Chief Scientist & Engineer

Independent Review of Coal Seam Gas Activities in NSW

Managing environmental and human health risks from CSG activities

September 2014

The Hon Michael Baird MP
Premier
Minister for Infrastructure
Minister for Western Sydney
Parliament House
SYDNEY NSW 2000

Dear Premier,

Managing environmental and human health risks from CSG activities

As part of the independent review of coal seam gas activities in NSW, I present a report focusing on the second term of reference, namely, "identify and assess any gaps in the identification and management of risks arising from coal seam gas exploration, assessment and production, particularly as they relate to human health, the environment and water catchments."

In investigating how best to manage environment and human health risk, the Review took an approach of relying on multiple sources of information. Four workshops were held, which were then followed with targeted meetings with key experts and industry personnel. This was supplemented with surveying the large amount of research available in peer-reviewed journals as well as in grey literature.

The management of potential risks associated with CSG, as with other industries, can be done with effective controls and regulation. This includes engineering solutions involving high levels of industry professionalism, monitoring and modelling, and comprehensive risk assessments. The recommendations of the report reflect this finding.

In presenting this report I would like to acknowledge the assistance of many people. Numerous research experts, industry personnel, government colleagues and community members made themselves available to meet with my team as they worked at understanding the issues involved in this crucial subject.

Yours sincerely,

Digitally signed by Mary O'Kane
Date: 2014.09.30 18:43:02 +10'00'

Mary O'Kane
Chief Scientist & Engineer
30 September 2014

Chief Scientist & Engineer
GPO Box 5477, Sydney NSW 2001, Australia | Tel +61 2 9338 6786
www.chiefscientist.nsw.gov.au

EXECUTIVE SUMMARY

The independent review of coal seam gas (CSG) activities in NSW by the NSW Chief Scientist & Engineer commenced in February 2013. This Report is a part of that Review and focuses on the identification and management of risk associated with CSG activities in relation to the environment and human health. It also comments on the characteristics of a regulatory framework required effectively to manage such risks. This framework is detailed in a companion report by the Review dealing with compliance (CSE Compliance, 2014d).

To examine this issue the Review conducted a series of expert workshops and meetings to identify potential risks from CSG activities to water catchments. It was not possible to determine in detail the likelihood and consequences (severity) of the risks as this matter are complex and highly dependent on local conditions (e.g. geology, hydrogeology, location, environment, etc.). These meetings highlighted the key types of potential risk, controls for those risks and gaps in risk management.

From these workshops, potential risks to the broader environment were considered to be those resulting in impact to surface water, groundwater, soil, or air quality. The potential environmental risks were grouped into four major causal 'themes': drilling, well integrity and fracture stimulation; seam depressurisation; spills and leaks; and produced water and solids.

Potential risks to human health were considered through exposure pathways, that is, the routes from release of a contaminant(s) to a person(s). These pathways were through water, soil and air, and indirectly in food. Dosage is critical in considering human health risks and effects, with most pathways leading to dilution resulting in a decrease in exposure for a person. Exposure pathways can be understood through the modelling of water and air movement, or ecological webs, which requires knowledge of the local environment and the potential contaminants. Potential human health risks from CSG activities are consistently raised as an issue of concern to the community.

Published peer-reviewed studies on this issue are limited to date, and it is also difficult to conduct epidemiological studies due to the small size of the CSG industry in NSW. Further the small population exposed to activities mean epidemiological studies do not have sufficient statistical power and so are unlikely to provide meaningful results at this time. However other approaches to predicting human health impacts are available such as environmental health risk assessments.

Management of potential risks associated with CSG, as with other industries, requires effective controls and regulation. This includes:

- engineering solutions – the application of technical and management approaches ensures that risks such as emissions, leaks, spills, aquifer connections, etc. are minimised. This is a rapidly evolving area and it is important that NSW has access to emerging technologies and expertise
- monitoring and modelling, conducted with a high level of expertise and available for independent, transparent and rigorous peer review, are important for i) understanding the processes occurring below ground, whether in the coal seam itself, or in the surrounding geology including the groundwater and ii) adaptive management approaches, whereby the activity proceeds, and can be terminated at any sign of deviation from expected responses (e.g. changes in water quality)
- comprehensive risk assessment – this involves risk identification, assessment and characterisation that then informs the development of management plans such as Trigger Action Response Plans. These risk assessments and management plans should be updated progressively over the course of the project.

- regulation of any industry needs to ensure that issues of concern in regard to risk are incorporated into planning stages and updated frequently. This is addressed in a separate report, “Study of Regulatory Compliance Systems and Processes for Coal Seam Gas” (CSE Compliance, 2014d).

As experience and technology with CSG (and other extractive industries) in NSW increases, this knowledge should be harnessed in one place and used to inform regulatory activities and approvals. Two recommendations to Government are made to achieve this goal.

RECOMMENDATIONS

Recommendation 1

That Government develop a centralised Risk Management and Prediction Tool for extractive industries in NSW. This would include a risk register, a database of event histories, and an archive of Trigger Action Response Plans. The tool would be updated annually based on Government and company reporting and would include information on risk management and control approaches and draw on data from the Whole-of-Environment Data Repository for the State. The risk tool would be reviewed and commented on by relevant expert and regulatory bodies. The risk tool would be used to assist with:

- assessing new proposals
- assessing compliance
- improving prediction capability for consequences of incidents in risk assessments
- improving prediction capability of risk likelihoods
- informing project design amendments to decrease risk levels (such as undertaken in the Dam Safety Committee)
- informing the calculation of cumulative impacts
- flagging issues or risks that require a higher level of regulatory protection such as inclusion in legislation.

Recommendation 2

That Government develop a plan to manage legacy matters associated with CSG. This would need to cover abandoned wells, past incomplete compliance checking, and the collection of data that was not obtained under licence and legislation. There will also need to be a formal mechanism to transition existing projects to any new regulatory system.

Contents

Tables

Figures

1 INTRODUCTION

Potential risks to human health and the environment are central concerns in relation to the coal seam gas (CSG) industry in NSW. In public submissions received by the Review, the most frequently raised issue was that of potential risks to groundwater, closely followed by human health and the environment (CSE Initial Report, 2013).

Communities that live in areas where CSG extraction is occurring, or is likely to occur, worry about the possible long-term effects to the environment, and, by extension, the health of the community. Some farmers are concerned about the potential long-term or unanticipated effects of CSG projects on the land or water resources that support their economic livelihood. These concerns are echoed overseas and interstate, where there have been numerous claims of health effects linked to unconventional gas extraction.

Term of Reference 2 of the Review required the Chief Scientist and Engineer to:
"*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*"

This Report examines the potential risks posed by the CSG industry to the environment and human health. The aims are to:

- present a coherent picture of the potential risks identified to date, risks that are a particular concern, and the controls currently available to mitigate risk
- provide guidance on characteristics of a management approach that can take full account of the risks to the environment and human health from CSG activities.

This report informs a separate report recommending an outcomes-based regulatory framework which could manage risks to the environment and human health effectively (CSE Compliance, 2014d).

1.1 CONTEXT

Risks considered here are those that could lead to impacts on the environment and/or human health. Impacts on the environment generally result in the pollution or depletion of a natural ecological setting or an environmental resource, such as irrigation water or farmland soil. Concerns about pollution of the environment are typically coupled with concerns about potential risks to human and ecological health. Assessing health risks from pollution relies on understanding the toxicity of the pollutant and the amount that reaches the community or individual over a given period of time.

Risks can be reduced, through measures that reduce the scale of the consequences or the likelihood of the event occurring. Adaptive management is an approach, which tracks the progress of activities, and allows for a change or cessation of those activities as risk thresholds or triggers are realised: see CSE Information Paper: Abandoned Wells (CSE Abandoned Wells, 2014a).

A key purpose of CSG-related legislation is to establish and enforce systems that monitor and control risk. Regulations, and other subordinate legislative instruments, including codes of practice, standards and guidelines, detail measures to be used for particular industries in NSW. (Appendix 1 provides a non-exhaustive list of measures for CSG). In addition, the current planning approvals, licensing frameworks and activity approvals establish conditions for each project, based on its location and individual characteristics.

The current regulatory system is highly complex, with many pieces of legislation and subordinate instruments applicable to CSG projects, administered by many government departments (CSE Compliance, 2014d). During the lifetime of a project (approximately 20 years for CSG), it can be difficult to change development or conditions for some licence types issued at the beginning, as information about the site improves or technology or circumstances change. Further complicating matters, some agencies may make changes to the conditions governing a project, while others may not – this is frustrating for industry and arguably does not serve the community well in addressing its concerns.

1.2 APPROACH

1.2.1 Understanding risks and controls

Understanding the potential risks posed by CSG activities has been an ongoing concern of the Review. The "Initial Report on the Independent Review of Coal Seam Gas Activities in NSW" (CSE Initial Report, 2013) gave an overview of risks to the environment and to human health – see Chapters 7, 10 and 11.

For this report, to create the list of risks associated with CSG, input was sought from experts within government, research organisations, industry groups, private scientific and engineering consultancies and the community through the workshop process described below. A particular benefit of the workshop approach was that it brought together a diverse set of people with a wide range of experience and perspectives. Information on the controls came in part from the workshops and in part from a series of meetings the Review held with expert practitioners from government, research organisations and industry. A list of those consulted is in Appendix 3.

When examining controls, the Review primarily discusses those mechanisms by which the likelihood or consequence of a risk is estimated, monitored or reduced. In many cases, there are regulatory requirements that ensure a particular control is used – for example, Codes of Practice for Coal Seam Gas Well Integrity (DTIRIS, 2012) that enforce the use of various engineering controls. The Code of Practice itself was not considered the control for the purposes of this Report; rather the engineering controls available are discussed. In making this choice, the aim is to set out clearly which control measures are available; this can then facilitate a discussion as to whether, or how, those measures should be enforced through regulation. Regulatory instruments and technical controls currently available are listed in Appendix 1.

A series of four workshops was convened, with a particular focus on water catchments, although other issues such as air emissions, subsidence, seismicity and possible impacts to agriculture and human health were discussed.

There is no universally agreed methodology for doing risk assessments, whether for the environment or health. As a starting point, the Australian health and environmental risk assessment and management guidelines for drinking water supply (NHMRC & NRMMC, 2011) were used to provide a risk assessment framework for use in the workshops. However, from the first workshop it was clear that characterising risk was a difficult task. In trying to work through a traditional risk matrix, there was considerable disagreement as to how to estimate the likelihood of risks occurring and their severity. An expert's risk assessment depended strongly on factors such as the basins and projects in which they had experience. Also, characterising risk at a State level proved challenging as risk levels vary substantially between sites and situations.

There was also disagreement between experts about how to rate engineering controls and regulatory requirements, where available. Some considered a risk controlled if, for example, a produced water management plan had been created, while others emphasised that such a plan was only as good as its implementation and compliance level, and some contended that even with excellent compliance and the latest engineering solutions, accidents are still possible.

In discussions about controls that might be applied there was concern over presenting a single method as the best or most effective control, as its application may vary greatly depending on the local contexts.

When dealing with hypotheticals on a State-wide scale, the many variations in local geology and hydrogeology, combined with a large number of possible events and potential controls, can lead to very complicated pathways of risk or impact. Finding an agreed way to represent this thinking, such that each expert in the room was comfortable, was challenging.

The Review listed the possible risks, their causes, and attempted to understand the controls available. For the most part, the controls considered were the technical controls that could be used to reduce the likelihood or consequences of each event. The list of controls is neither comprehensive nor intended to be directive; rather, the most effective and efficient control for each situation will need to be chosen on the basis of local conditions and the level of risk encountered and deemed acceptable.

How to think about and describe risk was also in contention – whether to start with the event, the receptor, the underlying cause, or the stage of the CSG activity (exploration, production etc.) at which it was likely to occur. There are many possible events associated with CSG activities that could pose some risk to the environment or to human health, and there are also many technical and engineering approaches to control these.

To map out the possible exposure pathways by which the health of individuals and communities surrounding CSG projects could be affected, material related to the relevant vector (whether air, water, food or soil) was reviewed. This was then considered in the light of available information on the chemicals used and their health effects. This document provides advice on the areas of major concern, as a way to focus and prioritise future research and regulatory effort.

1.2.2 Out of scope

The following was considered beyond the scope in this report:

- formal risk assessment. The Review considers potential risks posed in a broad overview. Project-specific risk assessments are critical, but they need to be done for each individual project due the varying nature of the local environment (geology, hydrogeology, etc.) and surrounding land uses (agriculture, industrial, residential, etc.), and project details (e.g. density of wells, timeframes)
- risks common to other industrial activity, such as other natural gas and mining industries. This also includes practices common to any sort of development, such as land clearing, road building and traffic. These practices can result in significant environmental impact, including air pollution from particulate matter and diesel emissions, and have a visible impact on the landscape.
- workplace health and safety aspects, including occupational exposure. This is because few, if any, of these are likely to be unique to CSG operations. The CSE Initial Report (2013) does examine safety aspects for workers, and Recommendation 4 of that report calls on government to ensure mandatory training and certification requirements are implemented (CSE, 2013). Concerns about traffic safety offsite were raised a number of times during the Review
- potential health risks associated with climate change. As climate change is a global, multi-factorial process, it was not considered possible to assess the contribution of the local CSG industry to either increase or decrease the climate-related health impacts on populations

- company risk management audit. The Review, through its approach of undertaking workshops and individual discussions, consulted widely with industry, however the Report does not audit the systems that companies use to assess and manage risks.

1.3 STRUCTURE OF THIS REPORT

Chapter 2 of this report is an overview of the risks to the environment from CSG activities. This chapter draws on the results of the workshops attended by experts and other stakeholders held to give an overview of the key concerns and possibilities for release of contaminants to the environment. This chapter also discusses the controls that currently exist to prevent these risks from being realised. A list of available controls is included in Appendix 1.

