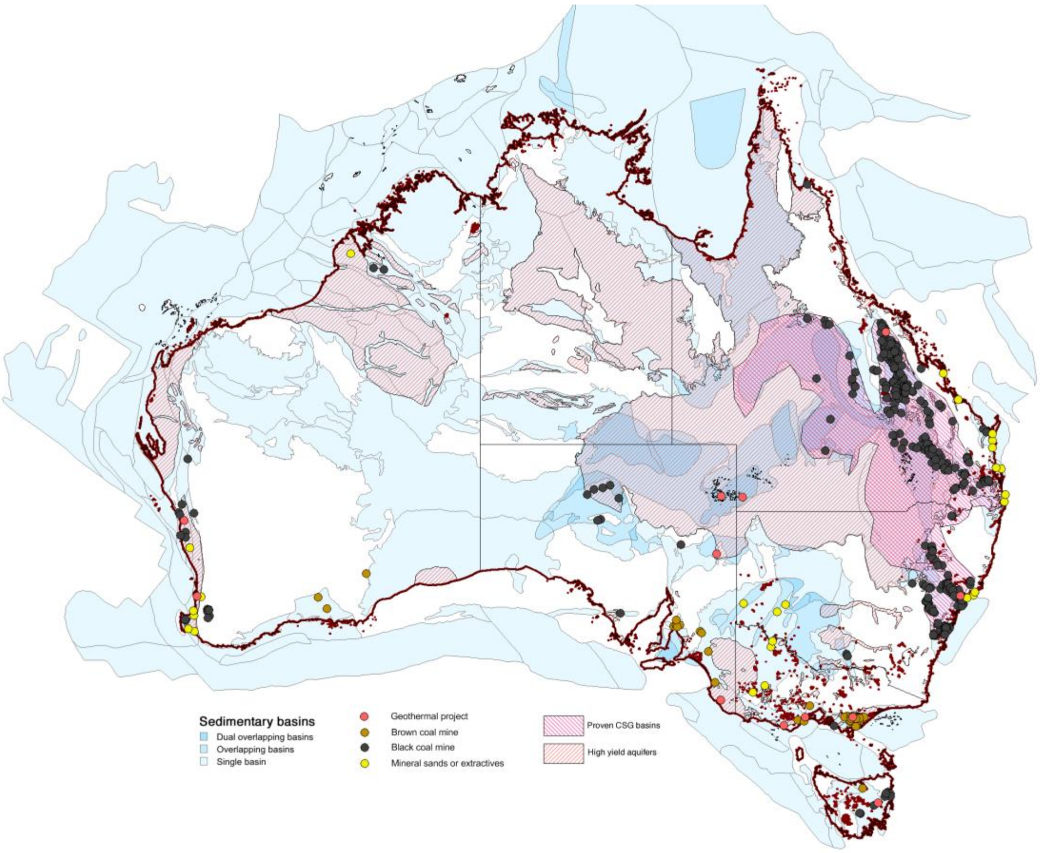


Figure 13.2: Australia's landmass and coastal waters are dominated by resource rich sedimentary basins shown in blue. High-yield aquifer systems - green, coal seam gas basins - purple, black coal mines- back, brown coal mines - brown, geothermal wells - red, mineral sands and ex- tractive industries - yellow (Rawling & Sandiford, 2013).

Table 13.1: Activities in sedimentary basins and potential impacts

Activity	Examples of specific activities	Examples of Potential Impacts

Coal Seam Gas	• infrastructure
	  ○ roads
	  ○ drill pads
	  ○ storage areas
	  ○ water storage
	  ○ pipelines
	  ○ processing plants
	• subsurface
	  ○ bore drilling
	  ○ gas production
	  ○ water extraction
	  ○ water disposal
	  ○ hydraulic fracturing
		• groundwater depletion
		• contamination (aquifer, soil)
		• groundwater dependent ecosystems
		• reducing biodiversity
		  ○ introduction of invasive species along new roads
		  ○ landscape and habitat fragmentation
		• noise
		• traffic
		• fugitive emissions and air quality
		• induced seismicity
		• health
		• dust

Mining	• infrastructure
	  ○ roads
	  ○ ventilation shafts
	  ○ tailings dams and water storage
	  ○ processing facilities
	  ○ train lines
	• subsurface
		• land clearing
		• subsidence
		• groundwater depletion
		• contamination (groundwater and soil)
		• induced seismicity
		• noise
		• traffic
		• dust

	○ explosives ○ digging equipment	
Agriculture	• land ○ land clearing ○ soil tilling ○ fertiliser and pesticide application ○ irrigation ○ monoculture • infrastructure ○ roads and fences ○ water bore ○ dams • introduction of production species (crops and animals)	• groundwater and surface water depletion • landscape and habitat fragmentation • reducing biodiversity ○ introduction of foreign plants and animals (invasive and can carry disease) ○ feral animals ○ weed species • soil structure • salinity • erosion • pollution • emissions and air quality • subsidence
Urban development	• infrastructure ○ buildings and houses ○ roads and train lines ○ sewerage ○ landfill ○ dams and reservoirs ○ drains and pipes ○ harbours and ports • electricity generation and usage • introduced pets • car, train and plane usage • gardens with foreign plants • land reclamation	• land clearing and habitat fragmentation • disease introduction • pollution – air, soil and water • reducing biodiversity • noise • light pollution • induced seismicity • subsidence

Agriculture, mining and urban development have had very significant historical and current impacts. The impact of CSG alone is likely to be much smaller than the cumulative effects of these historical impacts (Cook, 2013a). While CSG activities pose risks and many potential impacts, these need to be considered along with other major competing activities that are being conducted within a region.

Any planning and modelling for new activities need, as far as possible, to take account of other activities that are currently being conducted in the region and may be conducted in the future. This will enable the risk of potential cumulative impacts on the community and the environment to be minimised and remediation activities to be planned in advance.

13.2 REGULATION OF CUMULATIVE IMPACTS

If comprehensive data and better modelling is key to gaining a better understanding of cumulative impacts, appropriate regulation is the first step in managing it. Regulation of cumulative impacts requires the cooperation and coordination of processes and policies between various government agencies within and between various jurisdictions. In some aspects this is a relatively new way of approaching planning, approval and monitoring activities, but is essential to ensure that no impact or activity is considered in isolation.

Various jurisdictions in Australia and internationally are developing methods, policies and regulations to take early steps to manage the potential for cumulative impacts from multiple activities in the same region. These include:

- Commonwealth Government

    - National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development with NSW, Victorian, Queensland and South Australian governments
    - establishment of an Independent Scientific Committee in Coal Seam Gas and Large Coal Mining Development (IESC) (http://www.environment.gov.au/coal-seam-gas-mining/)
- NSW Government
    - Strategic Regional Land Use Policy (http://www.planning.nsw.gov.au/srlup)
- Queensland Government
    - Cumulative Management Areas (http://www.ehp.qld.gov.au/management/coal-seam-gas/cumulative-management.html)
- Alberta Energy
    - Cumulative Effects Management System (CEMS)
    - (http://environment.alberta.ca/0891.html)
- European Union
    - SEA (Strategic Environmental Assessment) Directive of the EU (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:197:0030:0037:EN:PDF)

Much planning approval legislation also attempts to do this.

Many of these methods, policies and regulations are relatively new or are in development, so it is difficult to determine if and how successful they are or have been to date. Many only go part of the way to looking at cumulative impacts by only considering cumulative impacts from mining and CSG activities.

13.3 MONITORING AND MODELLING

As discussed in Chapters 7-10, better understanding of processes and systems is essential to managing our sedimentary basins. This requires data collection and knowledge-building through research, monitoring strategies and modelling.

A coordinated approach to data collection and sharing is required to ensure that all of the monitoring data from relevant activities is available to highlight potential impacts. This will require cooperation between different government organisations, industry and researchers to share information and expertise.

13.3.1 Monitoring and baseline data

Well-designed monitoring strategies are important for mitigating operational risks. Devising monitoring strategies to capture cumulative impacts involves bringing together data from monitors for specific projects in a specific area with data from monitors that have been placed to capture data, regardless of cause, on sensitive parts of that area with a view to building sophisticated dynamic data profiles of the area in question. These data profiles can then be continuously data mined/interrogated to see if any part of the area has become ‘unsafe’ in any way.

Establishment of ‘baselines’ by putting monitoring in place, or accessing measurements from pre-existing sources, e.g. water bores, before activities commence is essential and provides the ‘starting condition’ for the data profile. Solid baseline data helps to reduce concerns around an activity and helps with ‘social licences’ to operate by potentially removing inferred links to environmental impacts such as groundwater quality and seismicity. In other words, baseline data is critical in providing context and allowing critical assessment of any associated risks.

13.3.2 Modelling

Moving towards the development of robust computational models is also essential for informed management of cumulative impacts on sedimentary basins. Models ideally should be basin-wide (or at least regional) and commodity independent to allow effective analysis of multi-activity scenarios. Multipurpose basin models need to be adaptable and flexible to allow for updating as new data is acquired (which might include new data types not previously allowed for in the model).

The Namoi Catchment Management Authority is one agency that is looking at how it can better model the cumulative impacts of multiple mining and CSG activities. The Namoi Catchment Management Authority responded to concern, from farming, environmental interest groups and the community, about the cumulative impacts of multiple mines on natural resource assets in the Namoi Catchment by commissioning a study to quantify the risks of cumulative impacts. The study developed the Namoi Cumulative Risk Assessment Tool (NCRAT) (Eco Logical Australia Pty Ltd, 2011, 2012) (http://www.namoi.cma.nsw.gov.au/41885.html). The NCRAT is a spatial tool that aims to quantify the risk of cumulative impacts of any mining scenario (constituting one or more mines including open cut mines, longwall mines and CSG operations) across ten natural resource assets in the Catchment, including land use, soils, carbon, surface water, groundwater, vegetation extent, vegetation type, vegetation condition (intactness), vegetation connectivity and threatened species. The tool aims to develop a risk report that includes maps, area statistics, single and cumulative risk diagrams and statements about specific assets impacted. It must be noted that the tool only looks at the risks posed by the mining industry, not other major industries in the area such as agriculture.

Data fusion models which take in high-rate data from multiple, diverse sources are particularly relevant for developing comprehensive models aimed at providing insights into the processes leading to cumulative impacts. Data fusion techniques have been used in computer science (and in particular artificial intelligence) for decades but vastly increased computational power along with much greater sensor sensitivity means that data fusion models can now be built on a scale that was not possible until the last couple of years. That such models should soon be able to be constructed to reflect multiple activities taking place across a sedimentary basin is illustrated by the data fusion models currently being constructed by NICTA (headquartered in NSW) for precise deep geothermal mapping in Australia and for understanding aquifer-to-basin connectivity (described in Chapter 7 and touched on elsewhere in this report). This research on these super-scale models and associated visualisation tools is leading edge but is producing significant and unexpected insights in the domains currently being investigated in a way that gives hope that basin-wide models should be able to be constructed soon.

For situations such as assessing the impacts of several industries/activities on a basin-wide scale, a particular challenge in building basin-scale models is that the basins are complex in multiple dimensions and are essentially open systems and therefore particularly difficult to model comprehensively. That is why bringing powerful, newly-enabled modelling techniques such as data fusion to bear on the problem along with the more traditional hypothesis-driven models should lead to better understanding, provided sufficient research continues on this critical problem. NSW has encouraged such research for some time and is well equipped to encourage its growth through organisations such as NICTA, CSIRO, the universities, industry and government agencies.

