Submission
No 330

INQUIRY INTO COAL SEAM GAS

Name: Dr Stuart Khan

Date received: 9/09/2011

UNSW

DR STUART KHAN
SENIOR LECTURER
School of Civil
and Environmental Engineering

7 September, 2011

The Hon Robert Brown MLC
Committee Chair

General Purpose Standing Committee No. 5
Inquiry into Coal Seam Gas

Legislative Council
Parliament of NSW
Parliament House
Macquarie Street
Sydney, NSW, 2000

Dear Mr Brown,

SUBMISSION: INQUIRY INTO COAL SEAM GAS

Thank you for your invitation to provide a submission to this very important and timely inquiry. This submission relates to the Inquiry Terms of Reference item (1) The environmental and health impact of CSG activities, and most specifically to items (1a) "Effects on ground and surface water systems" and (1b) "Effects related to the use of chemicals".

1. MY BACKGROUND AND EXPERIENCE

I am a Senior Lecturer in the School of Civil & Environmental Engineering, where I undertake research and teaching activities in the fields of water chemistry, drinking water and wastewater treatment, environmental health risk assessment and sustainability. I also lead the research stream on trace organic chemicals in water at the UNSW Water Research Centre. I am a current member of the Water Quality Advisory Committee to the National Health and Medical Research Council (NHMRC). On that committee, I provide expert advice on many issues associated with water quality and health. The issue of coal seam gas activities and their potential impacts to existing and potential future drinking water supplies is of current interest to the committee.

2. KEY WATER QUALITY ISSUES

Poorly planned or managed coal seam gas (CSG) exploration or extraction activities pose considerable risks to both groundwater and surface water systems. Key water quality issues, from my own perspective, are listed below. Specific issues may be of greater or lesser significance for particular projects, but all of these issues should be thoroughly and transparently assessed for all proposed (or existing) projects.

- **Drilling through aquifers, impervious rock and coal seams risks 'interconnecting' otherwise confined aquifers.** In such circumstances, aquifers holding large volumes of pristine water can be contaminated by mixing with other contaminated waters. Many shallow groundwater systems in urban and rural areas are contaminated by industrial and agricultural chemicals. Some aquifers are highly saline and may contain naturally occurring toxic chemicals. Waters from coal seams are known to naturally contain considerable quantities of toxic chemicals including benzene, toluene, ethylbenzene, and xylenes (collectively known as 'BTEX'). Interconnecting isolated pristine aquifers has the potential to seriously impact future valuable drinking water supplies.
- **Extracting large quantities of water will lead depressurisation of groundwater systems.** The natural balance and direction of flow within aquifers is determined largely by pressure gradients, which are in-part determined by large volumes and masses of water trapped within confined spaces and under the influence of gravity. The extraction of large volumes of water will significantly impact pressure gradients. This is, to some degree, the intention of extracting this water, but the practise may have numerous detrimental impacts. In some cases, the underground direction of flow may be altered, which can lead to changes in water chemistry. Many surface water systems (observed as wetlands, ponds, lakes, or rivers) are supplied by waters that are continually expelled from pressurised aquifers, -this is what causes many of them to be 'perennial' systems, meaning that they continue to flow almost independently of current rainfall and surface run-off. However, depressurisation of an aquifer can lead to a reversal of this flow, with surface waters rapidly recharging shallow aquifers. In this way, pristine aquifers can quickly become contaminated. The concomitant reduced flow in the surface water systems can also lead to significant environmental water quality impacts. Serious

depressurisation of aquifers may also lead to subsistence of land above the aquifer and, consequently, changes in overland flow paths and fracturing in aquifers, thus increasing hydraulic connectivity.