Chapter 3 examines potential exposure pathways for humans through water, air, soils and food. The controls which operate to stop environmental contaminants reaching the community are also discussed. It then gives a summary of the ways in which possible health impacts could be determined, and of the known toxins involved in CSG extraction.

Chapter 4 gives the Review's conclusions and recommendations.

2 MANAGING ENVIRONMENTAL RISKS

All industrial activities will impact the environment. The crucial question then becomes: what is the likelihood and consequence of different events occurring, i.e. what are the risks of CSG activities? Whether these risks are acceptable or not depends on the level or risk Government, in consultation with the wider community, deems acceptable. This Report is focused on the first of these considerations i.e. identifying the risks.

In order to consider how best to manage risks arising from CSG activities, the Review began by characterising the risks that apply across CSG activities in NSW. This was necessarily a broad overview, focused on highlighting significant categories of risk, exploring the corresponding controls, and then identifying gaps in the management of these risks. As a result of this State-wide approach, the risks discussed are not formally rated. Ratings depend on knowing likelihood and consequence, both of which are heavily influenced by local conditions.

The risks considered are those that result in impacts to the environment, including impacts to water catchments. Summary lists of the risks are in Tables 1 and 2. The tables consider the possible risks, the situations in which each risk may become more serious and the adequacy of the controls. Risk mechanisms are illustrated in Figures 1 to 4. These provide a basis for each risk, including where and how the controls available might operate to stop the occurrence, or reduce the consequences. The technical controls (TC) currently available to industry were identified by the Review and are listed in Appendix 1. They appear throughout the text, figures and tables of the report. The numbering system was constructed for the purposes of this report.

Those risks considered particularly significant for NSW are highlighted in the text of this Chapter. In deciding which risks to highlight, the Review considered:

- which type of risks need to be carefully watched?
- under which conditions can the risks become very serious?
- what controls are available?
- what effect will the risk, if realised, have on human and environmental health?
- are there prolonged or cumulative effects of the risk, if realised, that we need to be aware of?

The risks presented in this report have been grouped into four major ‘themes’. These are: drilling, well integrity and fracture stimulation; seam depressurisation; spills and leaks; and produced water and solids.

2.1 DRILLING, WELL INTEGRITY AND FRACTURE STIMULATION

The process of drilling and casing a well, and, when extraction is finished, plugging and abandoning that well has several associated risks. In addition, some wells may undergo ‘seam stimulation’ (processes designed to enhance the permeability of a coal seam), thereby making the recovery of the methane easier. The most common of these stimulation techniques is fracture stimulation (commonly called ‘fracking’), where a mixture of water, sand and other additives are pumped under high pressure into the coal seam in order to widen and hold open the cleats within the coal.

The risks associated with these processes are grouped together because they share similar mechanisms. As seen in Figure 1, which sets out the risk pathways and technical controls available, risks associated with these activities relate to the potential establishment of conduits between strata, coal seams or the surface. Under certain conditions, these conduits can facilitate the vertical movement of water or gas, which in turn can lead to chemical contamination of soil, air, surface water or groundwater.

Table 1 summarises the key risks in this theme and those of particular concern in NSW are discussed further in the text below.

2.1.1 Well integrity

Poorly constructed wells, or wells that have degraded over time, can allow fluids (e.g. groundwater and drilling fluids), gases, and potentially contaminants, to move through a variety of pathways (Anderson, Parks, and Arellano (2013)). The well, or an annulus around the well, may act as a conduit to enable movement of water, gas, or drilling and fracking fluids between different geological intervals , potentially contaminating a beneficial aquifer. For new wells, this risk is controlled by a variety of design, construction, inspection and maintenance standards (TC5 to TC7 in Appendix 1), but these have not yet been tested over the very long term, and it is not known how they will perform on generational time scales.

Abandoned wells, drilled prior to the use of these standards are of greater concern. Historical wells constructed for various purposes, including coal and petroleum exploration and production, water supply and monitoring, carry an unquantifiable environmental contamination risk. Such abandoned wells in the area of CSG projects, if they are not discovered and planned for, can act as unexpected hydraulic connections between previously separated aquifer systems and strata. Mobilised gas can migrate to near surface aquifers via these abandoned wells, and as a result of depressurisation at the coal seam, near surface aquifers can be depressed via the abandoned wells.

The Review has prepared a separate information paper on abandoned wells in NSW which discusses these issues further (CSE Abandoned Wells, 2014a).

2.1.2 Fracture stimulation

There is a high degree of community concern associated with the practice of fracture stimulation (‘fracking’). This issue has been discussed in a number of papers commissioned by the Review (A. Anderson et al., 2013; Carter, 2013; Gore & Davies, 2013; Khan & Kordek, 2014; O'Neill & Danis, 2013; Ward & Kelly, 2013) and in a separate information paper on the issue of fracture stimulation in NSW (CSE, 2014b). Much of the discussion about fracking is ill-informed, especially regarding the US experience of fracking shale deposits. NSW, however, is currently extracting gas from coal seams, where fracking is not always required, and, when it is, is typically done at much lower pressures than is required for shale gas (Cook, 2013), and therefore there is a lower likelihood of fracking neighbouring rock.

The key risks from fracking are the creation or activation of conduits for flow between the coal seam and surrounding strata. If created, these connections can then act as conduits for fracking fluids to leave the coal seam and possibly enter the groundwater system or, in the case of gas, dissipate through overlying strata and into the atmosphere (Figure 1). Risks from fracking arise because of the uncertainties in our understanding of the geology and groundwater for different regions in the State.

The main controls for these risks centre on detailed characterisation of the geological setting, careful planning, testing and the technical ability to immediately stop the fracking operations if any signs of problems are detected. The chemistry of the fluids used can also be restricted to ensure that the consequences are minimal should they escape the coal seam (TC1, TC9, TC10 and TC12).

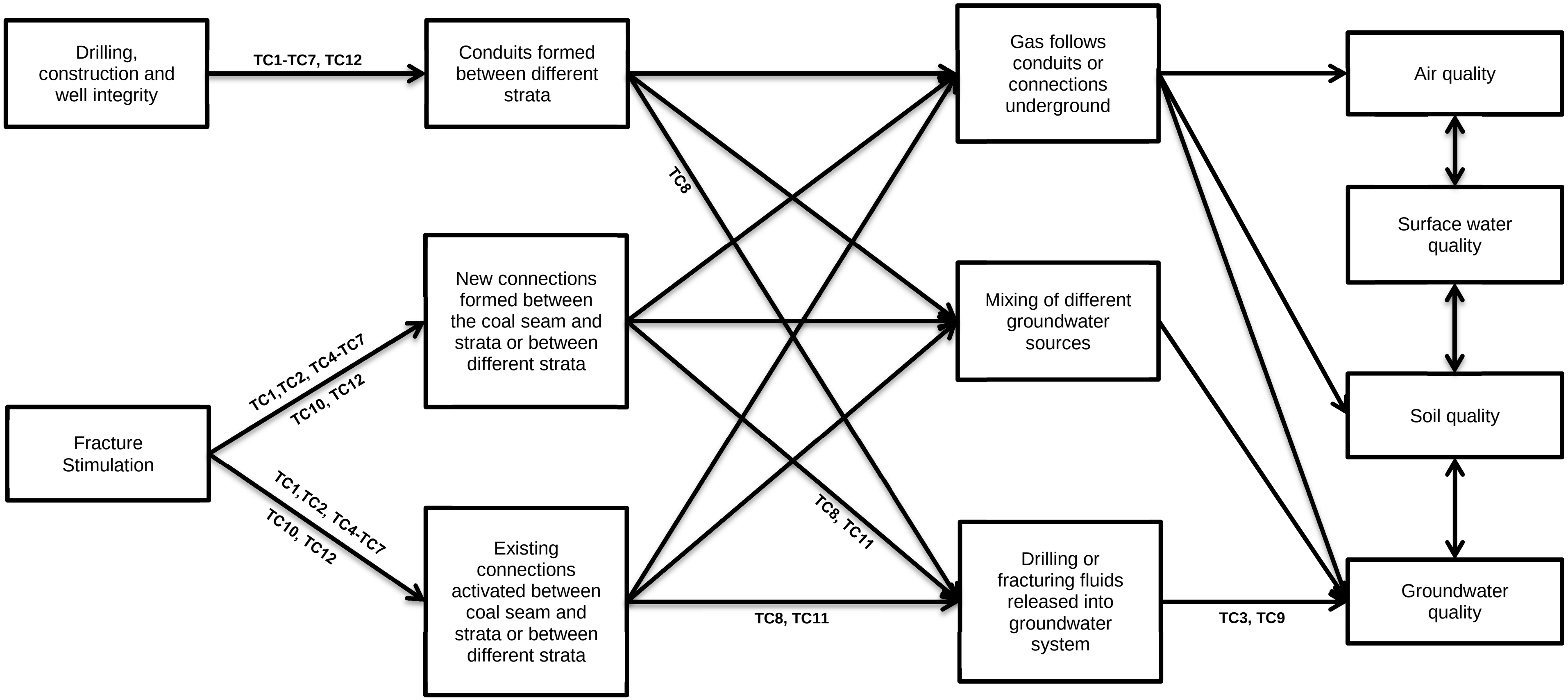

Figure 1: Risks and controls for drilling, well integrity and fracture stimulation
(For the list of technical controls (TC) see Appendix 1)

2.2 SEAM DEPRESSURISATION

To allow the methane originally adsorbed onto the coal matrix to be released and flow from the seam and for the production well for processing, the seam is depressurised by pumping water out to reduce the local water pressure in the coal seam (Anderson, Rahman, Davey, Miller, & Glamore, 2013; Cook, 2013). Figure 2 illustrates the potential mechanisms for key risks from this activity and Table 1 summarises these risks. The key risks related to coal seam depressurisation are the possible consequent quality and quantity effects on surface water or groundwater.

The main risk of concern in this theme is connection between the depressurised zone of the coal seam and adjacent or connected aquifers such that a beneficial-use aquifer is affected. This can cause mixing of water from different aquifers, affecting water quality, or a decline in pressures and groundwater levels such that water availability declines, among other consequence. Controls for this risk rely on a detailed understanding of underground conditions as well as an adaptive management approach (the activity proceeds with caution, and can be stopped at any sign of deviation from expected responses) (TC1, TC15).

The reduction of seam pressure also allows gas to be released from the seam which may not only move towards the extraction well but also along pathways underground and into the shallow groundwater, surface waters, and ultimately the atmosphere. This is particularly the case where other conduits from the seam already existed such as other wells. Again, an adaptive management approach is required (TC1, TC15).

The removal of water and gas from the coal seam and possibly surrounding strata will result in a redistribution of the stresses at depth and consequently to possible vertical movements at the ground surface (i.e. subsidence) (for further details see Lemon, Tickle, Spies, Dawson, and Rosin (2013); McClusky and Tregoning (2013); Pineda and Sheng (2013) The magnitude of subsidence is related to the permeability, compressibility, strength and thickness of the coal seam and surrounding strata. Experts in the workshops anticipated that, in general terms for NSW, the magnitude and extent of subsidence from CSG activities will be very low. Nevertheless, as this is controlled by geological, hydrogeological and geomechanical factors that vary from site-to-site, there may be exceptions to this general rule. Consequently, it is necessary that the risk is assessed and managed by suitable experts on a site-by-site basis (TC1, TC15).

The risks from seam depressurisation are highly dependent on the geology of the specific project site, including the groundwater and surface water systems. It is essential to have reliable data and models in order to assess the connectivity between a coal seam and the surrounding groundwater system, or between the groundwater and surface water systems, or to determine, if the impacts will be limited to those parts of the groundwater system that are not ecologically sensitive, or used to supply irrigation, stock or domestic water supplies. There will be areas where the risks to water resources will be acceptable in terms of quantity impacts or consequences of mixing, as well as other areas where the risks may not be acceptable.

The best way to understand risks associated with seam depressurisation are to create geological and hydrogeological models at both basin and project scales to inform the selection of appropriate sites. These models need to be driven by field data, as opposed to estimates of parameters, especially measurements of the hydraulic conductivity, storativity, and diffusivity of the groundwater system.

Producing a single model is not adequate to assess these risks. In areas of complex geology, multiple models have been developed. An example of this is the AGL Gloucester Basin project, where a number of models have been developed and debated by multiple experts (AGL, n.d.; Gloucester Shire Council, n.d.). This has led to much debate and controversy in the community. In this case all three levels of government have been involved to help resolve the issues of concern. Recent efforts of the Gloucester Shire Council include the establishment of the Water Study Project (Gloucester Shire Council, n.d.). A further concern is the longer term, cumulative impacts of coal seam depressurisation on the quality and quantity (in particular, reduced pressures and levels in groundwater systems) of water resources across the State. This concern is due to potentially long time lags (possibly multi-decadal) between CSG activities and the manifestation of impacts on water quality and quantity. For some of the expert participants in the workshops, this was their biggest concern with CSG. This issue was also addressed in the Report undertaken by the Chief Scientist and Engineer entitled “On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment” (CSE Catchment, 2014c).

Critically, the geological and hydro(geo)logical models need to be revised as new data becomes available during the production phase. While numerical models have an important role to play in guiding the initial risk assessment process, they cannot be relied on to predict the true local impacts for hydrological processes that are multi-decadal in nature such as the impacts from seam depressurisation.