13.4 NEED FOR IMPROVED ENGINEERING PRACTICE

The notion of assessing cumulative impacts has long existed in the practice of engineering. However, even though engineers attempt to take into account all issues that could impact systems in design and development, there is considerable need for improvement in the formal quantification and management of cumulative impacts.

The formal study of cumulative impacts takes place primarily within the discipline of Complex Systems Engineering, with the most comprehensive work to date occurring in safety- and performance-critical domains such as nuclear engineering. This work needs to be extended much more along the lines described in the modelling section above into yet more complex domains such as multiple-use sedimentary basins

But short of the availability of suitably-comprehensive models there are many circumstances in which cumulative impacts can be anticipated and appropriate monitoring for specific events/effects put in place. Engineering practice needs to develop practices that encourage such approaches and include coverage of cumulative impact management in engineering curricula for all fields of engineering.

Just as more than 20 years ago engineers across the world embraced the importance of quality systems, a similar emphasis is now required for cumulative impacts especially in relation to introduction of new industries such as CSG.

An appropriate body to take a lead on this is Engineers Australia, the body that is charged with registering engineers in Australia. This professional body has considerable experience in working with government on issues and is respected by industry and, by and large, by the community.

13.5 COMMENTS FROM THE REVIEW

Cumulative impacts on the environment and the community need to be considered when looking at past, present and future activities in the environment. Resource-rich sedimentary basins need to be managed effectively to ensure sustainable use and ensure that the risk to the environment is minimised.

Multiple activities can have a cumulative impact which can be hard to predict, not least because it can be hard to link specific cause and effect. This in turn can make it hard to determine which of the component activities in a region should be modified or stopped.

Legislation which anticipates the problems caused by cumulative impacts is a vital underpinning step in addressing the problems that can be associated with multiple industries/activities operating in a single geographical location.

Monitoring is critical. Monitoring is usually mandated for individual operations; however requirements for monitoring need increasingly to take into account multiple activities and potential cumulative impacts.

Data from multiple sources, including a variety of monitors, is critical to ensure that informed decisions can be made about the management of activities and cumulative impacts. Baselines need to be established prior to development activities and monitoring needs to continue for a period after operations have ceased to look at recovery.

High-rate diverse data is also crucial as input to effective sedimentary-basin-scale models. Building models of this scale with appropriately-accurate predictive capability is still a research challenge but one which seems likely to be able to be met in the near future through the use of techniques such as data fusion.

Coordinated approaches across agencies, governments and industry, including agriculture, are needed to assess, manage and regulate cumulative impacts.

To date it has been difficult to consider and analyse cumulative impacts due to availability and expense of technologies including monitoring equipment, data storage capabilities and processing power for complex models. It is also difficult to place a value on each of the competing activities which may have short and long term impacts and benefits. Better engineering tools and practice are required to manage and model cumulative impacts more effectively.

13.6 INFORMATION SOURCES

Information used in this chapter of the report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- "Multi basin usage/cumulative impacts", Associate Professor Tim Rawling and Professor Mike Sandiford, Melbourne Energy Institute, University of Melbourne
- "Life cycle of Coal Seam Gas Projects: Technologies and Potential Impacts", Professor Peter J Cook CBE, FTSE.

14 DATA

14.1 IMPORTANCE OF DATA FOR CSG

The timely, appropriate and accurate monitoring and oversight of all CSG activities in NSW is critical to understanding developments, ensuring compliance and responding to incidents relating to CSG. The fundamental requirement to enable such monitoring and oversight is data. It must be authoritative, reliable and up-to-date. And it must be comprehensively collected, effectively and expertly managed and readily shared, through a blend of automatic, semi-automated and human processes.

Almost half (44%) of the community submissions received by the Review expressed concern about a lack of data enabling a scientific understanding of the effects of CSG on the environment, human health and water. Current data collected on and through CSG activities is collected more for the purposes of legislative compliance and less for monitoring a complex system, which is what the total CSG activities of the State constitute.

Understanding or building knowledge requires specific information or data from various sources, such as an activity in the system (including company reporting), specific monitoring programs and monitoring programs for cognate activities (e.g., water allocation or coal mining) and research projects. Without effective spatially-enabled and open data repositories, the cumulative impacts of multiple activities (e.g., agriculture, mining, urban development) sharing the same space also cannot be effectively analysed and monitored. The more extensive the data, the more sophisticated the capacity for modelling the likely impact of future activity proposals becomes.

It became clear during the Review that monitoring, data management and data sharing are all key needs. In relation to CSG, it is noted in previous chapters that complex issues can be managed if high standards of operation and performance are in place; however, they need to be monitored effectively and the resulting data needs to be curated appropriately and be widely accessible.

This is not just an issue for CSG activities but for other major industries as well, such as mining and agriculture.

14.2 DATA ISSUES ENCOUNTERED BY THE REVIEW

As noted through submissions and in meetings, community groups demanded that data and information be collected and made publicly available to ensure impartiality and substantiation of claims, and to ensure compliance. In particular there were calls for more baseline data, production data, groundwater data, air emissions data and health data – all data that enable a better understanding of the environmental, social and cumulative impacts of CSG activities.

Councils and government agencies noted that they did not have access to simple spatial data such as location of CSG wells, including details on horizontal wells – direction and depth - as well as other CSG-related infrastructure, which would be helpful for planning and approval processes and for communicating with landowners.

Various other data access and provision issues were encountered by the Review:

- there are many aspects of CSG processes where relatively cheap monitoring would provide data for improved performance and would provide early warning of incidents. The incident leading to the ‘Pilliga spill’ could have been detected immediately if 24-hour camera monitoring and alerts were in place on the relevant pipe

- data that is held by various offices, departments and agencies, which is required under legislation and for compliance, has in many cases been difficult to source – even with the ready cooperation of the groups involved
- there is no consistent method for the management, sharing, storage and assessment of data. Different formats and checks for accuracy make it difficult to combine data sets for analysis and quality checking
- data is owned and governed by various groups including governments, industry, agriculture and researchers. This makes it difficult to determine the amount of data that actually exists and to access it easily. Also, while some CSG companies provide charts on various aspects of their activities, they are less ready to provide the raw data to government voluntarily
- requirements for confidentiality and privacy are not always clear.

14.3 MONITORING AND DATA

Better monitoring of the different activities and outputs from CSG operations is essential. This assertion is made throughout this report including the chapters on water, subsidence, induced seismicity, health and cumulative impacts. Monitoring could take various forms including camera monitoring, remote sensing and down-hole sensors, acknowledging that the resulting data will be varied in its spatial coverage, types, precision and quantity.

The development of new and cheaper sensors and related ICT will increasingly allow for more extensive and cheaper monitoring in real time. This will be useful for compliance purposes, and also for research. However, the dispersed nature of the industry, with many remote sites and multiple monitoring factors (level of gas and water production, air emissions, pressure etc.) means that although the unit cost of monitoring might reduce rapidly, overall costs might still increase. Any increases in cost will need to be picked up by industry through increased government licence fees and levies.

Increased monitoring will mean more data being available but will also mean more data to manage and interpret. Sophisticated and in some cases automated curation systems will be required to check the data quality, manage it, and share it.

The vast amounts of monitoring and other data will be important for development of better models of systems such as groundwater. The use of machine learning and data fusion techniques (as used by NICTA in its groundwater modelling project – see Chapter 7) requires a common data repository.

14.4 DATA HELD IN NSW GOVERNMENT AGENCIES SURVEY RESULTS

To help the Review understand the types, format, and extent of data that is currently collected on CSG by various agencies, and to find out how the data is managed, stored, accessed and shared, a data collection and management survey was sent out to those NSW Government agencies that, the Review had been told, collected and managed data on CSG and conventional gas. The agencies sent the survey were:

- the Department of Premier and Cabinet
- the Office of Environment and Heritage
- the Office of CSG, NSW Trade and Investment
- Minerals and Resources, NSW Trade and Investment
- the Environment Protection Authority
- the NSW Office of Water, Department of Primary Industries
- Office of Agricultural Sustainability and Food Security, Department of Primary Industries
- Department of Planning and Infrastructure
- Ministry of Health.

Completing the survey took considerable time for the agencies and several reported difficulty assessing their relevant holdings; no agency that actually collects CSG data was able to provide the data within the specified time (2 weeks). In other words, it was not available 'at the press of a button'. The Department of Premier and Cabinet (apart from OEH) and the Office of Agricultural Sustainability and Food Security reported they collected no relevant data. Table 14.1 summarises the responses from the other agencies and highlights the variety of data types and formats of data held.

Table 14.1: Types of data collected by NSW Government agencies

Agency/Department	Data Types	Formats
Minerals and Resources, NSW T&I	• Geological Cores • Seismic survey line locations • Petroleum Boreholes information • Notification of activities/approvals • Incident reporting and tracking • Return of royalties and statistics • Health and safety	• Spatial information formats • Databases (geological and spatial) • Spreadsheet • PDF, MS Word files, emails • Hard copy
Department of Planning and Infrastructure	• Planning – development assessments, consents and approvals • Complaints • Activities	• PDF and spreadsheet • Hard copy
Environment Protection Authority	• Impact Assessments • Environmental Protection Licence information • Monitoring data • Workflow management	• PDF, Microsoft applications • Hard copy • Databases
NSW Office of Water	• Water licensing system • New Environmental Review Database (NERD) • Compliance Database • Environmental Review Database • Water databases • Monitoring data	• Hard copy • Databases • iPhone app tracking • Logger data – telemetered • Online
NSW Health	• Health information exchange • Computer-assisted telephone interviews • Death registry • Cancer registry • Real-time emergency department surveillance system • Perinatal data	• Databases
Office of Environment and Heritage	• Air quality monitoring • Climate change corridors • Fauna corridors • Fauna key habitats • Wildlife Atlas • Aboriginal Heritage Information Management System • Soils • Land use • Salinity • Rivers • National Parks and wildlife • Wetlands	• Databases • Metadata • Spatial data

It is clear from the survey that data related to CSG (and other petroleum) activities are held in a wide variety of formats. Many agencies have databases to manage certain types of data but there is a considerable amount of data held in hardcopy or in PDF (or MS Word) formats that make accessing and interrogating it difficult. This has the potential to make compliance monitoring and checking difficult, especially as much of the industry response to compliance requirements is in the form of large documents and monitoring reports.

Several agencies indicated that increased data sharing or shared data holdings between them would be useful for various CSG-related activities. The Department of Planning wrote that it would like baseline and modelling results from individual environmental impact assessments to be collated into a State-wide map and would like State-wide mapping of all coal seam gas related infrastructure (NSW Department of Planning & Infrastructure, 2013).

The survey highlighted to the Review that the data available is not always accessible or, when accessible, is not always in machine-readable formats, that not all agencies have access to the data they would like, and that there are gaps and other quality issues in data collected.

14.5 OPEN DATA AND DATA SHARING

Governments around the world are committing to principles of open data – the idea that data and information should be open and accessible to the public, with any confidentiality restrictions and controls limited as much as possible.

Making previously inaccessible information available to all sections of the community enables it to be used for research, business and policy-making purposes, and can lead to significant innovation and productivity benefits in the private, public and community sectors.