- **Lowering of water levels in adjacent aquifers may affect water quality in those aquifers.** Exposure of naturally occurring minerals to an oxygen-rich environment may cause chemical change to the minerals that can affect solubility and mobility. Increased solubility will lead to increased salination of the water, and may also involve the mobilisation of toxic chemicals such as chromium, strontium, lead, iron, arsenic, fluoride and selenium. Bacterial growth may also be stimulated by lowered water tables, leading to taste and odour problems. Furthermore, aquifer depletion can lead to upwelling of lower quality water from deeper within an aquifer.
- **Extracted CSG waters present a significant risk to adjacent surface water and groundwater qualities.** The large volumes of water that must be extracted in order to recover coal seam gas have to be stored and ultimately disposed of. This may be a simple matter, except that CSG waters are typically highly contaminated by salt and toxic organic chemicals. Produced waters may be stored onsite in storage tanks or waste impoundment pits or holding basins. There is potential for releases, leaks, and/or spills associated with the storage or CSG waters, which could lead to the contamination of shallow drinking water aquifers and surface water bodies. Disposing of CSG waters directly to surface waters will significantly impact the quality of those surface waters, with deleterious ecological implications. Attempts to beneficially reuse extracted CSG waters (without treatment) for applications such as irrigation, pose risks to soil quality and shallow groundwater quality. It is entirely feasible to treat CSG waters to a very high quality (including a quality suitable to supplement drinking water supplies) using treatment techniques such as reverse osmosis. However, poorly managed discharge of reverse osmosis-treated waters to the environment may also pose a risk to some surface water systems by disrupting (diluting) natural mineral and nutrient compositions, essential for many aquatic ecosystems. Uncontrolled discharges to ephemeral streams will disrupt natural flow regimes with potentially significant ecological implications.

- **Concentrates and residuals from CSG water treatment pose risks to adjacent groundwaters and surface waters.** Extracted CSG waters can be effectively treated using water treatment technologies such as reverse osmosis. However, such treatment processes merely concentrate the salts and other contaminants, -they do not destroy them. The concentrated contaminant solution (known as 'concentrate' or 'brine') must still be disposed (Khan *et al.*, 2009). In inland environments, the most common and most economically viable approach is by evaporation in very large evaporation basins. Such basins need to be lined and very carefully managed to prevent seepage to the groundwater table. It is notable that the NSW Government has announced a ban on the use of evaporation ponds relating to coal seam gas (Hartcher, 2011). If maintained, this ban will clearly mitigate these potential problems. As an alternative to evaporation basins, salt crystallisation using thermal or mechanical vapour recompression crystallisers is possible. However, such processes are highly energy intensive and expensive to operate. The solid contaminated salts will still require disposal, but once the wastes have been significantly reduced in volume and mass, they can arguably be transported to another location for final disposal.
- **Reinjection of CSG wastewaters into other aquifers has the potential to contaminate those aquifers.** In some locations, extracted CSG waters are disposed of by 'deep well injection'. Such practices have the potential to destroy future opportunities for beneficial use of the native waters in the receiving aquifer.
- **Injection of fraccing fluids to coal seams may contaminate groundwater supplies.** In some CSG activities, fraccing is used to open up relatively tightly concealed coal seams in order to aid enhanced CSG recovery. Fraccing involves the pressurised injection of often complex solutions of chemical additives and proppants into the coal seam. Proppants are suspended particles that are used to hold fractures open after a hydraulic fraccing treatment, thus producing a conductive pathway that fluids can easily flow along. Sand grains or ceramic materials are commonly used proppants. Chemical composition of fraccing fluids is variable, but some generalised description is provided below. The ultimate fate of these chemicals will be dependent upon the degree to which

they are recovered from the coal seam. The fate of unrecovered chemical will be dependent upon their physical and chemical properties, but may include adsorption to solid materials, oxidation/reduction reactions, and aerobic or anaerobic biodegradation. Such processes will be both chemical- and aquifer-specific. However, insufficient information is currently available to provide accurate predictions of chemical fate in most circumstances.

- **Fraccing fluids are designed to alter the natural geochemical conditions, thus have the potential for mobilising other chemicals.** The injection of fraccing fluids may lead to changes in acid-base conditions (pH) and redox conditions (Eh) in aquifer environments. Such changes can lead to changes in speciation of groundwater and solubilisation of some minerals from previously stable aquifers. In some cases, this will lead to mobilisation of otherwise stable chemicals such as chromium, strontium, lead, iron, arsenic, fluoride and selenium. Detailed understanding of coal seam and aquifer geochemistry is required to effectively predict such changes. Very limited information is currently available for most Australian aquifer systems.