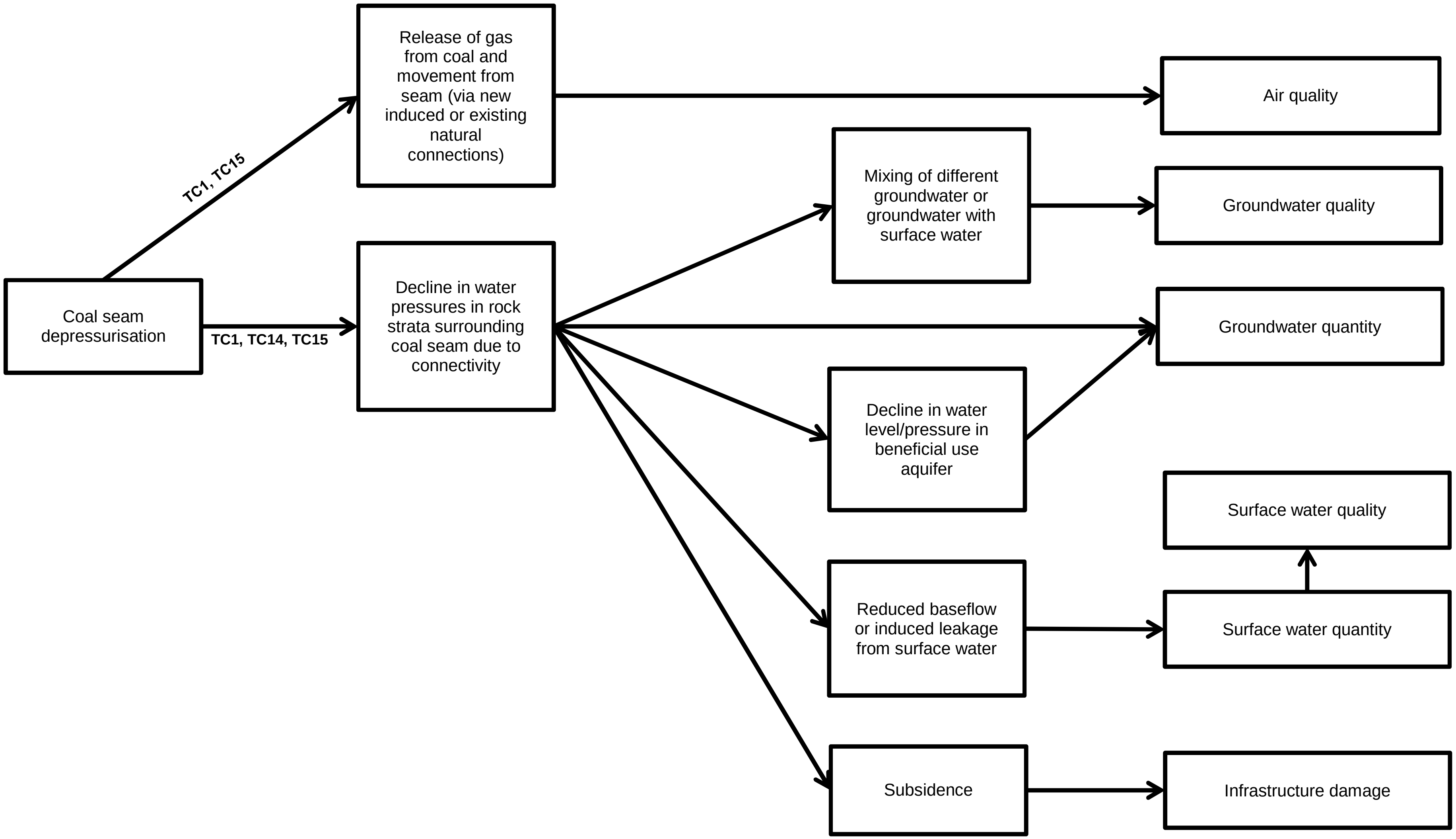

Figure 2: Risks and controls for coal seam depressurisation
(For the list of technical controls (TC) see Appendix 1)

2.3 SPILLS AND LEAKS

Several different types of fluid are handled at a CSG site. The fluid present in the greatest volume is produced water, which is drawn from the seam along with the gas during production. Other liquids present on site include drilling fluids, fracking fluids, and flowback water, which is a mixture of the fracking fluid and the produced water from the seam.

Figure 3 illustrates the potential ways in which spills and leaks of these fluids may occur and Table 1 provides a summary of the risks arising from these. For pipelines, tanks, ponds and so forth, poor engineering practice, wear and tear, and human error are the underlying sources of risk.

Controlling these risks can be approached in a number of ways, including restricting the types and amount of chemicals used (TC4, TC8, TC9), ensuring containment materials and devices are of a high standard (TC16-TC19) with wear and degradation monitored, and monitoring to detect any fast or slow breaches of containment material (TC20).

Ponds used to hold produced water have proved particularly problematic in this regard. The design and siting of ponds is critical, if they are to be used. NSW at present does not enforce a specific standard for pond design and construction for CSG produced water. Other standards or guides are available for NSW for similar systems such as tailings dams (DSC, 2012), liquid waste disposal (DEC, 1999a), as well as Queensland Government CSG pond design standards (Queensland Government, 2014a). In the absence of agreed design standards, companies have used standards in place for other jurisdictions. The Review notes there are opportunities to move away from the use of in-ground ponds altogether by using sealed tanks and keeping produced water stored on site to an absolute minimum.

Fugitive air emissions can be minimised by keeping fluids in enclosed containers such as tanks and by ensuring infrastructure such as wells and pipes are monitored and checked for leaks (Day, Dell'Amico, Fry, & Tousi, 2014).

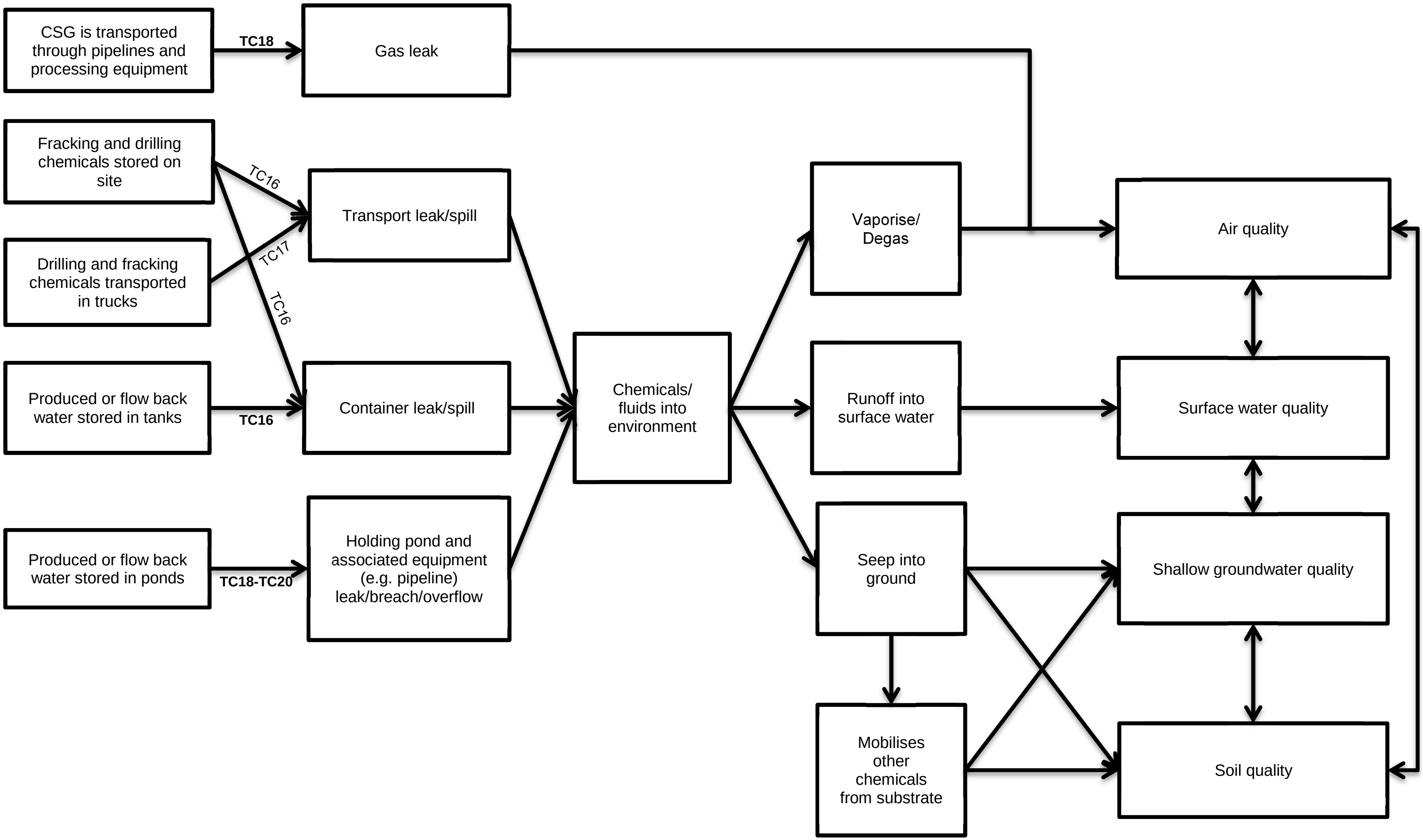

Figure 3: Risks and controls for spills and leaks

(For the list of technical controls (TC) see Appendix 1; for controls related to produced water solids see Figure 4)

Table 1: Overview of risks from CSG activities

What could go wrong?	When might it impact the environment?	How might it impact the environment?	Could it affect humans/livestock?	What could potentially cause it?	To what extent and how can we control for it?	Under what conditions could it become serious?	Can controls minimise all potential risks?
Drilling, well integrity and fracture stimulation							
New connections are formed between the coal seam and the groundwater system or between groundwater systems	When connections allow water of different qualities to mix in the groundwater system When connections allow chemicals such as fracking or drilling fluids to mix with groundwater When connections move water away from beneficial use aquifers or surface water resources When connections provide preferential pathways for gas release to surface	Could pollute surface or shallow groundwater potentially causing a build-up of salts or ecotoxic chemicals that harm biota Could reduce available surface water for environmental flows and have unintended quality effects Could reduce available groundwater – impacting groundwater dependent ecosystems	Could pollute or cause a reduction in or contamination of drinking water or other beneficial use water resources Could have air quality impacts where volatiles escape from water Food quality and quantity could be affected through affected water, soil or air	The drilling process Poorly completed wells; poorly plugged and abandoned wells; material failure Fracture that connects the seam to neighbouring aquifer Induced fracture that connects to other fractures outside of the seam	For both well integrity and fracking, controls are engineering related and relatively well understood Site selection is also critical and must be based on a good understanding of local conditions, geology. Responses must also be incorporated and this can be more problematic.	If groundwater sources of different quality and type are mixed If fracking or drilling chemicals used are toxic and present in large amounts If area is highly fractured or faulted before fracking takes place and the new connections further enhance the connectivity throughout the fracture network	Unknown for well integrity to some extent, and failure may take place over long time scales Yes, for fracking, as proper monitoring should allow for shut down if any problem detected
Seam depressurisation							
Depressurising coal seam causes a decline in groundwater levels, and/or subsidence in the overlying rock	When surface water is groundwater dependent When shallow groundwater sources are connected to affected aquifers with high conductivity	Could reduce available surface water and groundwater Could affect air quality through gas escape	Could pollute or cause a reduction in drinking water or other beneficial use water resources Could have air quality impacts Subsidence induced by water removal could cause damage	If connections to nearby deep aquifers exist, and a significant quantity of water is removed from coal, may cause a decline in pressure in those deep aquifers and follow-on effects through the	Controls centre on understanding local geological conditions and their responses. These must be well characterised, modelled and monitored.	Where there is a high degree of connectivity between the coal seam and surrounding rock strata, and between the rock strata and aquifers.	Yes. If appropriate sites are chosen

What could go wrong?	When might it impact the environment?	How might it impact the environment?	Could it affect humans/livestock?	What could potentially cause it?	To what extent and how can we control for it?	Under what conditions could it become serious?	Can controls minimise all potential risks?
	When pressure changes cause the mixing of groundwater sources with different quality ant type When the pressure changes cause surface water to recharge groundwater, introducing organic matter and mobilising geogenic contaminants. When gas moves to other geological strata due to pressure changes		to infrastructure	system Removal of large volumes of water, causes an increase in inter-granular stress in the solid matrix (particularly clays and silts) of the overlying strata. This results in compression of the matrix, and causes subsidence at the ground surface.			
Spills and leaks							
Liquid spill or leak from CSG project. Liquids could include: • Produced water • Fracking fluid • Flowback water (mixture of the above two) • Drilling chemicals • Other industrial chemicals onsite	When fluids are released directly onto a soil surface and can seep into groundwater or runoff into surface water	Salinity effects from saline water or from volume of water released Changes in water quality and/or quantity Soil erosion from volume of water released Ecotoxic contaminants present in damaging concentrations	Could affect drinking water quality if not sufficiently diluted Could affect air quality Could affect food (livestock, crops) quality and yield	Pipeline, container and transport leaks or spills Holding pond leaks or spills Chemical interactions between liquid and local substrate	Engineering controls are well understood but human error is a risk.	When the spill is extensive (large volume of water released) Where toxic chemicals in significant concentrations are contained within, or mobilised by, these liquids	Yes, when fully implemented.

What could go wrong?	When might it impact the environment?	How might it impact the environment?	Could it affect humans/livestock?	What could potentially cause it?	To what extent and how can we control for it?	Under what conditions could it become serious?	Can controls minimise all potential risks?
Gas leak from CSG project.	Cumulative issues of air emissions from leaking pipes and equipment or uncovered ponds. Where significant quantities of non-methane hydrocarbons are produced	Air contaminants can be toxic to biota Contaminants may concentrate in soil, or may settle into surface water resources Additional greenhouse gases	If air quality is affected, in particular where weather or geography cause confinement and pathway to human receptors If soil or biotic contaminants affect food quality or quantity If drinking water quality is affected If leak occurs in enclosed environment	Pipe and well leaks, poor well integrity Evaporation of volatiles from produced water at surface Gas escape through strata as a result of depressurisation	Engineering controls are well understood and can be applied. Monitoring of emissions and maintenance of equipment. Most NSW wells so far have low levels of non-methane hydrocarbons.	Where air currents move concentrated pollutants to sensitive receptors	Yes, when fully implemented.