Open data and open government policies have been enthusiastically promoted by the US Government over the last 5 years and frequently reinforced. In May 2013 President Obama signed an Open Data Executive Order and released an Open Data Policy to help "institutionalise the principles of effective information management" among government agencies (Executive Office of the President, May 2013). The US already has its data.gov initiative, an online platform which makes available government data sets. Similarly the UK government has data.gov.uk being led by the Transparency and Open Data team in the Cabinet Office. The Australian Government established the Gov 2.0 Taskforce in 2009 to advise on open initiatives generally and it maintains data.gov.au.

Within Australia, the NSW Government was an early proponent of both open government and open data with strong emphasis on the themes of access, engagement and accountability. In the Government's *NSW2021 plan*, Goal 31 is to "improve government transparency by increasing access to government information"; this was elaborated in the NSW Government ICT Strategy released in 2012 (see http://www.finance.nsw.gov.au/ict/sites/default/files/NSW%20Government%20ICT%20Strategy%202012_1.pdf).

NSW legislation also clearly promotes the concept of 'open'. As noted on the relevant NSW Government website:

> The *Government Information (Public Access) Act 2009* (GIPA Act) establishes a freer, more open approach to gaining access to government information in NSW. The objects of the GIPA Act are to maintain and advance a system of responsible and representative democratic Government that is open, accountable, fair and effective, by:
>
> - authorising and encouraging the proactive public release of government information by agencies
> - giving members of the public an enforceable right to access government information, and
> - ensuring that access to government information is restricted only when there is an overriding public interest against disclosure.

> The GIPA Act applies to all NSW government departments, and also extends to Ministers and their staff, local councils, State-owned corporations, courts in their non-judicial functions, and to certain public institutions such as universities.
>
> The guiding principle of the GIPA Act is the public interest, with a general presumption that disclosure of information is in the public interest unless a strong case to the contrary can be demonstrated. Under the GIPA Act it is compulsory for agencies to provide information about their structure, functions and policies, while agencies are encouraged to proactively and informally disclose as much other information as possible.
>
> Formal access applications should only need to be lodged as a last resort. Where formal applications are required, the Act outlines the process that applicants and agencies should follow, as well as the options for reviewing decisions (see http://www.ipc.nsw.gov.au/privacy/gipa_act.html).

The Review draws attention to this matter at length as it is an issue that was largely missing in the CSG submissions to, and discussions with, the Review. Community groups seemed unaware of the Government's strong commitment to transparency; and Government agencies, while aware of it, have not moved far in data sharing as CSG data and compliance matters are spread across so many agencies.

14.6 IMPORTANCE OF DATA SHARING FOR CSG

Data sharing initiatives allow for access to a diverse array of information and data-related assets that span organisational, geographic and temporal boundaries. This is especially important for activities that are managed and monitored by multiple government agencies, such as mining and CSG.

Information that is sought by other agencies and the public usually exists in isolation within the specific area managing a component of the overall activity. Requests for information, both between agencies and from the public through the GIPA Act, have meant in many cases that portions of the data are provided in hardcopy or PDF form. Many government agencies have data available online but the data is generally dispersed over different departmental websites and is often in formats that are not compatible with each other, making the data difficult to mine and manipulate.

It has therefore been difficult for various agencies, researchers and interested members of the community to extract useful knowledge from the available data sources. Advances in technology mean that governments now have the ability to store and manage massive amounts of data through common data repositories and make all data in such repositories available easily and efficiently to groups that would benefit from access.

The ability to access multiple data sets has many advantages for CSG, but also other areas of government, industry and research. Combining data from multiple sources enables fresh insights to be made. And it allows for research on major data fusion modelling, using heterogeneous data sources, to be undertaken in critical areas such as the shallow-to-deep aquifer modelling being undertaken by NICTA for the NSW Office of Water and for Geoscience Australia.

14.7 UNDERSTANDING HOW CROSS-AGENCY AND CROSS-INSTITUTION DATA SHARING AND COMMON DATA REPOSITORIES WORK

The Review commissioned a study on what is needed for good practice in data management for CSG from Intersect Australia Ltd. The report of this study is available at http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review. As well as providing a detailed analysis of the issue, the study describes several examples of different systems or projects aiming to manage vast amounts of heterogeneous data sets for a variety of uses, including:

- Alberta Energy Regulator – Digital Data Submission (DDS): petroleum and gas data
- Secure Unified Research Environment (SURE): Australian health data
- Centre for Health Record Linkage (CHeReL): Australian health record linkage
- NSW Office of Environment and Heritage, NSW MER Strategy (Monitoring, Evaluation and Reporting): monitoring the condition of natural resources.

14.8 COMMENTS FROM THE REVIEW

As identified in the previous chapters, the Review team heard from many stakeholders that lack of data inhibits better understanding CSG activities and their potential impacts, and it hinders monitoring and compliance review. The Review found there is a wide array of data kept by industry, researchers, and by government agencies including spatial, numerical, photographic and written reports in many differing formats with little in the way of an open and common approach to data requirements.

To monitor compliance and increase community trust, the Government needs to ensure that CSG activities and issues are effectively tracked, analysed and communicated to the public through better data collection, handling and sharing practices. Moreover Government and industry need to anticipate the advantages offered by the rapid evolution of monitoring and associated ICT to improve the overall regulation of the CSG industry in NSW.

Better data collection and access will also bring benefits to government planning and policymaking, to research and innovation.

Recommendations 1 (in part) and 2 address this issue. These recommendations are presented in the next chapter.

14.9 INFORMATION SOURCES

Information in this chapter of the Report was taken from background information papers on various topics commissioned by the Review. Specific information was taken from:

- “NSW coal seam gas data management background paper”, Intersect Ltd.

PART THREE

15 CONCLUSION AND RECOMMENDATIONS

15.1 GENERAL CONCLUSION

The study of CSG matters covered by the Terms of Reference for this Review is not complete but certain issues are clear at this stage.

From the consultation part of the Review, it is very clear that there is a widespread belief by those not particularly involved in CSG extraction that CSG is dangerous in some way. For those closer to the issue, the situation is often more complex. Many of those who had concerns with CSG made it clear that they were not against CSG in absolute terms, but that they did not want it to proceed either on or near their land until certain conditions were met.

There certainly are groups whose views are sharply polarised for and against. Groups concerned about CSG are often distrustful of Government's intentions and believe that Government is not concerned about the issues that worry them. They cite lack of enforcement of legislative compliance, lack of baseline and ongoing data collection, and an unwillingness to punish non-compliance. The CSG industry on the other hand is concerned about what it sees as a constantly changing regulatory and legislative regime. Several of the smaller companies have already suspended their operations in New South Wales. The larger companies say they are considering doing likewise. All sides of the debate are united in being cross with Government.

From consideration of the technical matters studied within the Review, it is clear that CSG extraction, like all forms of energy production, poses environmental and health challenges. These challenges are various but include ones that we have been long familiar with, even though we do not know fully how to characterise or meet them (e.g. management of underground water resources: we do not have a comprehensive map/model of these resources in Australia yet, but we still proceed with major agricultural and mining activities whose total impacts on our groundwater system are much more significant than CSG developments in Australia at this stage). Then there are challenges which we know can be met with good engineering solutions (e.g. managing produced water, and drilling and completing wells). In these cases we know great care needs to be taken to apply engineering best practice and this needs to be matched by superb monitoring systems on the part of industry, transparent and diligent checking of compliance by the regulators, and rapid and effective response and then remediation by all parties to any accidents or emergencies.

It cannot be emphasised too strongly that CSG exploration and extraction does indeed require engineering solutions of a very high order performed by organisations with a track record of delivering excellent performance to high standards of environmental care and human safety.

Monitoring such activity, especially from an industry which is geographically dispersed and where many of the ongoing production operations take place without direct human supervision, is nontrivial and expensive. Good monitoring, alarm and compliance systems on complex engineering structures produce massive amounts of data which need to be managed effectively to address the purposes for which the data are collected. Covering the cost of monitoring, compliance and any needed remediation is something that needs to be calculated carefully to see that the costs of operation are fully met through industry levies, insurances and bonds. This is a matter that is being addressed over the next phases of the Review.

CSG exploration and extraction on the State-wide level needs to be thought of as a complex system requiring well-articulated and detailed engineering solutions. This is not an industry for undercapitalised players.

The CSG industry should be considered as more analogous to major infrastructure projects such as State-wide traffic systems or designing and building new high-tech aircraft than as a cottage industry.

Unconventional gas exploration and extraction is a new and evolving industry and as such needs to be prepared to operate in a regime of continuous improvement where government, industry and the community together encourage good research on the issues that still need further clarification (such as aquifer modelling and management) and where engineering solutions are expected to improve markedly over a relatively short period of time. Legislative frameworks need to be developed so they can be updated frequently to reflect and encourage improving knowledge and good practice.

As the recent report on unconventional gas production by the Australian Council of Learned Academies presented to the Prime Minister's Science, Engineering and Innovation Council (2013) (Cook et al., 2013) said, referring to shale gas – but it applies just as well if the words 'coal seam gas' are substituted for 'shale':

> Because of the manner in which shale gas is produced it has the potential to impact on the landscape, on ecosystems, on surface and groundwater, on the atmosphere, on communities, and rarely may result in minor induced seismicity.
>
> It will be vital for industry and government to recognise the complexity of the challenges posed by these possible impacts.
>
> However, most can be minimised where an effective regulatory system and best monitoring practice are in place and can be remediated where they do occur.
>
> If the shale gas industry is to earn and retain the social licence to operate, it is a matter of some urgency to have such a transparent, adaptive and effective regulatory system in place and implemented, backed by best practice monitoring in addition to credible and high quality baseline surveys.
>
> Research into Australia's deep sedimentary basins and related landscapes, water resources and ecosystems, and how they can be monitored, will be essential to ensure that any shale gas production is effectively managed and the impacts minimised.

15.2 PHILOSOPHY BEHIND THE RECOMMENDATIONS

At this stage the Review recommendations are aimed at assisting Government to build trust in the wider community that it has the intention and capacity to oversee the safe introduction of a new industry which can have significant economic benefits. To reap those benefits, a set of significant risks and challenges need to be addressed and managed.

15.3 RECOMMENDATIONS

The first recommendation deals with Government intent and commitment.