3. NATURALLY OCCURING CHEMICALS IN COAL SEAMS

Naturally occurring substances that have been found in hydrocarbon-containing formations include trace elements such as mercury, arsenic and lead. In some locations, radioisotopes such as radium, thorium and uranium may be present in significant quantities. A very wide range of naturally occurring organic chemicals can be expected, including organic acids and polyaromatic hydrocarbons. Much attention has been paid to the semi-volatile organic chemicals, benzene, toluene, ethylbenzene, and xylenes (collectively known as 'BTEX'). These chemicals include known human carcinogens, and therefore contamination of water supplies is of significant concern.

4. CHEMICAL CONSITUENTS OF FRACCING FLUIDS

Fraccing fluids may contain a wide range of chemical constituents, which vary from one operation to another. Much of the information regarding the identity and concentration of chemicals used in fraccing fluids is considered by the industry to be proprietary, and therefore confidential. However, various lists have been compiled, one of the most comprehensive being that recently published by the United Sates Environmental Protection Agency (US EPA, 2011). A brief summary of fraccing solution components and their intended purpose as provided in Table 1, which is also adapted from the US EPA (2011).

Table 1 Known types of components that may be included in some fraccing solutions (US EPA, 2011).

Component/Additive Type	Purpose	Example compound(s)
Proppant	Keep fractures open to allow gas flow out	Silica, quartz sand
Acid	Dissolve materials, initiate cracks in the rock	Hydrochloric acid
Friction reducer	Minimise friction between fluid and the pipe	Polyacrylamide, mineral oil
Surfactant	Increase the viscosity of the fluid	Isopropanol
Potassium chloride	Create a brine carrier fluid	
Gelling agent	Thickens the fluid to suspend the proppant	Guar gum, hydroxyethyl cellulose
Scale inhibitor	Prevent scale deposits in the pipe.	Ethylene glycol
pH adjusting agent	Maintain the effectiveness of other components	Sodium or potassium carbonate
Breaker	Allow delayed breakdown of the gel	Ammonium persulfate
Crosslinker	Maintain fluid viscosity as temperature increases	Borate salts
Iron control	Prevent precipitation of metal oxides	Citric acid
Corrosion inhibitor	Prevent pipe corrosion	N,N-dimethylformamide
Biocide	Eliminate bacteria	Gluteraldehyde

The often confidential nature of fraccing fluid compositions makes identifying the toxicity and human health effects associated with these chemicals difficult or impossible. However, chronic human toxicity has been associated with identified fraccing fluid constituents, such as ethylene glycol, gultaraldehyde and N,N-dimethyl formamide. Actual risks to drinking water qualities and to human health will be dependent on the precise use and management of the fraccing fluids and on consequential human exposure to the chemical components.

A recent review of chemical substances used during natural gas operations has recently been reported (Colborn *et al.*, 2011). The authors concluded that many chemicals used during the fracturing and drilling stages of gas operations may have long-term health effects that are not immediately expressed. The discussion provided in this paper highlights the difficulty of developing effective water quality monitoring programs. To protect public health, the authors recommend full disclosure of the contents of all products, extensive air and water monitoring, coordinated environmental/human health studies, and regulation of fraccing in the USA under the U.S. Safe Drinking Water Act.

5. NEED FOR CLEAR GUIDANCE ON ENVIRONMENTAL RISK ASSESSMENT FOR COAL SEAM GAS ACTIVITIES

Regulators and other decision makers in NSW are faced with a severe lack of guidance, support, knowledge and experience for assessing and overseeing the safe management of CSG activities in this state. It is essential that the NSW environment and health agencies play effective roles in assessing all future CSG proposals and that they be equipped with the skills and resources to do so. My own experience and interactions with these two agencies (both before and after the departmental restructuring that succeeded the 2011 NSW State election) has convinced me that neither is currently properly resourced for this role.

In order to properly resource Australian environmental and health decision makers, I believe that comprehensive national guidelines for risk assessment of coal seam gas activities are essential. Such guidelines should be developed by an inclusive panel of experts, with sincere opportunities for effective stakeholder and community consultation. Essential expertise would include chemical toxicology, hydrology, resource extraction, drinking water management, risk assessment, occupational health and safety and environmental protection. In addition to the development of national guidelines, comprehensive training courses should be made available for regulators and decision makers in this area.

Government funding for environmental and health regulatory agencies should be reviewed and increased to ensure that sufficient personnel can be devoted to the rapidly increasing demand and need for assessment of coal seam gas related proposals.