2.4 PRODUCED WATER AND SOLIDS

How to manage the produced water and solids is a significant issue for the CSG industry. Several management options are available, ranging from beneficial reuse (such as industrial or irrigation use of treated produced water) to disposal of the products as waste. Options for the disposal or reuse of the produced water, brines and solids are covered in detail by three papers commissioned by the Review (Fell (2014); Gore and Davies (2013); Khan and Kordek (2014)). Each option has associated risks. Potential mechanisms by which risks to the environment arise are illustrated in Figure 4, with the key risks summarised in Table 2.

The main risks associated with produced water and solids in NSW are connected with the use of produced water for irrigation and the disposal or reuse of the brines or solids from treatment.

Using produced water for irrigation also has associated risks. In NSW, an irrigation trial is underway which uses treated water. The final quality of the treated water is important as contaminants in the water can build up in the soil, run off into waterways or percolate into shallow groundwater. The composition of the soil is also important as this will determine how robust the soil is to introduced contaminants and how trace elements in the soil may interact with the water. The latter is problematic especially where phosphate fertilisers have been used that can leave cadmium behind which can then be mobilised by produced water with high levels of chloride. Also, the major ion water type and sodium adsorption ratio are of concern, as these influence soil dispersion and structure. Finally, the selection of crops to grow with the produced water is important as different crops will have different uptake rates of contaminants, and store them in different tissues.

Produced water contains dissolved salts, including relatively high levels of sodium and bicarbonate as well as other geogenic substances originating from the coal seam. The amount of water produced and the exact composition of the water varies by location and the specific seam being targeted. Treating the produced water to remove brines and solids is part of many management actions (TC21), but this will create concentrated brines or solids which must then be disposed of.

The quantity, concentration and composition of the salts depend on the characteristics of the CSG water and the treatment process. In 2011, a report commissioned by the National Water Commission estimated the produced water volumes from NSW CSG productions based on the estimated water-energy ratio and known gas reserves across the four basins currently under exploration and/or production. The Commission estimated that over the next 25 years the total quantity of produced water will be between 5.6 and 46.8 GL (RPS Australia East, 2011). Firmer numbers will only be possible as the industry expands and further data on the produced water volumes become available. For example, it is now estimated that for the single Pilliga project, the volume of produced water will be approximately 37.5 GL over 25 years (Khan & Kordek, 2014).

While acknowledging that the concentration of dissolved salts varies from area to area, assuming a concentration of dissolved salts of 20,000 mg/L (based on the values given in Khan and Kordek (2014), and assuming a total volume of 50 GL over 25 years for NSW, the corresponding salt production would be in the order of 1,000,000 tonnes of crystallised salt over 25 years (assuming all the dissolved salt is crystallised). To put these numbers in context, in NSW the agriculture industry uses approximately 4,000 GL of water per year (ABS, 2013) and approximately 3 million tonnes of salt per year is exported from the Murray River System into the Southern Ocean (MDBA, 2013). While the salts are a relatively minor waste stream at present, if the industry is to grow this issue will need further consideration.

At present, no use has been found for the brines and salt recovered from produced water. Export or industrial uses of the salt are unlikely to be profitable in NSW in the near future

(Fell, 2014). Furthermore, the amount of produced water recovered declines over the lifetime of a project, so that the supply is not constant. At present, salts are generally disposed of by sending them to an EPA-approved solid waste landfill (TC26).

There is also the potential risk of inducing seismicity from CSG activities. This could conceivably occur by the reactivation of existing faults if waste water were re-injected into the sedimentary basins (see Drummond (2013)). Recently, the Government announced that it will introduce return flow rules which will likely enable water re-injection to water sources to be an option for produced water management in NSW in the future. Technical controls exist to manage these risks (see particularly TC25).

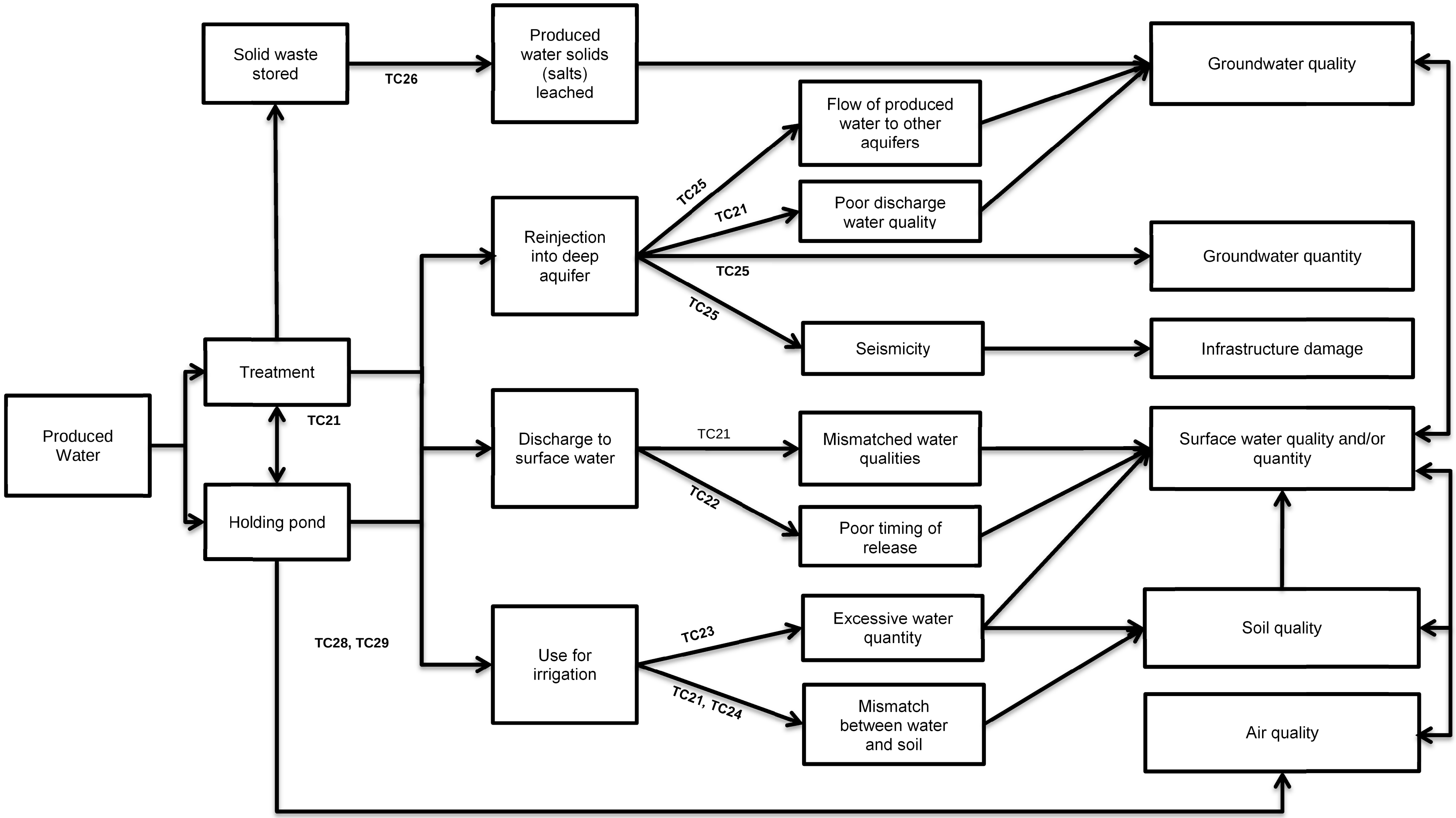

Figure 4: Risks and controls associated with produced water and solids

(For the list of technical controls (TC) see Appendix 1; for controls related to produced water spills or leaks see Figure 3)

Table 2: Overview of risks associated with produced water and solids

What is the management option?	When might it impact the environment?	How might it impact the environment?	Could it affect humans/livestock?	What would cause impacts?	To what extent and how can we control for it?	Under what conditions could it become serious?	Can controls minimise all potential risks?
Produced water used for irrigation	When large volumes of water are used for irrigation When high concentrations of salt and other contaminants are present in the water When there are connections between the irrigated area and surface water resources or groundwater resources If the water mobilises trace elements from soil	Soil quality could be affected and soil erosion may occur Soil dispersion and damage to soil structure Surface water or shallow groundwater quality and quantity changes could negatively affect biota Vegetation exposed to significantly more trace elements from soil which may move through the food chain	Could pollute drinking water or other beneficial use water resources Could have air quality impacts where volatiles escape from water Food quality and quantity could be affected through water, soil or air	Using incompletely treated or untreated produced water Inappropriate volume or rate of water used Unsuitable soil chemistry	Detailed characterisation of the water post-treatment and the soil to be used combined with careful selection of the crops to be grown should control accumulation risks. Volume and rate of water application can also be controlled and water recaptured.	Where soils that were previously subject to a large amount of phosphate fertilisation are used for irrigation – this can mobilise cadmium	Yes
Produced water used for stock water or aquaculture	When high concentrations of salt and other contaminants are present in the water	Wildlife can also drink stock water Seepage of water from stock watering points into the soil may occur	The quality of livestock drinking water can affect animal development and reproduction. Certain chemicals can remain in animal tissue.	Using incompletely treated or untreated produced water	Can be well controlled with water treatment and animal testing.	If elevated levels of certain chemicals results in chronic or toxic effects.	Yes
Disposal of produced water to surface water system (ie: discharge to	When water quality dramatically differs from local water quality	Could cause build-up of ecotoxic chemicals that harm biota Could cause	Could pollute drinking water or other beneficial use water resources Could have air quality	Releasing water of unsuitable quality Releasing water in unsuitable	Can be well controlled by understanding local ecology and surface water characteristics and	If water introduces high bicarbonate levels to sensitive aquatic ecosystems.	Yes

What is the management option?	When might it impact the environment?	How might it impact the environment?	Could it affect humans/livestock?	What would cause impacts?	To what extent and how can we control for it?	Under what conditions could it become serious?	Can controls minimise all potential risks?
river, stream, lake, sea, wastewater management etc.)		inappropriate stream stage and flow, or affect other physical parameters that could unbalance ecosystems Potential erosion or damage to river banks etc from large releases	impacts where volatiles escape from water	amounts	matching water in volume and quality. However, long-term (~20y) release could lead to build up of salts and chemicals		
Reinjection of produced water or brine removed from treated water – into depleted coal seam or other appropriate formation	If contaminants from reinjected water can move away from the depleted coal seam and into the groundwater system If reinjection causes significant seismic events	Could pollute surface water or shallow groundwater potentially causing a build-up of ecotoxic chemicals that harm biota	Could pollute drinking water or other beneficial use water resources Seismic events could damage infrastructure	Connections between coal seam and groundwater system such that movement of contaminants is possible Injected water raises pressure in coal seam causing rupturing along faults	Controls centre on understanding local geological conditions and their responses very well. These must be well modelled, monitored and understood prior to proceeding	If large amounts of water were reinjected into a geologically unstable area or one with connections to the groundwater system	By restricting the use of reinjection to suitable sites only, yes.
Disposal of produced solids	If landfills leak during rainfall or flooding events. When landfill linings degrade over time	Salt permeation can detrimentally affect local soils and groundwater systems	Could pollute drinking water or other beneficial use water resources	Heavy rainfall or flooding events. Poor site selection. All impermeable linings have a finite lifetime	Careful site selection Recovering salts from the landfill before the lifetime of the impermeable lining is reached	If impermeable linings are breached releasing large quantities of salt over a short duration	Yes. But salts recovered from landfills would again require further disposal

2.5 MANAGING ENVIRONMENTAL RISKS

In this chapter, many potential risks to the environment from CSG activities in NSW have been identified. Of these, spills and leaks have been recorded at several sites.

There are two main groups of risk. The first of these is risks for which engineering controls can be used: best-practice approaches to problems such as well integrity should control emissions, leaks and spills. This can be a fast-moving field and it is important that NSW have access to the very best technology and expertise to ensure the best possible solutions are implemented.

Clear gaps in the current management of such risks exist in NSW and should be given immediate attention. These are:

- managing the many abandoned wells around the state. The issues of abandoned wells (e.g. from water, coal and petroleum) is further discussed in CSE Abandoned Wells (2014a)
- ensuring good quality design, construction and maintenance of new and legacy (holding tanks and ponds
- strategies to manage and dispose of produced water and the brines or solids that result from its treatment

The second group of risks requires an adaptive management approach, as there is often uncertainty in understanding the system. These are mostly about underground processes that take place in the seam itself, or the surrounding geology and hydrology. These require a very good understanding of the site characteristics, followed by detailed and sensitive monitoring and modelling, which must be conducted with a high level of expertise and be available for independent, transparent and rigorous peer-review.

There is also the potential for cumulative impacts from various projects and industries in the same general area over time. In particular, potential regional impacts on groundwater over the long term will require new data and modelling at a basin scale.