Recommendation 1

That the Government commits to establishing a regime for extraction of coal seam gas that is world class. This involves inter alia:

- *clear public statements of the rationale/need for coal seam gas extraction (including, for example, within the State planning policies on energy and resources; environment and conservation; infrastructure; hazards; agricultural and rural resources; and development assessment being developed following the 2013 White Paper, a New Planning System for NSW)*
- *insisting on world best practice in all aspects and at all stages (exploration, production, abandonment) of CSG extraction*

- *sending a clear message to industry that CSG extraction high performance will be mandatory; compliance with legislation will be rigorously enforced; and transgressions will be punished with published high fines and revocation of licences as appropriate*
- *treating coal seam gas extraction in NSW as a complex system with appropriate mechanisms to estimate risk both in toto and locally on a dynamic basis*
- *having a clear, easy-to-navigate legislative, compliance and monitoring framework that evolves over time to incorporate new engineering and science developments*
- *high levels of transparency*
- *having a fair system for managing land access and compensation for those whose land is affected by coal seam gas activities*
- *maintaining reliable, complete, current and authoritative data on all aspects of CSG and having this data held in a central, comprehensive, spatially-enabled, open, whole-of-environment data repository. All data collected by the private and public sectors relevant to CSG extraction, coal, other mining, and water would be sent directly to the repository. Such a repository supports transparency and enables rapid compliance checking, fast response to alarms and accidents, increased understanding of cumulative impacts, and research on complex issues*
- *developing within government a system to assess cumulative impacts of multiple industries operating in sensitive environments with formal assessments being updated annually with any major problems identified being addressed promptly*
- *the Ministry of Health continuing to monitor any unusual symptoms reported in areas where coal seam gas is being extracted and looking for correlations with changing environmental factors*
- *committing to high levels of monitoring with an understanding that the amount and sophistication of monitoring is likely to increase rather than decrease over time as sensors become even cheaper and communications and data technologies become even better*
- *adjusting on a regular basis industry levies, bonds and insurance to make sure all financial costs of overseeing the State's coal seam gas system and maintaining infrastructure are covered, as are all contingencies and making sure industry understands that fees can be adjusted at annual notice*
- *ensuring all coal seam gas companies have structures in place to ensure full legislative compliance not only by themselves but also by any subcontractors they retain*
- *ensuring all those working in the coal seam gas industries have appropriate training and certification*
- *ensuring those working in the public sector on CSG legislation and compliance are provided with a sound compliance and monitoring framework within which to operate, and given appropriate on-the-job training to ensure up-to-date knowledge of this fast-moving industry and of latest developments in monitoring and compliance worldwide*
- *commitment to ramping up research on difficult issues such as continuing to develop comprehensive and detailed models of the State's underground water and how to build robust engineering approaches to assessing cumulative impact of multiple industries affecting underground resources in a dynamic way*
- *working closely and continuously with the community, industry, industry bodies, and research organisations to keep the coal seam gas system in NSW up to world standard.*

The Review appreciates that moving towards the world-class system as described in Recommendation 1's statement of intent would be best done in phases as each element is complex, potentially costly, needs to be well resourced, and requires working with stakeholders to get processes right. However, there are certain elements which should be commenced quickly in order to provide a sound base for a robust and responsible CSG policy regime. Accordingly the Review provides recommendations on establishing the data repository, making well operator training and certification mandatory and continuing research activities.

Recommendation 2

That Government commission the design and establishment of a whole-of-environment data repository for all State environment data including all data collected according to legislative and regulatory requirements associated with water management, gas extraction, mining, manufacturing, and chemical processing activities. This repository would, as a minimum, have the following characteristics:

- *have excellent curatorial systems*
- *be designed and managed by data professionals to highest world quality data-handling standards*
- *be open except for limited exceptions where the data is commercial-in-confidence and to which access is restricted to varying degrees*
- *be not only accessible by all under open-data conventions but also able to accept citizen data input*
- *be able to be searched in real time*
- *be spatially enabled*
- *hold all data electronically*
- *hold data of many diverse formats including text, graphics, sound, photographic, video, satellite, mapping, electronic monitoring data, etc*
- *be the repository of all research results pertaining to environmental matters in NSW along with full details of the related experimental design and any resulting scientific publications and comments*
- *be the repository of historical data with appropriate metadata*
- *for all bodies governed by relevant legislation, generate an automatic deposit schedule, and notify the regulator and the organisation involved automatically of overdue deposits.*

That any legislation amendments needed to direct all environment data to the Data Repository are undertaken.

The location and responsibility for the State Environment Data Repository could be with:

a) an independent expert data organisation – including a quasi-governmental body such as INTERSECT
b) the DTIRIS which already collects mining, CSG and water data for NSW
c) the Office of Environment & Heritage which has commenced work on an open data project, *Open OEH*
d) the Department of Finance & Services which has carriage of the NSW ICT Strategy.

Above all, the principles of the repository must be clear: data is collected directly by the repository once only and not separately by different agencies; everyone who requires access is provided with access; and the system incorporates a sophisticated automatic notification model to ensure data collected is continually updated and shared.

Because Australia has access to satellite data using a variety of sensors over many decades, this data can be drawn on to understand subsidence in NSW *in globo* over time, drawing on the Government's existing Land and Property Information expertise. Queensland is already using such data to understand subsidence historically and as it applies now, and the two states are close partners on spatial matters.

Recommendation 3

That a pre-major-CSG whole-of-State subsidence baseline be calculated using appropriate remote sensing data going back, say, 15 years. And that, from 2013 onwards, an annual whole-of-State subsidence map be produced so that the State's patterns can be traced for the purpose of understanding and addressing any significant cumulative subsidence.

As noted, Queensland is undertaking a historical-to-now subsidence study using similar methods. This recommendation could easily be extended to cover both NSW and Queensland or, indeed, the whole of Australia for little extra computational cost.

Recommendation 4

That all CSG industry personnel including subcontractors working in operational roles be subject to mandatory training and certification requirements and that these mandatory training and certification requirements be included in the codes of practice relevant to CSG.

A related recommendation was made by the Chief Scientist & Engineer when advising on the Codes of Practice in CSG extraction in 2012. The Government accepted this recommendation but it is not yet fully implemented and the matter needs urgent attention to allay fears especially about subcontractors. Queensland has a more developed system of mandatory licensing and NSW officers are working with their Queensland counterparts to move towards a harmonised system. This makes good sense but some immediate action on this matter especially regarding well-bore operators might need to be taken before the full harmonised training system is introduced.

Recommendation 5

That the Government continue and extend its role as a champion of research relevant to the hard problems related to under-earth especially the development of sophisticated predictive underground models and a formalisation of engineering processes for cumulative impact assessment. The Government should not only lead by example in encouraging and funding such research to be undertaken and discussed in NSW, but should exhort other governments and organisations to take a related approach through mechanisms such as COAG and international partnerships.

15.4 WHERE THE REVIEW IS HEADING NEXT

In the next phase the Review will focus particularly on the following:

- the industry compliance study
- completion of the study of the appropriate insurance levels for the CSG industry
- understanding more about government best practice in managing coal seam gas extraction especially through a study of international good practice
- undertaking an in-depth study of how to assess and manage risk dynamically for CSG systems.

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Acronyms, abbreviations and units of measure

APPEA	Australian Petroleum Production and Exploration Association
BREE	Bureau of Resources and Energy Economics (Commonwealth)
CRCSI	Cooperative Research Centre for Spatial Information
CSE	Chief Scientist & Engineer (NSW)
CSG	Coal seam gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIICCSRTE	Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, (Commonwealth)
DTIRIS	Department of Trade and Investment, Regional Infrastructure and Services (NSW)
GA	Geoscience Australia
LNG	Liquefied natural gas
NGERS	National Greenhouse and Energy Reporting Scheme (Commonwealth)
NSW	New South Wales
OCSE	Office of the Chief Scientist & Engineer (NSW)
PAL	Petroleum Assessment Licence
PEL	Petroleum Exploration Lease
PPL	Petroleum Production Lease
Qld	Queensland
UNSW	University of New South Wales

Units

Bbl	Barrels
Bcf	Billion cubic feet
GJ	Gigajoule – 10^9 joules (billion)
GW	Gigawatt – 10^9 watts
KJ	Kilojoule – 10^3 joules (thousand)
kWh	Kilowatt-hour
M^3	Cubic metres (mcm/bcm = million/billion cubic metres)
MJ	Megajoule – 10^6 joules (million)
ML	Megalitre – 10^6 litres (million)
Mmbbl	Million (10^6) barrels
Mt	Million (10^6) tonnes
MW	Megawatts – 10^6 watts
PJ	Petajoule – 10^{15} joules (quadrillion)
Tcf	Trillion (10^{12}) cubic feet
TJ	Terajoule – 10^{12} joules (trillion)
tpa	Tonnes per year (Mtpa = million tonnes per year)
TWh	Terawatt-hours – 10^{12} watt-hours

APPENDICES

APPENDIX 1 TERMS OF REFERENCE

Review of coal seam gas activities in NSW

At the request of the NSW Government, the NSW Chief Scientist & Engineer will conduct a review of coal seam gas (CSG) related activities in NSW, with a focus on the impacts of these activities on human health and the environment.

The Chief Scientist & Engineer is to:

1. undertake a comprehensive study of industry compliance involving site visits and well inspections. The Chief Scientist's work will be informed by compliance audits undertaken by regulatory officers, such as the Environment Protection Authority and other government agencies
2. identify and assess any gaps in the identification and management of risk arising from coal seam gas exploration, assessment and production, particularly as they relate to human health, the environment and water catchments
3. identify best practice in relation to the management of CSG or similar unconventional gas projects in close proximity to residential properties and urban areas and consider appropriate ways to manage the interface between residences and CSG activity
4. explain how the characteristics of the NSW coal seam gas industry compare with the industry nationally and internationally
5. inspect and monitor current drilling activities including water extraction, hydraulic fracturing and aquifer protection techniques
6. produce a series of information papers on specific elements of CSG operation and impact, to inform policy development and to assist with public understanding. Topics should include:
   - operational processes
   - NSW geology
   - water management
   - horizontal drilling
   - hydraulic fracturing (fracking)
   - fugitive emissions
   - health impacts
   - wells and bores
   - subsidence.

The NSW Chief Scientist & Engineer will provide an initial report to the Premier and the Minister for Resources and Energy on her findings and observations by July 2013.

APPENDIX 2 LIST OF TECHNICAL PAPERS COMMISSIONED FOR REVIEW

	Topic	Expert name	Organisation	Status
1	Baseline human health	Hilary Bambrick	University of Western Sydney	Under review
2	CSG processes	Professor Peter Cook	PJC International, National Centre for Groundwater Research and Training, Flinders University	Under review
3	Community concerns	Professor Raphael et al	University of Western Sydney	Finalised
4	Community interface	Sharon Davis	SD Consulting	Under review
5	Data management	Ian Gibson	Intersect	Under review
6	Gas modelling	Peter Rayner	University of Melbourne	Under review
7	Geology	Craig O'Neill and Cara Danis	Access Macquarie, Macquarie University	Under review
8	Geology	Professor Colin Ward	UNSW Global Pty Ltd	Under review
9	Groundwater	Doug Anderson et al.	Water Research Laboratory (WRL)	Finalised
10	Horizontal drilling	John Carter	Advanced Geomechanics	Under review
11	Insurance and risk management	Bernard Evans	Hicksons Lawyers	In prep.
12	Legislation and regulation	Sue Graebner	Independent consultant	In prep.
13	Methane	Linda Stalker	CSIRO	In prep.
14	Produced water	Damian Gore Peter Davies	Macquarie University	Under review
15	Produced water	Stuart Khan	UNSW	Under review
16	Sedimentary basins	Mike Sandiford Tim Rawling	University of Melbourne	Under review
17	Seismicity	Mike Sandiford Gary Gibson	University of Melbourne	Under review
18	Seismicity	Barry Drummond	Independent consultant, formerly with Geoscience Australia	In prep.
19	Subsidence causes	Phil Tickle	Cooperative Research Centre for Spatial Information (CRCSI)	Under review
20	Subsidence causes	Daichao Sheng Jubert Pineda	University of Newcastle	Under review
21	Subsidence monitoring	Simon McClusky Paul Tregoning	Australian National University	Under review
22	Subsidence monitoring	Phil Tickle et al.	CRCSI	Under review
23	Skills, training, onsite knowledge sharing	Jon Gibson	Independent consultant	Under review

Note: 'In prep.' refers to papers that have been commissioned by the Review and are currently under preparation by the author(s). 'Under review' refers to papers that have been received from the author(s) in draft form and are presently under review by the OSCE. 'Finalised' refers to papers which are completed and will shortly be uploaded to the OSCE website.