6. NEED FOR CONSIDERATION OF 'HAZARDOUS EVENTS' IN ALL RISK ASSESSMENT ACTIVITIES

Australia has important national guidelines for the assessment of human health risks from environmental hazards (enHealth Council, 2002). These guidelines are commonly referred to as the 'enHealth guidelines' and are consistent with the human health risk assessment framework that was pioneered by the US National Research Council nearly three decades ago (National Research Council, 1983) and now used (in adapted form) throughout the world. While the importance of this framework and the general approach are not in doubt, it is arguably insufficient for properly assessing risks associated with CSG extraction or exploration activities.

The enHealth framework requires the identification and characterisation of "hazards", which in this case applies to potentially toxic chemicals. The assessment of dose-response relationships of the chemicals, in conjunction with assessment of their expected levels of exposure are used to determine the risks associated with specific hazards (chemicals). However, an important consideration for CSG activities, which is not adequately addressed by the enHealth guidelines is that of potential 'hazardous events'.

It is arguable that the true risks associated with CSG activities are not those that can be identified according to when the activities are being undertaken in a manner in which they are proposed. On the contrary, the true risks are associated with unintended circumstances, such as extreme weather events or human errors or misjudgements. As an example, large CSG operations, especially those involving fraccing require extensive quantities of chemical substances to be present on site. This chemical storage creates risks of accidental releases, such as spills or leaks. Surface spills or releases can occur as a result of tank ruptures, equipment or surface impoundment failures, overfills, vandalism, accidents, fires or improper operations. Released fluids may flow into a nearby surface water body or infiltrate through the soil to the groundwater. Risks associated with such events are likely to be considerably greater than risks associated with normal operations in the absence of any hazardous event.

Accordingly, any risk assessment that only considers conditions associated with normal operations, without comprehensive assessment of potential hazardous events will severely underestimate the true environmental and human health risks associated with the operation.

Other potentially significant hazardous events for CSG activities include the unintended faulting or fracturing of an aquifer, and the unanticipated release of naturally occurring toxic chemicals.

The incorporation of hazardous events in risk assessment (and risk management) is most effectively addressed by the Australian Drinking Water Guidelines (National Water Quality Management Strategy, 2004) as well as the Australian Guidelines for Water Recycling (National Resource Management Ministerial Council & Environment Protection & Heritage Council, 2006). Accordingly, the consultation of these guidelines should be mandatory for the assessment of all CSG proposals and activities, until dedicated national CSG risk assessment guidelines can be made available.

7. WHOLE WATER TOXICITY TESTING / BIOANALYTICAL TECHNIQUES

The range of natural endogenous chemicals that may be present in coal seams is diverse and far from fully characterised. Furthermore, fraccing and other CSG extraction activities have the potential to change the chemical conditions within aquifers, potentially leading to chemical reactions and the formation of new chemical substances. Complex mixtures of chemicals in CSG waters are highly unlikely to be fully characterisable in terms of their chemical composition, and therefore the human health risks associated with these chemicals remain uncertain.

An alternative approach to the characterisation of risks associated with complex mixtures of chemicals is by the employment of bioanalytical techniques. Bioanalytical techniques involve the direct toxicity testing of whole water samples. A rapidly increasing range of *in vitro* bioanalytical tests have become available during the last decade and increasingly being applied to the assessment of alternative water sources such as recycled water (Chapman *et* *al.*, 2011). It is recommended that the assessment and uptake of bioanalytical techniques for the characterisation of whole water solutions of CSG waters be immediately investigated.

8. NEED FOR BACKGROUND ENVIRONMENTAL QUALITY ASSESSMENT PRIOR TO ANY CSG ACTIVITY

It is essential that any water quality monitoring that is proposed to be undertaken to assess the impacts of any CSG activities, be initiated well before the CSG activities begin. Such monitoring must be designed to capture a detailed description of the current condition of the water body including natural geographical and temporal variability. Only with this 'background' monitoring can the results of later monitoring studies be effectively interpreted and impacts identified. All monitoring programs should be designed with careful reference to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) and the Australian Drinking Water Guidelines (National Water Quality Management Strategy, 2004).

9. NEED FOR IMPROVED HYDRAULIC DATA

Hydraulic data to understand the connectivity and potential changes to connectivity between aquifers in most areas of Australia is a fundamental information gap. Research to improve our national knowledge base in this area is urgently required.