The "Study of regulatory compliance systems and processes for coal seam gas" (CSE Compliance, 2014d) has made recommendations on how to move towards a more strategic legislative and regulatory system. Such a system would need to allow for:

- variation in the type and level of risk encountered at the various projects across NSW. For example, at some sites the possible effects of seam depressurisation will need careful attention whereas for other sites the key issue is the disposal of produced water
- the adoption of new engineering controls being developed by the CSG industry
- the adoption of new innovative technologies and techniques in monitoring and modelling as they become available
- new information as it becomes available to be incorporated into CSG operations. This is particularly the case for the second group of risks where there are inherent uncertainties in the geology, hydrology, etc., that means the risks cannot be fully known at the beginning of a project and may require adaptive management strategies
- post-auditing of risks assessments. This is distinct from the need for ongoing monitoring or comparing predicted impacts with actual impacts. It means that that risk assessment used for project approval is not the final assessment, but instead evolves over time. An adaptive management approach requires such feedback loops to work effectively.

As discussed in CSE Compliance (2014d), the UK employs an outcomes-focused approach to managing health and safety risks. Goals are determined by the regulators and it is the operator's responsibility to identify how to achieve them. The goals may set: "a lower bound below which risks are acceptable", "an upper bound above which risks are deemed unacceptable" (this may require the activity to stop or action to be taken to reduce risk), or “an intermediate range where risks are regarded as acceptable provided they are reduced to as low are reasonably possible” (Royal Society & Royal Academy of Engineering, 2013). A report by The Royal Society and The Royal Academy of Engineering highlighted the advantages of such a regulatory system, in that operators are “forced to identify and assess risks in a way that fosters innovation and continuous improvements in risk management” (Royal Society & Royal Academy of Engineering, 2013).

Queensland is also moving towards a risks-based and outcomes-focused regulatory framework. This aims to: streamline application processes, increase focus on effective and targeted compliance activities, have a more consistent application of strong but proportionate enforcement activities, and develop a specialist knowledge base (linked to industry and academic partners) for all major activities that potentially pollute (Queensland Government, 2014b).

3 MANAGING HUMAN HEALTH RISKS

Potential health impacts from CSG activities are commonly raised as an issue of concern. Published peer-reviewed studies on this issue are limited and determining whether there is a causal relationship between a CSG-related activity and human health is difficult.

Exposure pathways describe the routes from release of a contaminant to humans or other receptors. Release of contaminants during CSG activities was covered in the previous chapter. The exposure pathways are via contaminant transport through air or water. Contaminant intake may occur through contact with contaminated water or soil, inhaling the air, eating food grown where there is contaminated soil or water, or drinking the contaminated water.

The purpose of studying exposure pathways is to give an indication of the quantity, concentration, timing and nature of potential contaminants that could affect people through ingestion, inhalation, and respiration. For direct exposure pathways the concentration of the contaminant is usually measured by sampling the soil, groundwater or food. For indirect exposure pathways the concentration at the point of exposure is commonly estimated using a fate and transport model. This sets the context for studies that seek to understand health impacts for CSG activities.

3.1 UNDERSTANDING EXPOSURE PATHWAYS

To characterise exposure pathways fully from the point of release to the human receptor requires detailed local knowledge and understanding of atmospheric, surface and subsurface conditions and nearby land uses. For some projects, and for some pathways, this characterisation will be necessary in order to ensure sensitive areas are protected. Fully characterising exposure pathways may include: where projects are sited close to drinking water sources for stock and domestic consumption; the geology is highly complex; or the topography and weather are such that the entrapment of air pollutants may be of concern.

This Report describes possible exposure pathways in broad outline for NSW, highlighting when contaminants could travel through the environment and reach a human receptor. Areas of further research are also outlined.

Figure 5 illustrates the generalised pathways by which contaminants already present in the environment may reach the community. Most of the pathways examined are likely to result in significant dilution of a contaminant and thus the further from the source a receptor is located, the lower the dosage is likely to be. For surface water and air, this is particularly true as mixing with clean water or air reduces the concentration of a given contaminant through dilution.

The situation, however, is more complicated for groundwater and biological pathways.

Groundwater generally does not experience turbulent flow and mixing will be limited, unlike in a surface water body where full mixing may occur. Laminar flow underground causes contaminants to move in plumes that slowly disperse. As a result, understanding the effect of the addition of a contaminant to a groundwater system is not simple, and the long timescales of groundwater mean that the results of an activity may not be detectable for a long time (decades).

However, during CSG extraction and the post-production period where the seam is naturally depressurised, the hydraulic gradient is toward the production well and seam, as water and gas are being drawn up the production well or into the seam as a consequence of the seam depressurisation process. Therefore, during these stages the flow of water and chemicals away from the seam and into another groundwater system will be low or negligible. The half-lives of chemicals and their daughter products, for each geological and ecological setting, need to be determined to enable the assessment of impacts distal to the point of contaminant release.

Biological pathways, the ways in which chemicals move through living systems, are also highly complex and not always well understood as they can be specific to the type of systems involved. In some cases contaminants can be concentrated. This is seen in the case of heavy metals, which can bioaccumulate through the food web. Characterisation and monitoring are important in bioaccumulation studies for understanding soil, water, and biota interactions.

The chemical behaviour of substances and mixtures (both natural or from drilling and fracking fluids) is another complexity, and knowledge of the major ions and trace elements in the water and soil is required to determine the potential mobilisation and bioavailability of some substances. Such data are a key input in exposure pathway models. The mixtures of concern include produced water, fracking and drilling chemicals used, background sources of pollution, and interactions of all of these with the local soil, geology and water.

Table 3 considers when each exposure pathway may be considered a concern and discusses what may be a result of the CSG industry in NSW.

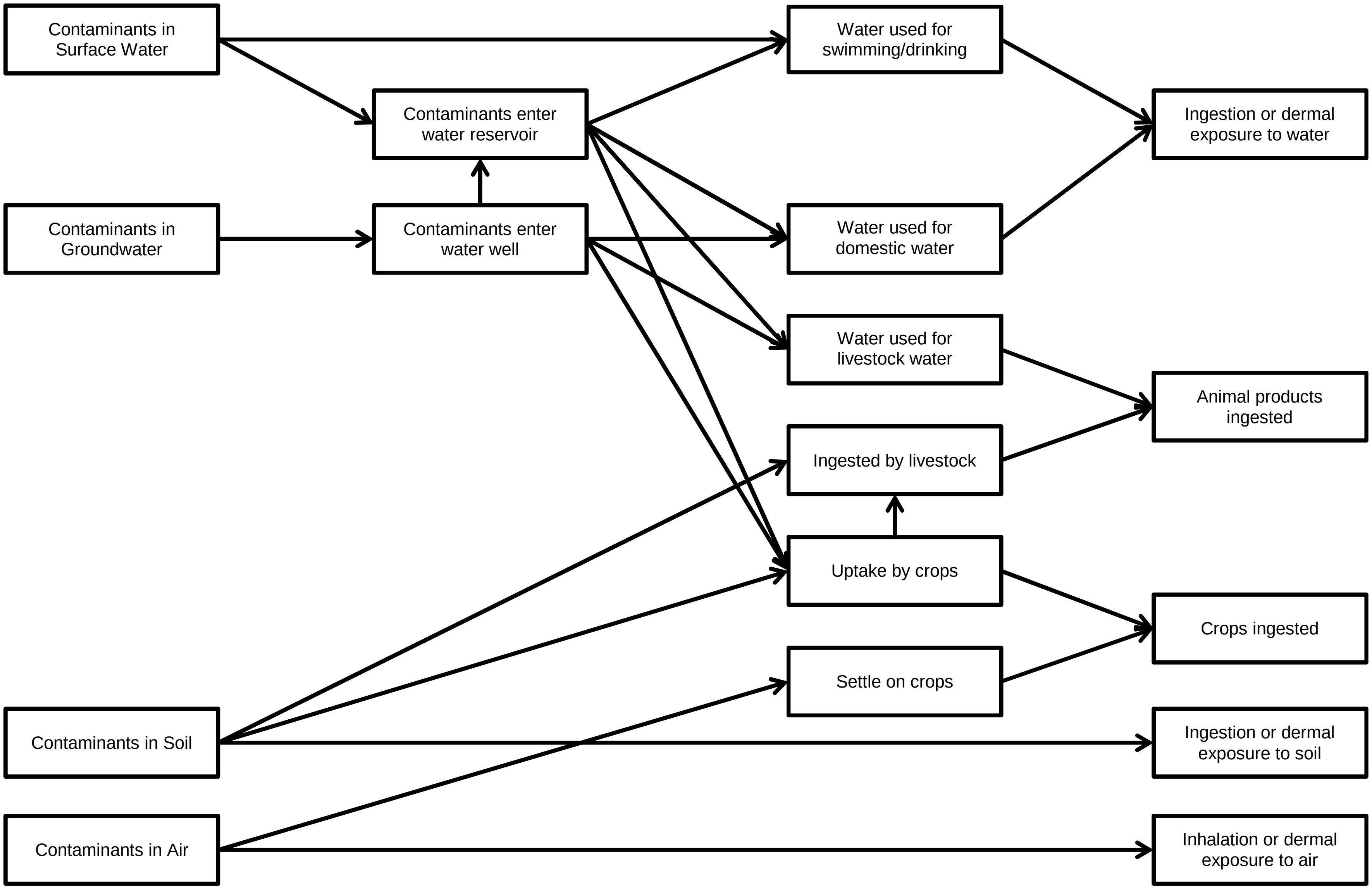

Figure 5: Schematic diagram of potential exposure pathways for contaminants once released from CSG operations

Table 3: Summary of possible exposure pathways

Potential Exposures	Possible contaminants	How could it happen?	How can we control for it?	When is it serious?	Is this a likely result of CSG in NSW?
Ingestion or dermal exposure – water	Heavy metals (e.g. Cd, Pb) Other inorganics (e.g. As, Cu) Radionuclides Organics – VOCs incl. BTEX, PAHs Assorted other chemicals from fracking or drilling fluids	Surface water with contaminants enters a drinking/domestic water reservoirs Contaminated surface water flows into a recreational body of water (lake, river, dam) Groundwater contamination, where that groundwater: • Is linked to surface water that connects to a drinking water dam or recreation body of water • Is linked to an aquifer used for drinking/domestic water	Significant dilution factors control exposure for most surface drinking water dams Drinking water utilities and local councils undertake regular testing and standard treatment on public drinking water Site selection to ensure spills and leaks cannot reach vulnerable water bodies For controls to prevent contamination in the first place see Chapter 2 Characterisation of produced water contents Selection of fracking fluids	If contaminants at a concentration of health concern were to reach the dams. If significant soluble organic and inorganic pollution were to present in the water and not treated. If contamination of bore water used directly (i.e.: untreated) for drinking or swimming/bathing were to occur.	Controls used in CSG operations should prevent the release of substantial volumes and concentrations of chemicals being released into the environment (see Chapter 2). Possible if CSG operations are sited such that contamination could occur in significant volumes near vulnerable water bodies. With upscaling of the industry, groundwater contamination may be possible.
Ingestion – animal products or crops	Heavy metals PAHs Radionuclides	From soil and/or water containing contaminants being used for irrigation, stock watering, or aquaculture.	Identify possible contaminant chemicals and which of these bioaccumulate By undertaking water quality assessment at the start of the project and developing a management plan with action levels By treating produced water prior to its use for irrigation. By selecting appropriate crops to be grown where produced water is used. By testing crops, soil and water regularly and operating accordingly.	If concentrations of contaminants in the food source were high enough to cause acute or chronic health effects.	Possible, if the use of produced water for irrigation is scaled up and: • The water is untreated or poorly treated • The soil to be irrigated is not characterised and treated in concert with the water • The soil is not regularly tested to determine the effects of irrigation If produced water with high sodium adsorption ratio is used on previously fertilised soils – likely to mobilise Cadmium. If crops irrigated with produced water concentrate contaminants

			By testing livestock feed and animal products produced using produced water.		and are used for livestock feed. If untreated produced water is used as livestock water and animals concentrate contaminants in meat or other products used as food.
Ingestion or dermal exposure – soil	Radionuclides PAHs	From contact with water or air containing contaminants From use of produced water for irrigation or environmental flows	Management protocols for produced water including testing, limits and use Water treatment Regular soil tested to determine the effects of irrigation Controls to prevent contamination in the first place see Chapter 2	If concentrations are high enough to cause acute or chronic effects.	Possible, if the use of produced water for irrigation is scaled up and: • The water is untreated or poorly treated • The soil to be irrigated is not characterised and treated in concert with the water
Breathing or dermal exposure – air	VOCs including BTEX PAHs (some) Ozone (secondary contaminant) H_2S (not likely an issue as occurrence of gas in Australian coal is rare) (Ward & Kelly, 2013)	Released with escaping CSG from coal seam or from infrastructure (wells, pipelines etc) From incomplete combustion of methane as CSG is flared	Air monitoring and modelling Topography/weather and distance to well site (dispersion) For controls to prevent contamination in the first place see Chapter 2	If concentrations, high enough to cause acute or chronic effects, can reach a population	Unlikely from gas escape due to low concentrations of these chemicals in NSW CSG Possible from other sources typical of any form of development such as traffic, engines used to run the well or other equipment at site, bushfires – could lead to decline in local air quality

3.2 UNDERSTANDING HEALTH IMPACTS

3.2.1 Health studies

The number of peer-reviewed studies that address unconventional gas and potential human health impacts are low, and of these the number of CSG-focused publications is limited in content. Potential health impacts from CSG activities were discussed in Chapter 11 of the CSE Initial Report (2013) and further studies and reports have been released over the last year.

Most of the studies on unconventional gas are from the US. These studies cannot be directly compared to Australian scenarios, due to differences in the US and Australian surface and subsurface environments and gas composition. The US unconventional gas industry is primarily shale gas, which leads to differences in the degree and frequency of fracking as well as the fluids used and the volume of flowback and produced water recovered (Cook, 2013). The composition of the natural gas, that is the percentages of methane vs other volatile gases (e.g. VOCs, including BTEX and Polycyclic aromatic hydrocarbons (PAHs)) will also vary across each individual site and between the source of the gas (CSG is approximately 95% methane in NSW).