APPENDIX 3 LIST OF SUBMISSIONS TO REVIEW

Submission	Name	Affiliated organisation, if any
SUB 0001	Michael Starr	
SUB 0002	Victoria Hamilton	
SUB 0003	Annette Dean	
SUB 0004	Mr G H Schorel-Hlavka OWB	Constitutionalist, Paralegal Independent Consultant & Author
SUB 0005	Bev L. Pattenden	
SUB 0006	Hayley Katzen	
SUB 0007	Jane Hughes	
SUB 0008	John Zanetic	
SUB 0009	**CONFIDENTIAL**	
SUB 0010	Tesla (Concerned Earth Dweller)	
SUB 0011	Krisstie Byrnne	
SUB 0012	Charlie	
SUB 0013	Lynne & Jim De Weaver	
SUB 0014	Philip Pells	Pells Consulting
SUB 0015	Josie Evans	
SUB 0016	Linnie Lambrechtsen	
SUB 0017	Patrick Longfield	
SUB 0018	Ian Walker	
SUB 0019	Harry Creevey	
SUB 0020	Colin Hunt	
SUB 0021	Phoebe Birks	
SUB 0022	John Edwards	Clarence Environment Centre
SUB 0023	Patricia Holt	
SUB 0024	Sue Wilmott	
SUB 0025	Mark Waye	
SUB 0026	Des Schroder, Acting General Manager	Clarence Valley Council
SUB 0027	Dr Steve Robinson	
SUB 0028	Peter Buchtmann	
SUB 0029	Charlie Zhang	ZM Partners
SUB 0030	Betty Panayiotou	
SUB 0031	Denis Wilson	Australian Water Campaigners
SUB 0032	Denise Chesney	
SUB 0033	Anara Carroll	
SUB 0034	Davina Riihimaa	
SUB 0035	Caitlin Spiller	Port Stephens Greens
SUB 0036	Graeme Batterbury	
SUB 0037	Peter Wynne	Consultant Mining Engineer, Underground Coal
SUB 0038	Effie Ablett	
SUB 0039	Jo Immig	National Toxics Network Inc

SUB 0040	Prof. Chris Von der Borch	Former Dean of the School of Earth Sciences at Flinders University
SUB 0041	Joanna Leoni	
SUB 0042	Kay Amon	
SUB 0043	Robin Ellis	
SUB 0044	Carolyn Eddy	
SUB 0045	Alex Arthur	
SUB 0046	Mark Westcott	
SUB 0047	Mrs Louise Somerville	
SUB 0048	Annette M Dean	
SUB 0049	Desley Banks	
SUB 0050	Dr Wayne Somerville	
SUB 0051	Paul Johnson	
SUB 0052	**CONFIDENTIAL**	
SUB 0053	Margaret Jackson	
SUB 0054	Mary Smith	
SUB 0055	**CONFIDENTIAL**	
SUB 0056	Wendy Sibley	
SUB 0057	Greg Smithers	Comptrain Australia (VET Adult Trainer and Assessor)
SUB 0058	Professor Chris Fell	Fell Consulting Pty Ltd
SUB 0059	Peter John Brown	
SUB 0060	Charlie Shuetrim	
SUB 0061	Assoc. Prof. Melissa Haswell	UNSW
SUB 0062	Helen Wilson	Hunter Valley Wine Industry Association
SUB 0063	**CONFIDENTIAL**	
SUB 0064	Vanessa Bennett	
SUB 0065	Alan Roberts	Nimbin Environment Centre
SUB 0066	**CONFIDENTIAL**	
SUB 0067	Jennifer O'Neill	
SUB 0068	Chris Lawrence, Corporate Development Manager	Apex Energy NL
SUB 0069	Marita Ranclaud	Caroona Coal Action Group
SUB 0070	Jeff Kite	
SUB 0071	Bruce & Belinda Robertson	
SUB 0072	WX & HJ Martin	Caroona Coal Action Group
SUB 0073	Margaret Scheidler	
SUB 0074	Prue Bodsworth	The Wilderness Society Newcastle
SUB 0075	Marylou Potts Pty Ltd	
SUB 0076	Paul Saunders	

SUB 0077	Beth Williams	
SUB 0078	Prue Green	
SUB 0079	Emma Langfield	Caroona Coal Action Group
SUB 0080	**CONFIDENTIAL**	
SUB 0081	Renate Pacione	
SUB 0082	Sonya Marshall (MG & SM Marshall)	
SUB 0083	Sister Jocelyn Kramer OCD	Discalced Carmelite Nuns, Varroville
SUB 0084	Helen Gillard	Winemaker, Mill Creek Vineyard
SUB 0085	**CONFIDENTIAL**	
SUB 0086	Trish Hay	
SUB 0087	Jean B Cooney	
SUB 0088	Sharon Wilkinson	
SUB 0089	Mr Rob Oakeshott MP	Federal Member for Lyne
SUB 0090	Graeme Healy Chairperson	Barrington-Gloucester-Stroud Preservation Alliance Inc.
SUB 0091	Lynda Fletcher	
SUB 0092	Sue Willis	
SUB 0093	Beverley Crossley	
SUB 0094	Boudicca Cerese	Lock the Gate Alliance
SUB 0095	Helen Wilson	Hunter Valley Wine Industry Association
SUB 0096	Wendy Leighton	
SUB 0097	Albert Mah	
SUB 0098	Jane Hughes	
SUB 0099	Doug Barron	
SUB 0100	Sharyn Proctor	
SUB 0101	Jan Marsh	
SUB 0102	Dan Hamilton	
SUB 0103	Karen Rees	
SUB 0104	Kirsten Anker	
SUB 0105	Gemma Hicks	
SUB 0106	Phil Harris	
SUB 0107	Sally Chapman	
SUB 0108	Andrew & Helen Strang	
SUB 0109	Dr Wayne Sommerville	
SUB 0110	Don Saville	
SUB 0111	Annee Lawrence	
SUB 0112	Dominique Jacobs	
SUB 0113	Lynden Jacobi	
SUB 0114	Cathy Burgess	

SUB 0115	Daphne & Peter Mitchell	
SUB 0116	Colin Duncan	
SUB 0117	Stephen Barnes	
SUB 0118	BJ and Ele Fraser	
SUB 0119	Peter Simmonds	
SUB 0120	Jason Gibbs	
SUB 0121	**CONFIDENTIAL**	
SUB 0122	Alcy Infinity	
SUB 0123	Leonie Stubbs	
SUB 0124	Tracey Murrell & Barry McGregor	
SUB 0125	Geoff Walton & Gaby Klika	
SUB 0126	Peter Lamb	
SUB 0127	Korinne Dodd	
SUB 0128	Annalise Friend	
SUB 0129	Susie Russell	
SUB 0130	Prudence Wawn	
SUB 0131	Susan J Benham & Roy Tang	
SUB 0132	Helen Brown	
SUB 0133	Shirley Gladding	
SUB 0134	Michelle Phillips	
SUB 0135	Nimna De Silva	
SUB 0136	David Ward	
SUB 0137	Dr Paddy McLisky	
SUB 0138	Will D'Arcy	
SUB 0139	Garry & Angela Owers	
SUB 0140	Andrea MacKay	
SUB 0141	Dr Sam Iyer	
SUB 0142	Wendy Royston	
SUB 0143	Rosemary Nankivell	Chairman of the CSG Committee, Caroona Coal Action Group
SUB 0144	Rendall Wagner	
SUB 0145	Cherry Hardaker	
SUB 0146	Dean O'Callaghan	CEO & Ideas Man, Good Brew Company
SUB 0147	David Farmer, General Manager	Wollongong City Council
SUB 0148	Steve Howlett	
SUB 0149	Wendy Bellamy	
SUB 0150	Stephanie Shoebridge	
SUB 0151	Lyall Howard, Policy Director NSW	Australian Petroleum Production & Exploration Association Limited

SUB 0152	Steve Turnock	
SUB 0153	Tang	
SUB 0154	Dr Deirdre Howard - Wagner	
SUB 0155	David Eden	
SUB 0156	Denis Slater	
SUB 0157	Fiona Armstrong, Convenor	Climate Health Alliance
SUB 0158	Lesley Lalor	
SUB 0159	Annabel McLisky	
SUB 0160	Daniel Berg	
SUB 0161	Ray Dawes	
SUB 0162	Duncan Fowler	
SUB 0163	Sean Corrigan	
SUB 0164	Geoffrey P Brown	
SUB 0165	John Hamparsum	
SUB 0166	Jeff Friend	
SUB 0167	Caroline Graham	
SUB 0168	Patricia Kahler	
SUB 0169	Rachel Walmsley	EDO NSW
SUB 0170	Richard Gould	
SUB 0171	John Lagerlow	
SUB 0172	Roger Marchant	
SUB 0173	Scott Sledge	
SUB 0174	Katrina McDonald	
SUB 0175	Dr Brian Marshall	Blue Mountains Conservation Society
SUB 0176	Johanna Evans and Sean Mackie	
SUB 0177	Liz Stephens	Medowie CSG Free Community Group
SUB 0178	Peter Henderson, Managing Director and CEO	Metgasco
SUB 0179	Dr Geralyn McCarron	
SUB 0180	Brian Cain	
SUB 0181	Margy McLean	FalBrook Wildlife Refuge
SUB 0182	Barrie Griffiths	North East Forest Alliance
SUB 0183	Lisa Norman	SOS Liverpool Plains
SUB 0184	David Johnson	
SUB 0185	Denise Gilbert	
SUB 0186	Suzanne Gray	
SUB 0187	Gail Curby	
SUB 0188	Aled Hoggett	
SUB 0189	Dr Jane Naylor	

SUB 0190	Rod and Robin Besier	
SUB 0191	Michael Moore	Public Health Association of Australia
SUB 0192	Allan & Marie Grant	Caroona Coal Action Group
SUB 0193	**CONFIDENTIAL**	
SUB 0194	Meredith Stanton	
SUB 0195	Maxine Blackburn, Specialist Clinical Psychologist	Chair Ethics & Values, Pillar Ecological Agriculture Australia Association
SUB 0196	Jenny Seymour	
SUB 0197	Glenn Winters	
SUB 0198	Roger and Heather Ranclaud	Caroona Coal Action Group, Upper Mooki Landcare Group, SOS Liverpool Plains Group
SUB 0199	Sue Wilmott	Caroona Coal Action Group and SOS Liverpool Plains Group
SUB 0200	Craig Miller	
SUB 0201	**CONFIDENTIAL**	
SUB 0202	Danica Leys, Policy Director - Environment	NSW Farmers
SUB 0203	Bruce Gilbert	
SUB 0204	Nan Nicholson	
SUB 0205	**CONFIDENTIAL**	
SUB 0206	**CONFIDENTIAL**	
SUB 0207	Bruce O'Connor	
SUB 0208	Jacqui Kirby	Scenic Hills Association
SUB 0209	Ross Murray	
SUB 0210	Glenda McLoughlin	
SUB 0211	**CONFIDENTIAL**	
SUB 0212	Michael Moraza, Group General Manager	AGL Limited
SUB 0213	Tony Pickard	
SUB 0214	Jon-Maree Baker, Executive Officer	Namoi Water
SUB 0215	Vicki Moseley	
SUB 0216	Peter Tyler	
SUB 0217	Peter Mitchley General Manager - Energy NSW	Santos Ltd
SUB 0218	Jacqui Kirkby	Scenic Hills Association
SUB 0219	Derek Dreyer	
SUB 0220	David Wilson	
SUB 0221	Joy Oddy	Doctors for the Environment Australia
SUB 0222	Les Timar, Managing Director	Government Relations Australia Advisory
SUB 0223	**CONFIDENTIAL**	
SUB 0224	**CONFIDENTIAL**	