10. PAYMENT OF A REFUNDABLE BOND BY CSG PROPONENTS

In cases were a reasonable degree of uncertainty exists regarding the potential environmental impacts of proposed CSG operations, the payment of a refundable bond may be a useful approach to ensuring that funds are available for necessary environmental remediation work. Such a bond could be required to be paid prior to proceeding with any activities and made available for refund once any environmental impacts are demonstrated to have been limited to acceptable (agreed) levels. The value of such a bond should be sufficiently great so as to meet the costs of major environmental remediation projects. All or part of the bond would be retained in order to cover such costs when demonstrated to be appropriate.

11. RECOMMENDATIONS FOR THE INQUIRY COMMITTEE

The following recommendations are provided for consideration by the Committee:

10.1. Recommend that the development of national guidelines for risk assessment of CSG activities be initiated by the formation of a steering committee to oversee the process.

10.2. Recommend that a comprehensive training course be developed for NSW decision makers with responsibilities to assess the potential environmental and human health risks of CSG activities.

10.3. Recommend that all chemical components of fraccing fluids and other substances used in CSG activities be subject to full public disclosure during the planning and assessment stage of any proposal.

10.4. Recommend that all CSG environmental and health impact assessments systematically consider impacts and risks associated with each of the individual chemical constituents of fraccing fluids that may be used.

10.5. Recommend that all CSG environmental and health impact assessment be required to include a comprehensive analysis of potential hazardous events.

10.6. Recommend that the use of whole water toxicity testing (bioanalytical techniques) be urgently investigated for application to CSG environmental risk and impact assessment.

10.7. Recommend that all potentially impacted water bodies be subject to detailed 'background' water quality assessment prior to the initiation of any CSG activities.

10.8. Recommend that detailed hydraulic assessment be undertaken in any coal seam/aquifer systems proposed for CSG activities. This assessment should establish, as far as possible, the connectivity and any potential changes to the connectivity between aquifers.

10.9. Recommend that proponents of CSG activities be required to pay a refundable bond of sufficient value to meet the cost of potential environmental clean-up or remediation activities, should unanticipated environmental impacts occur.

I hope that you will find my submission to this inquiry to be of value and interest to the Committee. Furthermore, I would be very happy to provide any required clarification or additional information that may be requested.

I wish the committee well in the important task ahead of them and look forward to reading the outcomes of this inquiry.

Yours sincerely,

Dr Stuart Khan

Senior Lecturer,
School of Civil & Environmental Engineering.

REFERENCES

ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines (Chapters 1-7). Commonwealth Department of the Environment and Heritage, Canberra.

Chapman, H. F., Leusch, F. D. L., Prochazka, E., Cumming, J., Ross, V., Humpage, A., Froscio, S., Laingam, S., Khan, S. J., Trinh, T. and McDonald, J. A. (2011) A National Approach to Health Risk Assessment, Risk Communication and Management of Chemical Hazards from Recycled Water, Waterlines Report Series No 48, National Water Commission, Canberra. ISBN: 978-1-921853-19-7.

Colborn, T., Kwiatkowski, C., Schultz, K. and Bachran, M. (2011) Natural gas operations from a public health perspective. *International Journal of Human and Ecological Risk Assessment,* In Press.

enHealth Council (2002) Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards, Department of Health and Ageing and enHealth Council, Canberra.

Hartcher, C. (2011) Media Release: NSW Govt has listened and acted: Tough new conditions for coal and coal seam gas. The Hon Chris Hartcher, Minister for Resources and Energy, Government of New South Wales.

Khan, S. J., Murchland, D., Rhodes, M. and Waite, T. D. (2009) Management of concentrated waste streams from high pressure membrane water treatment systems. *Crit. Rev. Env. Sci. Tech.,* **39**(5), 367-415.

National Research Council (1983) Risk Assessment in the Federal Government: Managing the Process. National Academy Press, Washington, DC.

National Resource Management Ministerial Council and Environment Protection &

Heritage Council (2006) Australian Guidelines for Water Recycling: Managing Health & Environmental Risks (Phase 1).

National Water Quality Management Strategy (2004) Australian Drinking Water Guidelines. National Health and Medical Research Council, Natural Resource Management Ministerial Council - Government of Australia, Canberra.

US EPA (2011) Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, United States Environmental Protection Agency, Office of Research and Development.