While there are some reports of health effects, the studies have been unable to find any clear link between CSG and health impacts. Many of the studies have methodological problems including sample size and statistical power issues, and fundamental confounding and bias concerns. Further research is required on both mental and physical health impacts.

3.2.2 Health studies and assessments

A number of approaches can be considered to try to determine potential health impacts that may arise from CSG activities. These include undertaking epidemiological studies and performing an environmental health risk assessment. There are uncertainties inherent in both methodologies and neither is able to provide a definitive risk level for an adverse health outcome for an individual in an at-risk population, such as people with particular sensitivities to chemicals.

Epidemiological studies

Epidemiological studies involve looking at patterns of disease in defined populations. Study designs that may be utilised to examine potential adverse health effects from environmental pollutants (Vaneckova & Bambrick, 2014) include:

- spatial study – which examine the regional distributions of disease
- case-control study – where groups are compared retrospectively with one group demonstrating an outcome of interest and a matched control
- cohort study – where subjects or a subset from the population are followed over time with repeated monitoring; can be prospective or retrospective
- time-series study – where observations, such as GP/ hospital records, over a specified time period is obtained and analysed
- cross-sectional studies – provide information on disease frequency at a given time.

Causation and correlation in an epidemiological study can be difficult to show. This is due to many factors including: obtaining an accurate assessment of exposure by individuals or the community; small population sizes exposed; varied and mild health effects; chronic low exposures in sensitive individuals; lifestyle; socioeconomic status; and alternative potential exposure sources such as combustion heating and power generators. Failure of a study to control for these factors adequately means that its ability to attribute a particular symptom to a specific chemical or industrial activity is limited.

The small scale and short history of CSG production in NSW; the small size of the potentially exposed population; and the difficulty of measuring individual or community level data on exposure to CSG related hazardous materials means that such epidemiological studies are not likely to be useful at this time (Chant, 2014).

Environmental Health Risk Assessment

Environmental health risk assessment (EHRA) is another and likely better approach to determining health risk. It aims to determine the risk to human health from a potential environmental impact, if relevant chemicals, their toxicity, concentrations and exposure pathways are known. If used early in the project approvals stage, an EHRA can provide a valuable tool in assessing potential risks, if any, to human health from CSG activities. This can provide an opportunity for third parties to review the assessment, and for regulators to request amendments to projects deemed high risk before approval is granted. An EHRA can be undertaken at any subsequent stage, with its results being incorporated into management plans and Trigger Action Response Plans

A nationally agreed framework, *Environmental Health Risk Assessment Guidelines for assessing Human Health Risks from Environmental Hazards* outlines the steps involved in undertaking such an assessment (enHealth, 2012) (see Figure 6). An EHRA can range in complexity from a simple screening study to a lengthy and complex analysis.

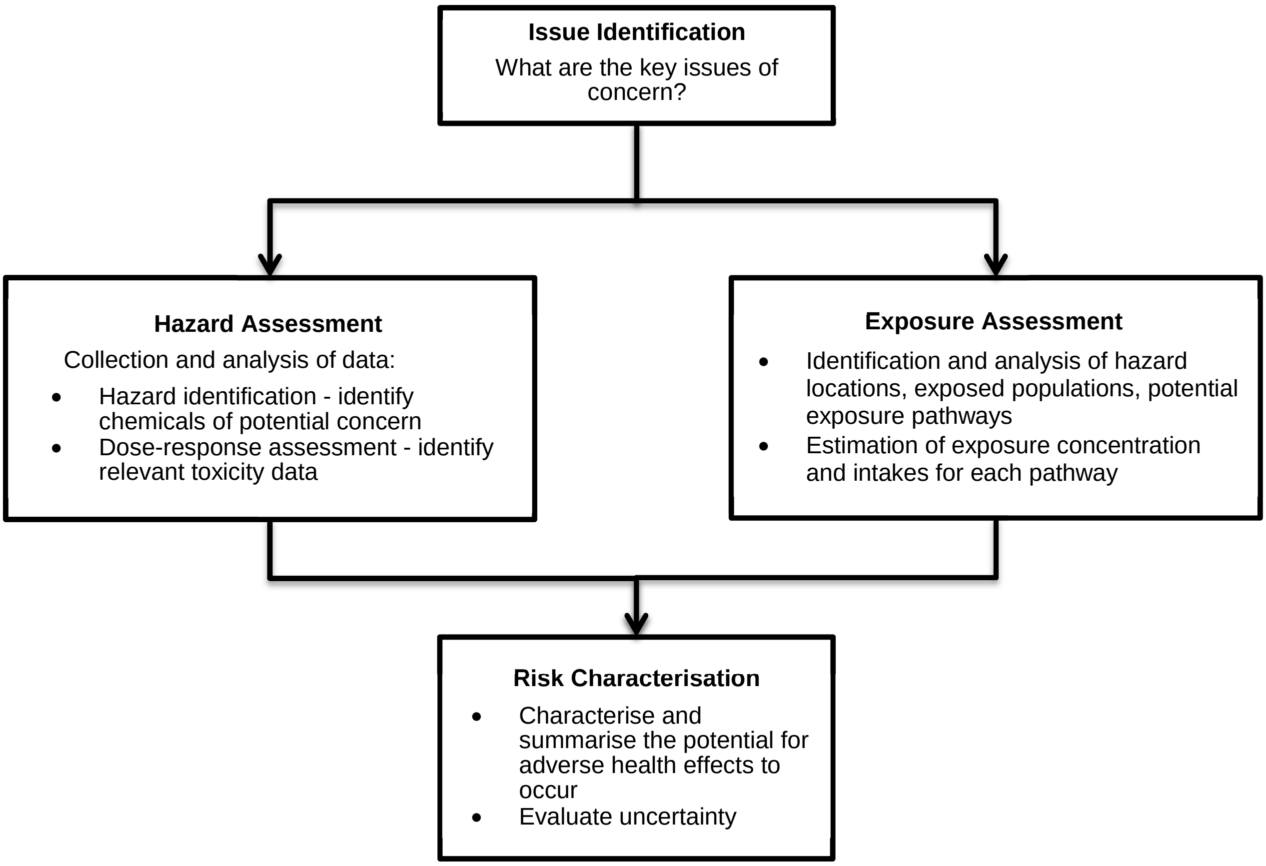

Figure 6: The environmental health risk assessment process

(Adapted from enHealth, 2012)

Risk assessments such as these estimate and compare risks at different times, and identify factors that affect the nature and magnitude of the risk. The assessments provide estimate values for comparison with health guideline and trigger levels (enHealth, 2012).

It is important that such risk assessments are done for a range of possible hazardous events and not be limited to assessing routine CSG operations with specific exposures to specific chemicals. To do otherwise may understate the risks. The risks to human health, arguably, are associated with highly unlikely events but which have very high consequences, and therefore need particular attention in both the risk assessment and risk management activities.

3.2.3 Standards for human exposure

Risk assessments are required to determine the potential impact on human health. These assessments make use of available health standards for water, air, soil and food.

Toxicity guidelines acknowledge that there is a grey area between concentrations of potential contaminants that are clearly safe and concentrations that are clearly unsafe, as unsafe levels have not always been reliably demonstrated. For this reason, the guideline values err on the side of caution, especially where scientific data are inconclusive or where the only data available are from animal studies. Safety factors of between 100 and 1000 are commonly incorporated into calculations (enHealth, 2012). Occasional concentration values that exceed the guideline trigger value are not necessarily an immediate threat to health; as with all potential toxicity issues, the amount and duration of the exposure are important (NHMRC & NRMMC, 2011).

The *Australian Drinking Water Guidelines* (NHMRC & NRMMC, 2011) contain information on an extensive list of chemicals that are potential pollutants of drinking water and include a health-related guideline value. This value is the concentration of a chemical of potential concern that does not result in any significant risk to the health of the consumer over a lifetime of consumption.

The *National Environmental Protection (Assessment of Site Contamination) Measure 1999* sets health investigation levels for a number of potential soil contaminants, including metals and other inorganics, polycyclic aromatic hydrocarbons (PAHs), phenols, polychlorinated biphenyls and polybrominated diphenyl ethers and volatile organic compounds. The measure also considers exposure pathways such as absorption through skin, ingestion and inhalation, and background intakes from other sources.

National ambient air quality standards are set by the Council of Australian Governments through the National Environmental Protection Council. These set maximum concentration levels for six key air pollutants, including particulate matter. An additional measure sets ‘monitoring investigation levels’ for five more substances, including benzene, toluene, ethylbenzene, and xylene (BTEX) and polyaromatic hydrocarbons (Department of the Environment, n.d.).

In Australia, various foods are tested for residues annually in the National Residue Survey, conducted by the Department of Agriculture. Residue standards are set by Food Standards Australia New Zealand (FSANZ) and the Australian New Zealand Food Regulation Ministerial Council (ANZFRMC) and include Maximum Levels (MLs) of specified metal and non-metal contaminants in nominated foods. MLs are established only for those foods that provide a significant contribution to overall dietary exposure (Department of Agriculture, 2012).

3.3 MANAGING HUMAN HEALTH RISKS

The most effective way of preventing community exposure to contaminants is to prevent as far as possible the release of contaminants into the environment in the first place. Managing environment risks (Chapter 2) is thus crucial to managing health risks; controls to do this were considered in the last chapter.

However, as is the case in a wide range of industrial and resource activities, the release of some contaminants is inevitable. This is because some of the CSG activities by virtue of the activity itself will release contaminants to the environment (e.g. produced water ponds will evaporate and fracking fluids will be injected underground during the fracking process). Also, accidents in an industrial operation will occasionally occur, even with the most stringent controls and regulation. Given this reality, a second level of risk mitigation is required.

If contaminants do enter the water, soil or air, in most cases these will undergo dilution that occurs naturally within the environment. This mechanism helps limit exposure to neighbouring individuals or communities, and it is imperative that cumulative impacts be modelled prior to any new activity taking place to assess the receiving environment's capacity to dilute contaminants of concern. Cumulative impacts and, for populations, cumulative exposure must be accounted for when approving new projects and establishing licence conditions.

An important management approach is for companies to undertake risk assessments, including taking account of worst-case scenarios through the environmental assessment stages of the approvals processes. The risk assessments must be followed by comprehensive Trigger Action Response Plans (TARPs) that outline the approach to managing contaminant releases and other events. The EHRAs and TARPs should be updated as projects grow, technologies change, and as new activities are approved as appropriate.

By having an understanding of the hazard profile of a chemical and an assessment of its dose response, it is possible to calculate the amount of a contaminant that can be released at the source without reaching the guideline trigger value at the receptor.

Part of managing the movement of CSG-related chemicals into and through the environment is to monitor the CSG system to identify cases of release (TC21). If a chemical is released this should be reported to the appropriate regulator and action then be taken to clean, remediate and make arrangements for any down-stream receptors that may be impacted. This requires that extensive and good quality data be collected before and during CSG activities.

The mechanism of transport of contaminants through groundwater systems is understood, with approaches available to predict the flow and transport of contaminants through groundwater. However it is commonly difficult to conceptualise the geometry of faulted and folded geological strata, characterise the heterogeneity within a strata, and predict the dynamic response of the strata due to depressurisation caused by CSG production. All these factors reduce the capacity of transport models to predict long-term impact and the true concentration of a contaminant at the point of exposure. Models need to be constantly updated as more information is made available.

Further research is needed to improve our understanding of the fate and transport of chemicals of concern associated with CSG activities. For each new CSG development this will be unique due to the great variability in earth materials (rocks and soil), local groundwater type, and local ecology. Finally, studies are needed on the interactions of biological systems with the contaminants associated with produced water or which may be mobilised from agricultural soils following irrigation with produced water.

As noted, studies of associations between health and CSG activities have been inconclusive due to the difficulty of small sample sizes and lack of data showing clear associations between CSG activities and symptoms. The small size of the current industry in NSW means that epidemiological studies are currently not feasible.

Therefore risk assessments, such as the EHRA, should be undertaken by proponents during the project planning phase and enable appropriate controls to be put in place before an activity commences, with the plans to manage these, such as Trigger Action Response Plans, reviewed and updated throughout the activities.

The CSE Compliance (2014d) report outlines the characteristics of a regulatory framework for CSG which includes a lead regulator to oversee all regulatory and compliance activities. This lead regulator is also charged with the development of health and environment targets. The health targets should be developed with input from the NSW Ministry of Health.

The regulatory system for managing CSG activities needs to ensure that:

- monitoring and modeling of the exposure pathways from source to humans occurs,
- standards or data on the exposure levels of contaminants, with reference to Australian and International guidelines and other toxicity studies, are accessible
- monitoring and modelling techniques can be adopted and standards revised, as new information and methods becomes available
- the formal and transparent assessment of potential hazardous events, which may lead to (unintended) exposures to hazards, occurs.

4 CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSION

This report covers an investigation of some of the potential risks associated with CSG activities and the controls for them.

Of the risks identified, spills and leaks appear to be the only ones that have occurred to date. However, the long time-lags between CSG activities and the manifestation of some impacts (e.g. declining pressures and levels in groundwater systems distant from the project site) mean that some impacts would not be expected to be seen as yet.

Many of the risks can be managed and impacts minimised through best practice engineering management and controls, site selection, monitoring, modelling and adaptive management.

There is also the potential for cumulative impacts from various projects and industries in the same general area over time. In particular, potential regional impacts on groundwater over the long term will require geological and hydro(geo)logical models underpinning risk assessments, at both project and basin scale, to be amended as new data becomes available.

Health risk assessments need to be conducted before a project commences to identify any possible risk to human health and methods to minimise those potential impacts. Following this, appropriate management plans need to be developed with action levels and triggers, with these being updated during the course of the project.