SUB 0225	Justin Hamilton Public Officer	Fullerton Cove Residents Action Group
SUB 0226	Naomi Hogan	The Wilderness Society Newcastle
SUB 0227	Andrew Spooner Manager Sustainable City and Environment	Campbelltown City Council
SUB 0228	Adrian Ingleby	
SUB 0229	Dr Peter Turner	
SUB 0230	Denis Slater	Stop CSG Sydney Water Catchment
SUB 0231	Andrea MacKay *Supplementary Submission*	
SUB 0232	Les McMahon General Manager	Wollondilly Shire Council
SUB 0233	**Name withheld** *Supplementary Submission*	
SUB 0234	Sister Jocelyn Kramer OCD *Supplementary Submission*	Discalced Carmelite Nuns, Varroville

APPENDIX 4 REVIEW MEETINGS

Date of meeting	Company/ Organisation	Representatives present
4.3.2013	Halliburton	David Guglielmo, Country Manager – Halliburton (Australia) Christopher Benscher, Manager Government Affairs – Halliburton (Washington) Mike Watts, Stimulation Affairs – Halliburton (Houston) Rebecca Moring, Environmental Attorney – Halliburton (Texas) Stuart Kemp, Assistant General Counsel – Halliburton (Houston) Miriam McGowan – Halliburton Les Timar, Managing Director – Government Relations Australia (Lobbyist)
6.3.2013	NRMA	NRMA Board meeting
8.4.2013	Metgasco	Peter Henderson, Managing Director and Chief Operating Officer
11.4.2013	Santos	Peter Mitchley, General Manager NSW Al Feely, Manager Water and Environment Rohan Richardson, Drilling Manager David Bailey, Operations Manager Michael Laurent, Subsurface Manager
16.4.2013	Halliburton	David Guglielmo, Country Manager – Halliburton Les Timar, Managing Director – Government Relations Australia (Lobbyist) Dr Sophie Wood, Partner – Environmental Resources Management (ERM)
17.4.2013	NSW Farmers Association	Fiona Simson, President Danica Leys, Environment Policy Director Adair Moar, Environment Policy Advisor
22.4.2013	Dart Energy	Robbert de Weijer, CEO Australia Andrew Collins, External Affairs Manager
6.5.2013	AGL	Mike Moraza, Group General Manager, Upstream Gas Gary Robertson, COO, Upstream Gas Julie Delvecchio, Head of Community Relations Mike Roy, Head of Gas Operations Suzanne Westgate, Head of Land and Approvals John Ross, Manager Hydrogeology
15.5.2013	Lock the Gate Alliance	Peter Martin, Convener Southern Highlands Coal Action Group Dr Philip Pells, Fellow Academy of Technological Sciences David Williams, Retired MD Alan Lindsay, former General Manager, Corporate Planning – Caltex Penny Blatchford, Bellata-Gurley Action Group Against Gas (via teleconference) Boudicca Cerese, Research Coordinator – Lock the Gate Alliance (via teleconference) Gordon Fraser, Educational Lecturer, Environmental Consultant (via teleconference)
15.5.2013	Australian Petroleum Production & Exploration	Rick Wilkinson, COO Eastern Region Siobhan Barry, Senior Policy Adviser

	Association (APPEA)	
27.5.2013	Gloucester Community representatives	Graeme Healey, Chairperson BGSPA Dr Steve Robinson, Deputy Chairperson and Health Spokesperson Jeff Kite David Hare-Scott Ed Robinson, Community Consultative Committee Member – Lower Waukivory Residents Group Julie Lyford, former Gloucester Shire Council Councillor and Mayor Ken Johnson OAM, Founder and President of The Gloucester Project
27.5.2013	Gloucester Shire Council	Councillor John Rosenbaum, Mayor Councillor Frank Hooke, Deputy Mayor Councillor James Hooke Councillor Jim Henderson Councillor Tony Tersteeg Danny Green, General Manager Graham Gardner, Director Planning & Environment
27.5.2013	AGL staff, during site inspection of Gloucester Gas Project, Gloucester	Therese Ryan, Community Relations Manager Adam Stepanoff, Operations Manager John Ross, Manager Hydrogeology Toni Laurie, Land and Approvals Manager Aaron Clifton, Environment Manager Brett Hayward, Environmental Advisor Ngaire Baker, Media Relations (Site inspection of production well WAUKI-3, PEL 285 & plugged/ abandoned well GIOU-2)
28.5.2013	Penny Blatchford	Penny Blatchford, Bellata Farmer, Bellata-Gurley Action Group Against Gas
30.5.2013	Environmental Resources Management (ERM)	David Snashall, Partner, Head of Impact Assessment and Planning, Global and Asia Pacific – ERM
20.6.2013	Apex Energy	Chris Lawrence, Corporate Development Manager – Apex Stephen O'Keefe, Director – Apex
21.6.2013	The Wilderness Society	Naomi Hogan, Campaign Manager – Wilderness Society Newcastle
21.6.2013	NSW Business Chamber	Paul Orton, Director Policy and Advocacy – NSWBC Larissa Cassidy, Policy Advisor, Infrastructure – NSWBC
27.6.2013	Regional Development Australia (Orana NSW)	Roger Summerill, Deputy Chair, RDA Illawarra David Humphries, a member of RDA Central Coast Gaye Hart, Chair RDA Hunter, (and RDAC Chair) Peter Crowe, Chair, RDA Murray Robin Edgecumbe, Chair, RDA Far West Rob Pollock Chair, RDA Far South Coast Sandy Morrison, Chair, RDA Central West Mal Peters, OAM, Chair, RDA Northern Inland Tony Marshall, Chair, RDA Mid North Coast Ken Prendergast, Chair, RDA Southern Inland Alan Pendleton, Chair, RDA Sydney Dr Ian Tiley, Chair, RDA Northern Rivers

		John Walkom, Chair, RDA Orana Tom Watson, Chair, RDA Riverina Roger Summerill, OAM, Deputy Chair RDA Illawarra David Humphries, Member, RDA Central Coast
1.7.2013	Campbelltown Council	Jeff Lawrence, Director Planning & Environment Dave Henry, Senior Environmental Officer Andrew Spooner, Manager Sustainable City and Environment
1.7.2013	Campbelltown community groups	Jacqui Kirkby, Spokesperson – Scenic Hills Association (SHA) Jennifer Jones, Committee member – SHA Jocelyn Kramer, Committee member – SHA Len Williamson – Stop CSG Macarthur Caroline Graham, Southern Coalfields representative – Rivers SOS Alliance; Macarthur Region organiser – Lock the Gate David Hunt – Rivers SOS Alliance Denis Slater – Stop CSG Sydney Water Catchment Association (SCSWCA) David Eden – SCSWCA
1.7.2013	AGL staff, during site inspection of Rosalind Park Gas Plant, Menangle	Jenny O'Brien, Community Relations Manager –AGL Site inspection of: - Menangle Park 25 (MP25, four dedicated watering bores recently installed as part of rehabilitation process), - Spring Farm 17 & 20 (SF17 and SF20, horizontal drilling and multiple wells in residential setting), and - The Rosalind Park Gas Plant
1.7.2013	Camden Council	Councillor Lara Symkowiak, Camden Mayor Paul Reynolds, Specialist Support Environmental Health Officer Geoff Green, Manager Environment and Health
10.7.2013	Santos staff, during site inspection of Bibblewindi, Narrabri	Jessica Creed – EPA Alan Feely, Manager Environment and Water Rohan Richardson, NSW Drilling and Completions manager David Bailey, Manager ENSW Operations Kym Bailey, Narrabri Operations Manager Annie Moody, Team Leater Community and Land Ron Anderson, Principal Advisor Compliance Glenn Toogood, Water Management Leader Andrew Abbey, Regulatory Policy Coordinator Ben Farmer, Rehabilitation Consultant
1.07.13	Narrabri community groups	Jon-Maree Baker, Executive Officer – Namoi Water Matthew Norrie – Namoi Water Angie Smith – Cotton Australia Sandy Young – Cotton Australia Tony Pickard, Local farmer Victoria Hamilton – North West Alliance (NWA) Jeff Carolan – NWA Milton Judd – NWA Ron Campey – People for the Plain Anne Kennedy – Great Artesian Basin Protection Group John Polglase, Hydrogeologist/Geochemist Dr Pauline Roberts, Scientist
	Narrabri Shire Council	Cr Conrad Bolton, Mayor Pat White, General Manager Paul Wearne, Director of Corporate Services

		Paul Bawden, Director of Planning and Development Bill Birch, Economic Development Manager Cr Robyn Faber Cr Catherine Collyer Cr Maxine Booby
22.7.2013	Gunnedah Shire Council,	Cr Owen Hasler, Mayor Cr Gae Swain, Deputy Mayor Mr Eric Groth, Acting General Manager Mr Mike Silver, Director Planning and Environmental Services Mr Warwick Giblin, Managing Director (Council Consultant) – OzEnvironmental Pty Ltd
23.7.2013	Pine Ridge landholders	Mrs Susan Lyle, Chair – Caroona Coal Action Group Mrs Rosemary Nankivell, CSG Committee Chair – Caroona Coal Action Group Mrs Kate Davidson, Secretary – Caroona Coal Action Group Mr Andrew Pursehouse, Farmer
22.7.2013	Minter Ellison Lawyers	Katrina Groshinksi, Partner Minter Ellison Lawyers.
26.7.2013	Sydney catchment community groups	Caroline Graham, Southern Coalfields representative – Rivers SOS Alliance; Macarthur Region organiser – Lock the Gate Peter Turner – Save Our Catchments

As mentioned in Chapters 1 and 2, the Review team consulted with various NSW, local, Commonwealth, Queensland, and South Australia government agencies throughout the Review. They are included in the following table.

Meetings with government stakeholders
NSW Government agencies
• Environmental Protection Agency • Department of Trade and Investment, Regional Infrastructure and Services, including Office of Resources & Energy, the Office of Coal Seam Gas, and the Mine Subsidence Board • Land and Water Commissioner • Department of Premier and Cabinet, including the Office of Environment and Heritage • Ministry of Health • Department of Primary Industries, including the NSW Office of Water • Sydney Catchment Authority • NSW Department of Planning • Natural Resources Commission • Department of Finance and Services, including the Land and Property Information
Local councils (see also table of Review meetings, above)
• Campbelltown Council • Camden Council • Gloucester Shire Council • Gunnedah Shire Council • Narrabri Shire Council
Commonwealth Government
• Department of Resources, Energy and Tourism, including the Bureau of Resources and Energy Economics • Department of Sustainability, Environment, Water, Population and Communities including the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, the Bureau of Meteorology and the Office of Water Science • Geoscience Australia

Queensland Government
• Department of Environment and Heritage Protection • Department of Natural Resources and Mines • Department of Science, Information Technology, Innovation and the Arts • Gas Fields Commission Queensland • Office of the Queensland Chief Scientist • Office of Groundwater Impact Assessment • Queensland Health, Environmental Health Branch
South Australia Government
• Department of Primary Industries and Resources South Australia • South Australian Chief Scientist
Alberta, Canada
• Energy Resources Conservation Board

The Review team also consulted research organisations, which are listed below.

Research organisations

• Association of Petroleum Engineers, Scientists and Managers
• ARC Centre of Excellence for Core to Crust Fluid Systems (Macquarie University)
• Australian National University – Research School of Earth Sciences
• Australian Nuclear Science and Technology Organisation
• Commonwealth Scientific and Industrial Research Organisation
• Flinders University - National Centre for Groundwater Research and Training
• Macquarie University including ARC Centre of Excellence for Core to Crust Fluid Systems
• Harvard University
• NICTA (National Information and Communications Technology Australia)
• University of Adelaide, National Centre for Petroleum Geology and Geophysics
• University of Melbourne
• University of Newcastle, including ARC Centre of Excellence for Geotechnical Science and Engineering
• University of New England
• University of New South Wales, including
    • School of Petroleum Engineering
    • Groundwater Research Centre, including Connected Waters Initiative
    • School of Public Health and Community Medicine
• University of Sydney
• University of Western Sydney
• University of Wollongong

APPENDIX 5 LIST OF CONCERNS EXPRESSED IN REVIEW CALL FOR SUBMISSIONS

The Review identified themes present in each submission. In order to maintain the contributing author's voice, several themes may overlap. (Examples of related or overlapping themes may include air, fugitive emissions and greenhouse gas/ global warming; CSG-related noise, fears for community vitality, property values and mental health; or hydraulic fracturing, chemical use, groundwater, produced water, environment, and perhaps even seismicity.)

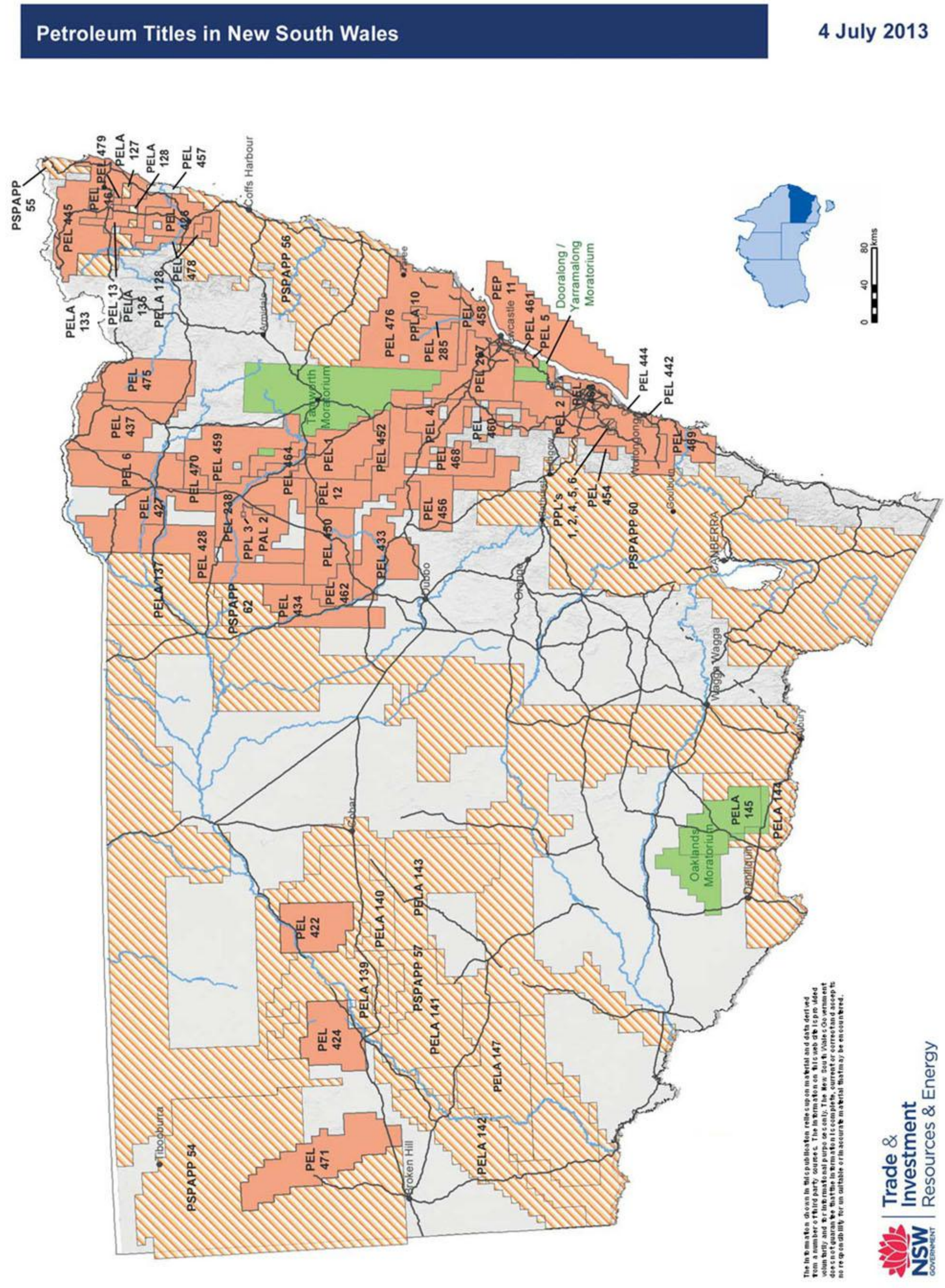
Of the 140 submissions that provided addresses, the bulk originated from within New South Wales (93.6%), while 2.1% of submissions came from Queensland, 1.4% from Victoria and 0.7% from the ACT, South Australia and United States. Of those from New South Wales, 75% came from parties in areas where CSG exploration and production are either taking place or are planned.

The following table includes concerns listed in the 233 submissions received between 26 March and 11 July 2013. These, and submissions made since this date, may be viewed in their entirety at www.chiefscientist.nsw.gov.au/coal-seam-gas-review .

Concern	**Number of times expressed** (out of 233 submissions)
Environment, general	115
Water, produced	42
Water, ground (aquifer) or surface (drinking)	173
Air	81
Global warming	22
Underground movement (seismic activity/ sinkholes)	27
Protection of agricultural land, animals	86
Native vegetation	15
Urban CSG development	9
Small town/ country community vitality	15
Private property rights	6
Want to establish high risk CSG 'no-go' zones	38
Finances, personal (devalued properties/ inflated supply costs/ superannuation)	22
Finances, economic loss/affect other industries (tourism/ agriculture/ manufacturing)	38
Finances, fallout from CSG mismanagement on taxpayers	1
Human health, physical (including present & future)	118
Human health, mental (solastalgia)	20
Safety, general	18
Chemical use	42
Fugitive emissions/leakage (incl. faulty extraction equipment)	54
CSG Companies, distrust	27
CSG Companies, development-related noise	6
CSG Companies, development-related traffic/ road damage	7
Hydraulic fracturing, 'fracking'	55
Decommissioned wells	3

Disinterested government/ monetary priority	23
Terms of reference/ scope of inquiry	39
Regulation (the current state, monitoring & enforcement)	74
Will of people ignored	15
Lack of CSG scientific data, including establishing baseline data (fear of unknown)	101
People distrust current information	12
Negative stories, overseas	19
Negative stories, within Australia	12
Don't need NSW CSG, plenty elsewhere, no need to export (foreign benefit)	7
Doubt cleanliness of CSG/ Delay to renewable energy/ carbon footprint	8
Anti-mining	7
Benefits of CSG, need public/media education	9
Benefits of CSG, cleaner energy	2
Benefits of CSG, economic impact	2
Greens Party ruining fossil fuels	1
Unrelated/ Promotional	2
TOTAL number of issues addressed	**1384** (Averaging 6 issues per submission)

APPENDIX 6 MAPS



Petroleum titles in NSW by title type showing Exploration and Production Titles (orange), Applications (orange stripe) and Moratorium areas (green), updated July 2013. Source: NSW Resources & Energy

Petroleum Titles in New South Wales - Key

4 July 2013

Petroleum Applications

Application	Applicant
PELA 127 (1991)	Trapuzzano, Tito
PELA 128 (1991)	Trapuzzano, Tito
PELA 130 (1991)	Metgasco Ltd
PELA 133 (1991)	Macquarie Energy Pty Ltd
PELA 135 (1991)	Summerland Way Energy Pty Ltd
PELA 137 (1991)	Comet Ridge Ltd
PELA 138 (1991)	Apex Energy NL
PELA 139 (1991)	Acer Energy Limited
PELA 140 (1991)	Acer Energy Limited
PELA 141 (1991)	Acer Energy Limited
PELA 142 (1991)	Acer Energy Limited
PELA 143 (1991)	Acer Energy Limited
PELA 144 (1991)	New South Wales Aboriginal Land Council
PELA 145 (1991)	Petro Tech Pty Ltd
PELA 146 (1991)	Petro Tech Pty Ltd
PELA 147 (1991)	Petro Tech Pty Ltd
PELA 148 (1991)	Petro Tech Pty Ltd
PPLA 9 (1991)	Metgasco Ltd
PPLA 10 (1991)	AGL Upstream Investments Pty Limited
PSPAPP 48 (1991)	Clarence Moreton Resources Pty Limited
PSPAPP 54 (1991)	Northern Territory Oil Limited
PSPAPP 55 (1991)	New South Wales Aboriginal Land Council
PSPAPP 56 (1991)	New South Wales Aboriginal Land Council
PSPAPP 57 (1991)	New South Wales Aboriginal Land Council
PSPAPP 60 (1991)	New South Wales Aboriginal Land Council
PSPAPP 62 (1991)	Ison Energy Pty Ltd

Petroleum Moratorium Areas

Petroleum Moratorium Areas

Moratorium Area 1 (Dooralong and Yarramalong Valleys)

The Minister has designated by notification published in the Gazette of 16 June 2006 that petroleum titles will not be granted in respect of the lands defined by the 9 graticular blocks set out in the following schedule:

Sydney 1:1,000,000 sheet:

Blocks: 952-953, 1024-1025, 1096-1097 and 1168-1170

The moratorium shall remain in force indefinitely.

Moratorium Area 2 (Tamworth)

The Minister has designated by notification published in the Gazette of 12 July 2009 that petroleum titles will not be granted in respect of the lands defined by the 158 graticular blocks set out in the following schedule:

Armidale 1:1,000,000 sheet:

Blocks: 2026-2032, 2098-2104, 2164, 2170-2176, 2236, 2242-2248, 2314-2320, 2386-2392, 2458-2464, 2527-2536, 2599-2608, 2672-2680, 2744-2752, 2816-2824, 2888-2896, 2961-2968, 3034-3040, 3106-3112, 3179-3184, 3251-3256, 3326-3328 and 3398-3400

Sydney 1:1,000,000 sheet:

Blocks: 14-16, 86-88, 158-160 and 231-232

This moratorium will allow the Mineral Resources Division of the Department of Primary Industries to undertake a seismic survey to extend its knowledge of the structure of the Hunter-Mooki Thrust Fault Zone. The results are expected to be released to the petroleum industry shortly after the moratorium expires.

The moratorium shall remain in force until further notice.