CSG Compliance (2014d) concludes that complexities of the current regulatory system poses a risk and that there is a need for a strong, well structured and articulated regulatory and compliance regime. Such a regime would set the framework for safe and effective operations by companies.

A regulatory system is needed that can manage variable risks associated with different sites and allow for the swift uptake of new technologies that can be used to reduce the impact of CSG activities and associated risks. The UK employs a 'goal based approach' to managing health and safety risks, and the Queensland Government has developed a regulatory strategy that focuses on acceptable environmental standards and targets, compliance and enforcement, and knowledge development. These systems put the onus on industry to assess risk and develop strategies to manage that risk, with heavy penalties associated with non-compliance. Sufficient regulatory capacity in Government agencies will be required to ensure compliance.

In managing risk, best practice engineering controls monitoring/modelling techniques are required. The regulatory system needs to allow for new modelling technologies and other innovations and knowledge to be taken up by the industry swiftly to manage risks well.

Risk-based and outcomes-focused regulation could be a useful tool in managing potential impacts associated with CSG activities. This system could employ environmental and health targets whereby companies develop solutions to meet the targets, thereby allowing for innovative solutions to be applied, as well as heavy penalties for non-compliance. The development of targets would require the development of a 'knowledge base' of risks. This would make use of current and developing knowledge in the field and allow for targets to be modified as knowledge improves.

In the context of environmental and health risks from CSG activities, the key features of a risk-based and outcomes-focused regulatory system would include:

- a set of environmental and human health objectives set by Government for any given project, with the ability to regularly review and optimise these
- flexibility to encourage uptake of new technologies and innovation
- ability to manage cumulative impacts as well as project impacts
- a comprehensive ‘knowledge base’.

4.2 RECOMMENDATIONS

This investigation found that some identified risks arising from CSG activities can be managed by good engineering and regulatory controls. Others risks are less well understood or may not be conducive to set/optimal management and require an adaptive management approach. The Review therefore proposes a centralised risk management and prediction tool specific to the extractive industries to assist in the latter circumstances.

The tool would provide a dynamic capability, drawing on existing and emerging knowledge and data from industry, the research sector and regulatory findings to inform the regulatory process itself, from setting standards, limits and targets to assessing compliance and updating lead practice. Consistent with business and regulatory best practice and directions in other jurisdictions, the tool would enable the regulatory process to place a greater focus on results and outcomes. An important component and underpinning to the tool is establishment of a Whole-of-Environment Data Repository as recommended in Recommendation 2 of the CSE Initial Report (2013) .

Recommendation 1
That Government develop a centralised Risk Management and Prediction Tool for extractive industries in NSW. This would include a risk register, a database of event histories, and an archive of Trigger Action Response Plans. The tool would be updated annually based on Government and company reporting and would include information on risk management and control approaches and draw on data from the Whole-of-Environment Data Repository for the State. The risk tool would be reviewed and commented on by relevant expert and regulatory bodies. The risk tool would be used to assist with:

- assessing new proposals
- assessing compliance
- improving prediction capability for consequences of incidents in risk assessments
- improving prediction capability of risk likelihoods
- informing project design amendments to decrease risk levels (such as undertaken in the Dam Safety Committee)
- informing the calculation of cumulative impacts
- flagging issues or risks that require a higher level of regulatory protection such as inclusion in legislation.

Legacy wells could potentially have been constructed or abandoned under less stringent conditions than currently required, owing to their age. This is an issue for all wells, not just those of the petroleum industry, as they are also a feature of mining and irrigation activities, and also have the potential to connect aquifers and emit fugitive emissions if their integrity is compromised.

A range of national and international codes and standards exist regarding well integrity. Experience suggests that if the current methods prescribed in these codes are adopted, the risk of a well failing is considered to be low. However, it is not certain that prior to the existence of these current standards, requirements were adequate to maintain well integrity after abandonment, as some of these wells in NSW were drilled more than a hundred years ago. This is an internationally recognised concern, but little scientific literature currently exists on the topic.

The exact number of legacy wells across all industries in NSW is currently unknown; however it is likely to be high. Similarly, how many of these wells leak gas or affect groundwater movement is also unknown. A cumulative desktop study aimed at developing an inventory of legacy wells in the state would be a useful first step in quantifying the potential problem. This should be followed by followed by a risk-based assessment of the wells to highlight any wells that may need further remediation.

Unlike petroleum wells in NSW, the locations of legacy wells used for mining and irrigation purposes will be largely unknown, meaning the remote sensing technologies, like those utilised by UNSW, Royal Holloway and CSIRO (UNSW, 2014), would have to be adopted to detect where these wells are located.

Recommendation 2
That Government develop a plan to manage legacy matters associated with CSG. This would need to cover abandoned wells, past incomplete compliance checking, and the collection of data that was not obtained under licence and legislation. There will also need to be a formal mechanism to transition existing projects to any new regulatory system.

.

REFERENCES

ABS. (2013). *ABS 4610.0 - Water Account, Australia, 2011-12*. Australian Bureau of Statistics. Retrieved from http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4610.0Main+Features302011-12.

AGL. (n.d.). Water management. *Gloucester Gas Project.* Retrieved 21 July, 2014, from http://www.agl.com.au/about-agl/how-we-source-energy/natural-gas/natural-gas-projects/gloucester-gas-project/water-management

Anderson, A, Parks, A, & Arellano, J. (2013, 30 September-2 October). *Field Deployment of Fracturing Site Sand Fill Dust Mitigation System.* Paper presented at the SPE Annual Technical Conference and Exhibition, New Orleans, LA.

Anderson, D.J., Rahman, P.F., Davey, E.K., Miller, B.M., & Glamore, W.C. (2013). Background paper on groundwater resources in relation to coal seam production. Paper commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist: Water Resource Laboratory, The University of New South Wales.

ARMCANZ & ANZECC. (1995). *National Water Quality Management Strategy: Guidelines for Groundwater Protection in Australia*. Canberra: Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council. Retrieved from http://www.environment.gov.au/resource/national-water-quality-management-strategy-guidelines-groundwater-protection-australia.

ARMCANZ & ANZECC. (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Canberra: Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council. Retrieved from http://www.environment.gov.au/water/publications/quality/australian-and-new-zealand-guidelines-fresh-marine-water-quality-volume-1.

Carter, John. (2013). Background Paper on Horizontal Drilling. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: Advanced Geomechanics.

Chant, Kerry. (2014). *Submission 261 to Indepedent Review of Coal Seam Gas Activities in NSW*. NSW Ministry of Health. Retrieved from http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/public-submissions

Cook, Peter J. (2013). Life Cycle of Coal Seam Gas Projects: Technologies and Potential Impacts Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist: PJC International Pty Ltd.

CSE. (2013). *Initial Report on the Independent Review of Coal Seam Gas Activities in NSW*. NSW Chief Scientist & Engineer. Retrieved from http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/initial-report-july-2013.

CSE. (2014a). *Information paper: Abandoned wells*. Produced for the Independent Review of Coal Seam Gas Activities in NSW: NSW Chief Scientist & Engineer. Retrieved from http://www.chiefscientist.nsw.gov.au/reports.

CSE. (2014b). *Information paper: Fracture stimulation activities*. Produced for the Independent Review of Coal Seam Gas Activities in NSW: NSW Chief Scientist & Engineer. Retrieved from http://www.chiefscientist.nsw.gov.au/reports.

CSE. (2014c). *On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment*. Report produced for the Independent Review of Coal Seam Gas Activities in NSW: NSW Chief Scientist & Engineer. Retrieved from http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0007/44485/140530_SCA-Report-Final-Combined.pdf.

CSE. (2014d). *Study of regulatory compliance systems and processes for coal seam sas*. Report produced for the Independent Review of Coal Seam Gas Activities in NSW: NSW Chief Scientist & Engineer. Retrieved from http://www.chiefscientist.nsw.gov.au/reports.

Day, S, Dell'Amico, M, Fry, R, & Tousi, H J. (2014). *Field Measurements of Fugitive Emissions from Equipment and Well Casings in Australian Coal Seam Gas Production Facilities*. Australia: CSIRO Retrieved from http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/csg-fugitive-emissions.

DEC. (1999a). *Environmental Guidelines: Assessment, Classification & Management of Liquid & Non-liquid Wastes* Sydney: NSW Department of Environment and Conservation. Retrieved from http://www.epa.nsw.gov.au/resources/mao/waste_guide.pdf.

DEC. (1999b). *Environmental Guidelines: Assessment, Classification & Management of Liquid and Non-liquid Wastes*. NSW Department of Environment and Conservation. Retrieved from http://www.epa.nsw.gov.au/resources/mao/waste_guide.pdf.

DEC. (2004). *Environmental Guidelines: Use of Effluent by Irrigation*. NSW Department of Environment and Conservation. Retrieved from http://www.environment.nsw.gov.au/resources/water/effguide.pdf.

Department of Agriculture. (2012, 27 June). About residues and residue testing. Retrieved 24 June, 2014, from http://www.daff.gov.au/agriculture-food/nrs/about-residues-and-residue-testing

Department of Planning and Infrastructure. (2012). *Strategic Regional Land Use Policy*. NSW Government through the Department of Planning and Infrastructure. Retrieved from http://www.nsw.gov.au/sites/default/files/initiatives/strategicregionallandusepolicy-brochure_sd_v01.pdf.

Department of the Environment. (n.d.). Air Quality Standards. Retrieved August 13, 2014, from http://www.environment.gov.au/topics/environment-protection/air-quality/air-quality-standards

DPI. (2014). *NSW Aquifer Interference Policy*. NSW Department of Primary Industries, Office of Water. Retrieved from http://www.water.nsw.gov.au/Water-management/Law-and-policy/Key-policies/Aquifer-interference.

Drummond, B. (2013). Background Paper on Seismicity. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer.

DSC. (2012). *Tailings Dams*. NSW Dams Safety Committee. Retrieved from http://www.damsafety.nsw.gov.au/DSC/Download/Info_Sheets_PDF/Dam/DSC3F.pdf.

DTIRIS. (2012). *Code of Practice for Coal Seam Gas: Well Integrity*. NSW Department of Trade and Investment, Division of Resources and Energy, Retrieved from https://www.nsw.gov.au/sites/default/files/csg-wellintegrity_sd_v01.pdf.

enHealth. (2012). *Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards*. Commissioned by the enHealth Council, Retrieved from http://www.health.gov.au/internet/main/publishing.nsf/Content/A12B57E41EC9F326CA257BF0001F9E7D/$File/DoHA-EHRA-120910.pdf.

EPHC, NRMMC, & AHMC. (2009). *National Water Quality Management Strategy Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge*. Canberra: Environment Protection and Heritage Council, the Natural Resource Management Ministerial Council and the Australian Health Ministers' Conference for the Department of the Environment. Retrieved from http://www.environment.gov.au/resource/national-water-quality-management-strategy-australian-guidelines-water-recycling-managing-1.

Fell, C. (2014). Water Treatment and Coal Seam Gas. Discussion paper commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: Fell Consulting Pty Ltd.

Gloucester Shire Council. (n.d.). Water Study Project. Retrieved 16 September, 2014, from http://www.gloucester.nsw.gov.au/environment/water-study-project

Gore, D, & Davies, P. (2013). Background paper on produced water and solids in relation to coal seam gas production. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: Department of Environment & Geography, Macquarie University.

Khan, S, & Kordek, G. (2014). Coal Seam Gas: Produced Water and Solids. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: School of Civil Environmental Engineering, The University of New South Wales.

Lemon, R, Tickle, P, Spies, B, Dawson, J, & Rosin, S. (2013). Subsidence Monitoring in Relation to Coal Seam Gas Production. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: CRC for Spatial Information.

McClusky, S. C., & Tregoning, P. (2013). Background paper on subsidence monitoring and measurement witha focus on coal seam gas (CSG) activities. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: School of Earth Sciences - The Australian National University,.

MDBA. (2013). *Murray Darling Basin Authority Annual Report 2012-13.* Australian Government, Murray Darling Basin Authority. Retrieved from http://www.mdba.gov.au/about-mdba/corporate-documents/annual-reports.

National Environment Protection (Assessment of Site Contamination) Measure (1999).

NHMRC, & NRMMC. (2011). *Australian Drinking Water Guidelines 6 National Water Quality Management Strategy*. (Version 2.0 updated December 2013). Canberra: Commonwealth of Australia, National Health and Medical Research Council, National Resource Management Ministerial Council. Retrieved from http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh52_aust_drinking_water_guidelines_update_131216.pdf.

NSW DEC. (2007). *Contaminated Sites: Guidelines for the Assessment and Management of Groundwater Contamination*. NSW Department of Environment and Conservation. Retrieved from http://www.environment.nsw.gov.au/resources/clm/groundwaterguidelines07144.pdf.

O'Neill, C, & Danis, C. (2013). The Geology of NSW: the geological characteristics and history of NSW with a focus on coal seam gas (CSG) resources. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: Department of Earth and Planetary Science, Macquarie University.

Pineda, J.A., & Sheng, D. (2013). Subsidence: An overview of causes, risks and future developments for coal seam gas production. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer.

Queensland Government. (2014a). *Guideline: Structures which are dams or levees constructed as part of environmentally relevant activities* Department of Environment and Heritage Protection. Retrieved from https://www.ehp.qld.gov.au/management/non-mining/csg-water.html#regulated_structures_including_dams.

Queensland Government. (2014b, 2 September). Regulatory Strategy. Retrieved 15 September, 2014, from http://www.ehp.qld.gov.au/management/planning-guidelines/policies/regulatory-strategy.html

Royal Society, & Royal Academy of Engineering. (2013). *Shale gas extraction in the UK: a review of hydraulic fracturing*. London: The Royal Society and The Royal Academy of Engineering Retrieved from royalsociety.org/policy/projects/shale-gas-extraction.

RPS Australia East. (2011). *Onshore co-produced water: Extent and management*. (Waterlines Report Series Number 54). Canberra: Report prepared for the National Water Commission, Australian Government. Retrieved from http://nwc.gov.au/__data/assets/pdf_file/0007/18619/Onshore-co-produced-water-extent-and-management_final-for-web.pdf.

Sinclair Knight Merz, & National Centre for Groundwater Research and Training. (2012). *Australian groundwater modelling guidelines*. Commissioned by the National Water Commission. Retrieved from http://www.groundwater.com.au/media/W1siZiIsIjIwMTIvMTAvMTcvMjFfNDFfMzZfOTYwX0F1c3RyYWxpYW5fZ3JvdW5kd2F0ZXJfbW9kZWxsaW5nX2d1aWRlbGluZXMucGRmIl1d/Australian-groundwater-modelling-guidelines.pdf.

UNSW. (2014). Study to assess water connectivity in the Condamine. http://www.connectedwaters.unsw.edu.au/news/2014/01/study-assess-water-connectivity-condamine

Vaneckova, P, & Bambrick, H. (2014). Approaches to baseline studies of human health in relation to industries with potential environmental impact (Draft ed.). Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: Centre for Health Research, University of Western Sydney.

Ward, C R, & Kelly, B F J. (2013). Background Paper on New South Wales Geology: With a focus on basins containing coal seam gas resources. Report commissioned for the independent review of coal seam gas activities in NSW by the NSW Chief Scientist & Engineer: UNSW Global Pty Ltd.

APPENDICES

APPENDIX 1 CONTROLS

This appendix lists the controls available for each risk. The unique identifier given next to each control is used throughout the report.

Regulatory mechanisms ensure a particular control is used. An outline of the key regulation for risks relating to CSG is below, noting that the legislative environment is highly complex. The reader is referred to Appendix 2 in the *Study of Regulatory Compliance Systems and Processes for Coal Seam Gas (CSE, 2014d)* for full detail of the current regulatory requirements.

Key Regulatory Instruments

Environmental Planning and Assessment Act 1979 and related regulation

- State Environmental Planning Policy (Major Development) 2005
- State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007
- State Environmental Planning Policy (State and Regional Development) 2011
- Development Consents for projects

***Petroleum Onshore Act 1991* and related regulation**

- Code of Practice for Coal Seam Gas Well Integrity (September 2012)
- Code of Practice for Coal Seam Gas Fracture Stimulation Activities (September 2012)
- Onshore Petroleum Exploration and Production Safety Requirements August 1992
- Petroleum titles and their conditions

Water Management Act 2000* and *Water Act 1912 and related regulation

Water supply work approvals and bore licensing must be obtained before drilling. Water Sharing Plans set the volumes of water that can be extracted.

Protection of the Environment Operations Act 1997 and related regulation

Environmental Protection Licences are issued under this Act. These set conditions and targets for quality for any production or flowback water that may be released to any receiving environment; for the robustness of water storages etc.

Environmental Protection and Biodiversity Conservation Act 1999 (Cth) and related regulation

Actions that involve CSG development and that are likely to have a significant impact on a water resource must be referred to the Federal Minister for the Environment for assessment and approval.

Select Guidelines and Policies

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ARMCANZ & ANZECC, 2000)
- Australian Drinking Water Guidelines (NHMRC & NRMMC, 2011)
- Australian Groundwater Modelling Guidelines (Sinclair Knight Merz & National Centre for Groundwater Research and Training, 2012)

- National Water Quality Management Strategy Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge (EPHC, NRMMC, & AHMC, 2009)
- NSW Aquifer Interference Policy (DPI, 2014)
- Environmental Guideline: Use of Effluent for Irrigation (DEC, 2004)
- Environmental Guidelines: Assessment, Classification & Management of Liquid and Non-liquid Wastes (DEC, 1999b)
- National Water Quality Management Strategy: Guidelines for Groundwater Protection in Australia (ARMCANZ & ANZECC, 1995)
- Guidelines for the Assessment and Management of Groundwater Contamination (NSW DEC, 2007)
- National Environment Protection (Assessment of Site Contamination) Measure 1999
- Strategic Regional Land Use Policy (Department of Planning and Infrastructure, 2012)

Technical Controls (TC)

TC1 – Site selection

Includes both project site selection (e.g. which area of a basin) and activity site selection (e.g. choosing location of well). Sites selected for drilling and fracturing have appropriate geological conditions (aquitards, overburden, fracture gradient, stress regime, etc.). Geological and hydrogeological characterisation is used to determine this including understanding features such as: fractures, faults and dykes (and whether these are conduits or inhibitors to flow), aquitards, overburden depth, stress regime, cleating, fracture gradient, location and condition of existing wells, physical properties of surrounding rocks.

TC2 – Good drilling practice

Drilling meets appropriate standards such as API Specification 13A /ISO 13500, Specification for Drilling Fluid Materials; API Recommended Practice 13B-1/ISO 10414-1, Recommended Practice for Field Testing Water-Based Drilling Fluids and API Recommended Practice 13D, Recommended Practice on the Rheology and Hydraulics of Oil-well Drilling Fluids.

TC3 – Safe drilling fluids

Water-based drilling fluids are used in accordance with the manufacturer's recommendations and Material Safety Data Sheets (MSDS) and all additives and their concentrations are compared with any relevant health guidelines.

TC4 – Sealing additives in drilling fluid

Additives such as clays, polymers, gelling agents, gums and cellulose seal pores and fractures.

TC5 – Wells cased and cemented with leak proof joints

Physically robust and corrosion-resistant steel well casings are used to isolate wells, and wells are completely surrounded by cement. Wells must comply with a recognised code of practice such as: American Petroleum Institute (API) HF1, Hydraulic Fracturing Operations-Well Construction and Integrity Guidelines; API Specification 5CT/ISO 11960, Specification for Casing and Tubing; API Recommended Practice 10D-2/ISO 10427-2; Recommended Practice for Centralizer Placement and Stop Collar Testing; API Technical Report 10TR4, Technical Report on Considerations Regarding Selection of Centralizers for Primary Cementing Operations; and API Specification 5B, Specification for Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads; API 65-2, Isolating Potential Flow Zones During Well Construction, Second Edition/December 2010; and API

Recommended Practices 10A, 10B, 10D, Guidance Document HF-1 and Technical Report 10TR

TC6 – Wells logged and monitored

Using electronic sensors for pressure, acoustics, sonics and temperature. On line monitors used for gaseous releases. Features monitored include: characteristics of source water, injection fluid, flowback water and produced water (e.g. levels, pressure, quantity and quality) as well as pressure testing of well casings.

TC7 – Suspended / abandoned wells sealed

Wells are plugged and leak-proofed to gas or water with producing intervals isolated. Pressure testing is used to confirm isolation. If abandoned the well is backfilled to the surface with cement.

TC8 – Gas in place of fracking fluid

Gaseous fracking agents can be used, such as CO_2, N_2 or non-flammable propane injection.

TC9 – Safe fracking fluids

Chemicals in fracking fluids are compared with relevant guidelines or background concentrations.

TC10 – Fracture propagation predicted and monitored

Fracture activity test done via an initial injectivity test, mini-frac, or a full frac, using pressure and level monitoring before, during and after fracking. Before, during and after fracking, pressure and levels of aquifers, as well as qualities and quantities of water injected, flow back water and produced, can also be monitored to characterise facture behaviour. Microseismometers (both within the well and within approximately 500 m of the well) can also be used.

TC11 – Fracking fluid removed from seam

Fluid (flowback water) is pumped out of well following the frack until quality returns to ambient (produced water). Tracer fluids used to identify flowback water.

TC12 – Operations stopped

If early warning of any adverse consequences are detected, the operations can be stopped.

TC13 – Blowout preventers fitted to well heads

Well heads, blowout prevention and production tree equipment accord with API standards including API Specification 6A/ISO 10432, Specification for Wellhead and Christmas Tree Equipment; API Specification 16A, Specification for Drill Through Equipment; API Recommended Practice 53, Blowout Prevention Equipment Systems for Drilling Operations and API 11IW Recommended Practice for Independent Wellhead Equipment.

TC14 – Detailed and robust groundwater models

Use of multiple model realisations combined with local, empirically derived model parameters along with the reporting of upper bound or “worst case” estimates. Modelling should be able to predict pressure, level and quality of groundwater and surface water. Baseline monitoring for up to two years prior to activity, initial pump testing and monitoring to determine if rapidly realisable connections exist between coal seams and groundwater systems as well as to inform predictions of water extraction rates.

TC15 – Depressurisation monitored

Measurements include assessment of pressures, levels and yielded gas levels from the coal seam and potentially connected aquifers and surface waters as well as water quality analysis. Specific details of the monitoring that would be applied would be based on case-by-case considerations, for example, if the likelihood of subsidence is high, surface movement can be assessed using tilt meters and satellite imaging.

TC16 – Suitable tanks

Tanks are well designed, constructed, maintained and monitored.

TC17 – Suitable tankers

Tankers are maintained in such a condition as to prevent leaks from tanks, fittings and transfer assets. Tankers are fit-for-purpose with respect to the soundness of their design and construction.

TC18 – Suitable pipelines

Ongoing monitoring of pressure, flow and physical inspections of integrity is used to help detect and stop leaks early. Pipelines should be fit-for-purpose with respect to the soundness of their design and construction.

TC19 – Ponds and dams suitably constructed

Best practice lining involves the use of double-linings with leak monitoring between the two layers of lining. Ponds and dams are structurally robust and able to handle rain events. Storages have sufficient freeboard so as to capture such wet events and avoid over-topping. Storages should be fit-for-purpose with respect to the soundness of their design and construction.

TC20 – Automatic leak detection installed

Leaks can be readily detected through changes in level which can be monitored automatically and continually or manually at regular risk-based intervals.

TC21 – Appropriate water treatment

Treatment of recovered water (produced and flowback) to remove contaminants is appropriate to local conditions. Options include reverse osmosis, nanofiltration, ion-exchange, adsorption, blending, salt balance adjustment, stabilisation, falling-film evaporative brine concentration.

TC22 – Water discharge controlled

Water is treated to match local water quality and water volumes released are matched with seasonal flows within known local variations.

TC23 – Irrigation water carefully applied

Volume and rate of application of water used in irrigation is managed using irrigation guidelines such as ANZECC/ARMCANZ 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volume 3. Sites are selected to ensure rapid percolation into groundwater does not occur.

TC24 – Soil and crops used in irrigation selected and tested

Composition and contaminant levels in receiving soil are known and soil is tested periodically during use for concentrations of contaminants – including sodicity and salinity. Crops can be selected and matched to the quality of water to be irrigated and edible parts of crops tested for contaminants

TC25 – Reinjection aquifers tested and monitored

The full range of relevant hydrogeological features such as fracking, faulting, structure, thickness, continuity, porosity, permeability, pressure and geochemistry are considered. Seismic monitoring undertaken reinjection and reinjection stopped if adverse consequences are noted.

TC26 – Solid waste stored in landfills

Solid waste storage should ensure that salts cannot be re-dissolved and leach into surface or groundwater at the landfill location.

TC27 – Characterisation and modelling of geology

Characterising the geological and geotechnical nature of the coal seams and surrounding strata.

TC28 – Monitoring for spills and/or leaks

Monitoring for acute or chronic leaks and, and spills. This includes leaks of air emissions and liquid material from holding and transport infrastructure and other equipment

TC29 – Produced water characterisation and testing

Measuring the baseline characteristics of produced water, and testing it over the time of extraction, including prior to reuse.

APPENDIX 2 REPRESENTATION AT RISK WORKSHOPS AND MEETINGS

Table 4: Organisations represented at risks workshops

AGL Energy Limited
APEX Australia
APPEA
Australian Nuclear Science and Technology Organisation (ANSTO)
Bureau of Meteorology
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Department of Earth and Planetary Sciences, Macquarie University
Department of Environment and Geography, Macquarie University
Department of the Environment, Office of Water Science (Cwlth)
Fell Consulting Pty Ltd
Fodder King
Geoscience Australia
Hunter Water Corporation
Magnum Gas and Power Limited
Metgasco
MidCoast Water
National ICT Australia
NSW Department of Planning and Environment
NSW Department of Primary Industries
NSW Environment Protection Authority (EPA)
NSW Farmers
NSW Food Authority
NSW Irrigators' Council
NSW Ministry of Health
NSW Office of Coal Seam Gas
NSW Office of Environment and Heritage
NSW Office of Water
Pells Consulting Pty Ltd
Pells Sullivan Meynink (PSM)
Rivers SOS
Santos Limited
School of Biological, Earth and Environmental Sciences, UNSW Connected Waters Initiative, UNSW
School of Civil and Environmental Engineering, UNSW
School of Earth and Environmental Sciences, University of Wollongong
School of Earth Sciences, The University of Melbourne
School of Environmental and Life Sciences, Newcastle University
School of Mining Engineering, UNSW Connected Waters Initiative, UNSW
Soil Futures Initiative
Sydney Catchment Authority
Sydney Water

Table 5: Organisations consulted in targeted meetings

AGL Energy Limited
APPEA
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Fell Consulting Pty Ltd
Halliburton
NSW Dams Safety Committee (DSC)
NSW Environment Protection Agency (EPA)
Queensland Department of Environment and Heritage Protection
PJC International Pty Ltd
Santos Limited
Schlumberger Limited
School of Biological, Earth and Environmental Sciences, UNSW Connected Waters Initiative , UNSW
School of Mining Engineering, UNSW Connected Waters Initiative , UNSW
School of Petroleum Engineering, UNSW