Moratorium Area 3 (Oaklands)

The Minister has designated by notification published in the Gazette of 5 December 2008 that petroleum titles will not be granted in respect of the lands defined by the 122 graticular blocks set out in the following schedule:

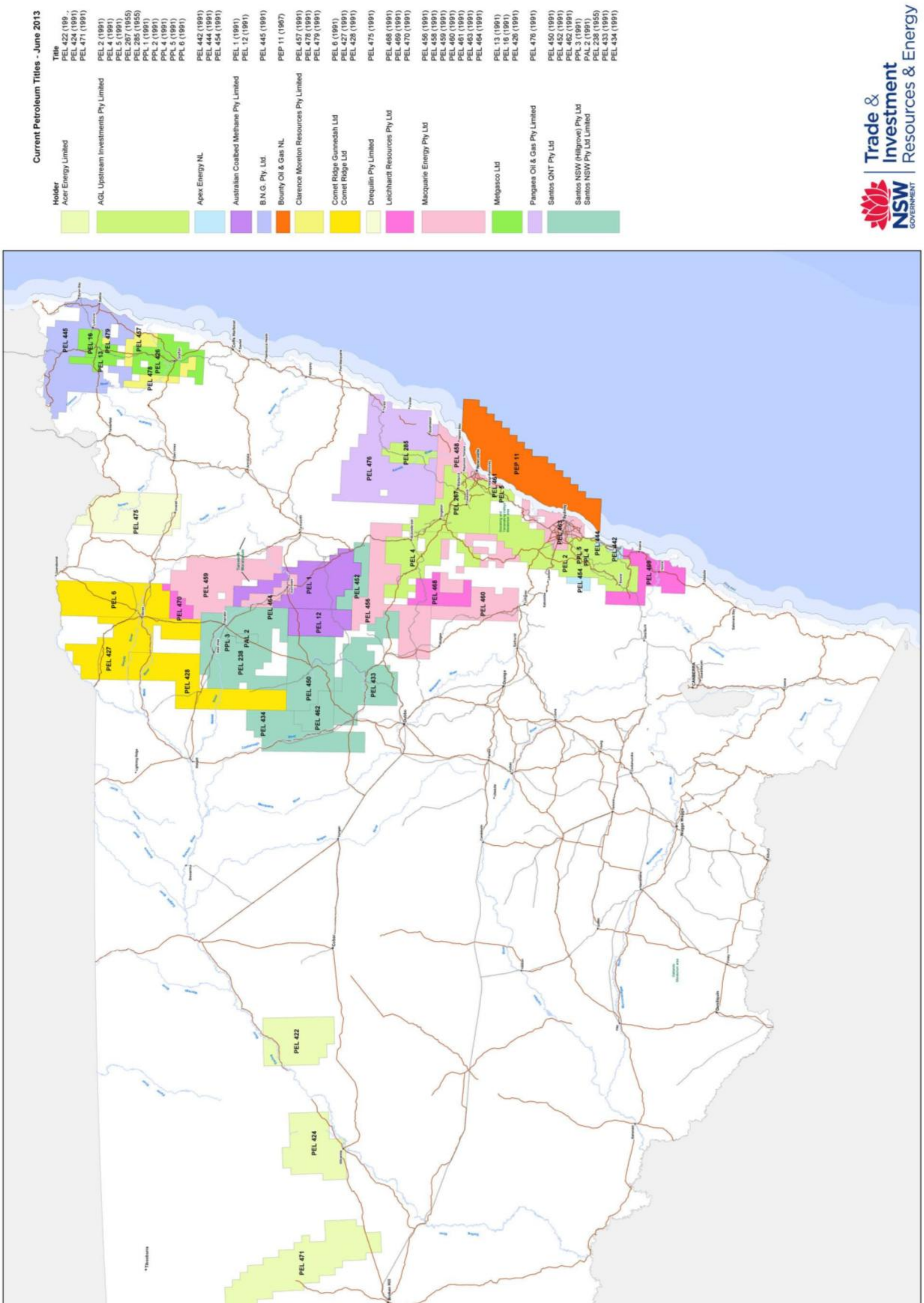
Canberra 1:1,000,000 sheet:

Blocks: 2249, 2250, 2321, 2322, 2323, 2392 - 2395, 2462 - 2470, 2533 - 2544, 2604 - 2616, 2674 - 2690, 2746 - 2762, 2827 - 2834, 2901- 2908, 2973 - 2980, 3046 - 3052, 3118 - 3124, 3190 - 3196.

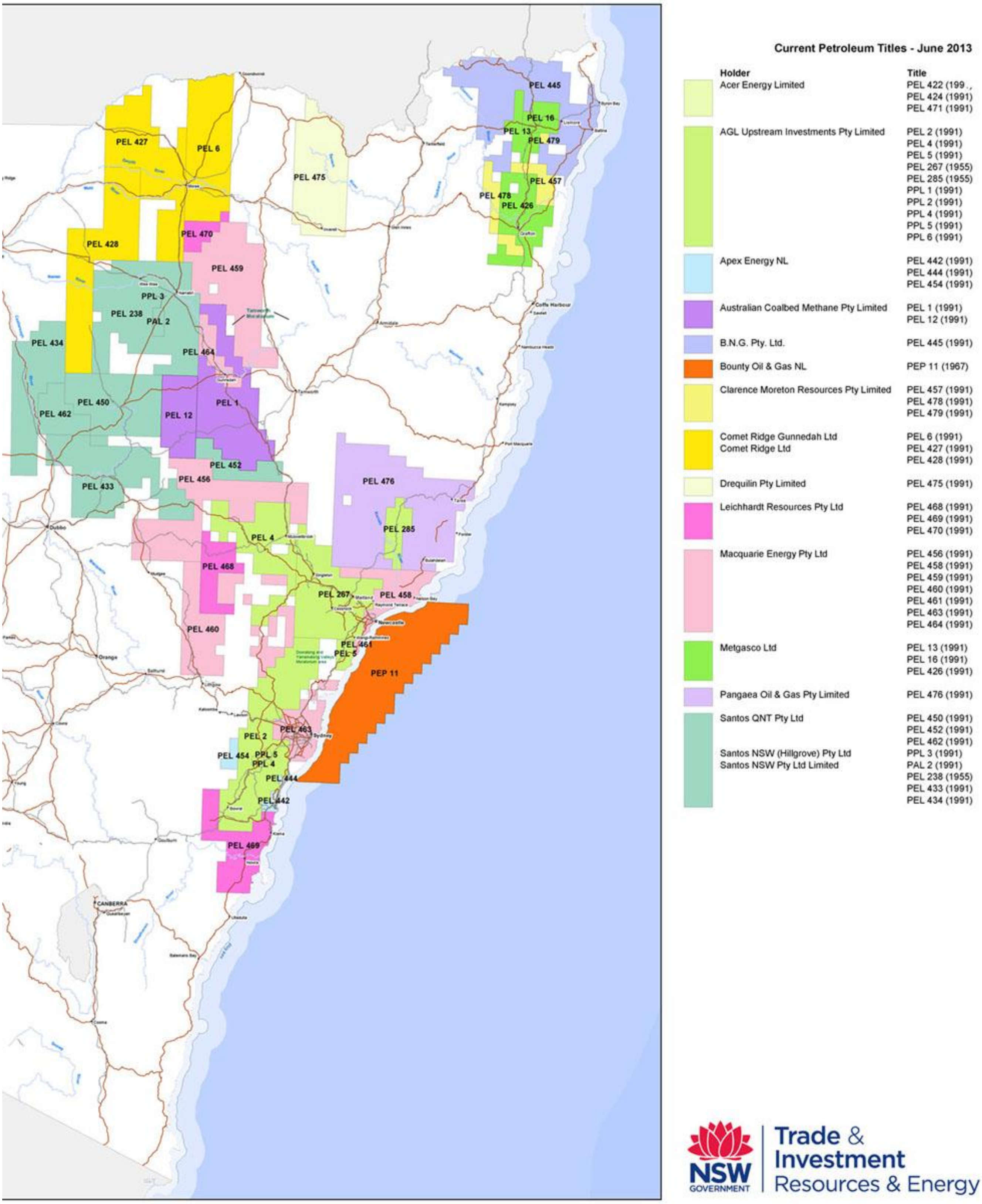
The moratorium shall remain in force until further notice.

Petroleum Titles

Title	Holder
PAL 2 (1991)	Santos NSW Pty Ltd
PEL 1 (1991)	Australian Coalbed Methane Pty Limited
PEL 2 (1991)	AGL Upstream Investments Pty Limited
PEL 4 (1991)	AGL Upstream Investments Pty Limited
PEL 5 (1991)	AGL Upstream Investments Pty Limited
PEL 6 (1991)	Comet Ridge Gunnedah Pty Ltd
PEL 12 (1991)	Australian Coalbed Methane Pty Limited
PEL 13 (1991)	Metgasco Ltd
PEL 16 (1991)	Metgasco Ltd
PEL 238 (1955)	Santos NSW Pty Ltd
PEL 267 (1955)	AGL Upstream Investments Pty Limited
PEL 285 (1955)	AGL Upstream Investments Pty Limited
PEL 422 (1991)	Acer Energy Limited
PEL 424 (1991)	Acer Energy Limited
PEL 426 (1991)	Metgasco Ltd
PEL 427 (1991)	Comet Ridge Ltd
PEL 428 (1991)	Comet Ridge Ltd
PEL 433 (1991)	Santos NSW Pty Ltd
PEL 434 (1991)	Santos NSW Pty Ltd
PEL 437 (1991)	Pangaea PEL 437 Pty Limited
PEL 442 (1991)	Apex Energy NL
PEL 444 (1991)	Apex Energy NL
PEL 445 (1991)	B.N.G. Pty Ltd
PEL 450 (1991)	Santos QNT Pty Ltd
PEL 452 (1991)	Santos QNT Pty Ltd
PEL 454 (1991)	Apex Energy NL
PEL 456 (1991)	Macquarie Energy Pty Ltd
PEL 457 (1991)	Clarence Moreton Resources Pty Limited
PEL 458 (1991)	Macquarie Energy Pty Ltd
PEL 459 (1991)	Macquarie Energy Pty Ltd
PEL 460 (1991)	Macquarie Energy Pty Ltd
PEL 461 (1991)	Macquarie Energy Pty Ltd
PEL 462 (1991)	Santos QNT Pty Ltd
PEL 463 (1991)	Macquarie Energy Pty Ltd
PEL 464 (1991)	Macquarie Energy Pty Ltd
PEL 468 (1991)	Leichhardt Resources Pty Ltd
PEL 469 (1991)	Leichhardt Resources Pty Ltd
PEL 470 (1991)	Leichhardt Resources Pty Ltd
PEL 471 (1991)	Acer Energy Limited
PEL 475 (1991)	Drequilin Pty Limited
PEL 476 (1991)	Pangaea Oil & Gas Pty Limited
PEL 478 (1991)	Clarence Moreton Resources Pty Limited
PEL 479 (1991)	Clarence Moreton Resources Pty Limited
PEP 11 (1967)	Bounty Oil & Gas NL
PPL 1 (1991)	AGL Upstream Investments Pty Limited
PPL 2 (1991)	AGL Upstream Investments Pty Limited
PPL 3 (1991)	Santos NSW (Hillgrove) Pty Ltd
PPL 4 (1991)	AGL Upstream Investments Pty Limited
PPL 5 (1991)	AGL Upstream Investments Pty Limited
PPL 6 (1991)	AGL Upstream Investments Pty Limited



Current petroleum titles in NSW by title holder, updated June 2013. Source: NSW Resources & Energy



Current petroleum titles in NSW by title holder, eastern NSW enlarged, updated June 2013. Source: NSW Resources & Energy