Submission to Victorian Parliamentary Inquiry into Unconventional Gas

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Background & qualifications (full academic CV available on request)

I am an academic at RMIT conducting teaching and research in hydrogeology (ground water science). I hold a PhD in groundwater chemistry and have four and a half years' experience as a lecturer, teaching courses about groundwater to 3rd and 4th year engineering and science students. I also supervise three PhD projects on groundwater quality. I am currently being funded by the Victorian State Government (through the Department of Environment Land Water & Planning) to conduct research into the baseline groundwater chemistry in major Victorian aquifers that have been proposed as potential targets for unconventional gas activity (Gippsland and Otway Basins). My preliminary report for that research has been submitted to the department and is available on request. For these reasons, I feel qualified to provide expert opinion to the inquiry (and I would be happy to appear at any public hearings).

Risks to groundwater and the environment from unconventional gas

There are a number of potential risks to the environment (particularly groundwater and surface water) and human health from unconventional gas, and these have been the subject of intense worldwide debate over the last 5 years (Vidic et al, 2013; Vengosh et al, 2014; US EPA, 2015). The following is a brief international review of academic literature related to these risks.

The extraction of unconventional gas from shale, coal and other sedimentary rocks requires either groundwater extraction ('de-watering'), or hydraulic fracturing to release gas trapped under pressure. Gas extraction is therefore associated with either extractions of large volumes of water (particularly for coal seam gas, e.g., Biggs et al, 2012) or the need to source a water supply from the nearby environment (this mostly applies to shale and tight gas, see US EPA, 2015). Since 2010, a growing body of research has been carried out worldwide (particularly in the United States) to understand the risks and impacts to the environment and human health associated with these and other aspects of unconventional gas development. The main risks are:

a) Risk of increasing stray or 'fugitive' gas into shallow aquifers and/or the near surface atmosphere
b) Pollution risks associated with spills of 'flow-back' or 'produced' water that is generated during hydraulic fracturing and/or gas well development (note that 'produced' waste water is generated from coal seam gas mining regardless of whether hydraulic fracturing is employed or not, and is a pollution risk in most unconventional gas developments)
c) Risk of increasing pathways for fluids (including potential contaminants) to travel between different geological layers, for example from coal seams into important groundwater or surface water bodies.

Each of these risks is reviewed further below, based on a survey of the recent research literature:

a) Fugitive gases to shallow aquifers and the atmosphere

When a gas reservoir is disturbed by drilling, hydraulic fracturing, de-watering or a combination of these, gas may potentially migrate from the reservoir to other parts of the sub-surface, such as aquifers above the gas deposit (which may be used for water supply), and/or the surface atmosphere. There is now clear evidence that fugitive methane has migrated from deep gas reserves into shallow water supply wells in parts of the US, such as the Marcellus shale in Pennsylvania and the Barnett shale in Texas, due to shale gas development in these areas (US EPA, 2015; Darrah et al., 2014; Osborn et al., 2011; Jackson et al., 2013a).

Osborn et al, (2011) was the first high-profile study to document this impact. The basis of their findings was examination of dissolved methane concentrations, isotopes of methane ($\delta^{13}C_{CH4}$ & $\delta^{2}H_{CH4}$) and higher chain hydrocarbons (ethane and propane) in groundwater from areas close to (<1km) and far from (>1km) major areas of hydraulic fracturing. This study, and follow up work by Jackson et al (2013a) determined that water wells close to hydraulic fracturing activity contained significantly elevated methane (and ethane) concentrations compared to those outside areas of hydraulic fracturing activity.

This work was challenged (e.g., by Saba and Orzechowski, 2011; Schon, 2011; Davies, 2011) who argued that the gas industry deliberately targets areas that are naturally high in methane for gas extraction, and so the correlation observed in these studies does not prove *causation* due to hydraulic fracturing. Following this, Darrah et al, (2014) showed that in wells sampled in the Marcellus Shale (Pennsylvania) and Barnett Shale (Texas), there was evidence of increasing methane over time in areas of hydraulic fracturing. They also found distinctive gas compositions which finger-printed fugitive gases in certain water samples. The observed compositions could only be explained by rapid migration of gases from deep formations below into shallow wells, as a result of shale gas development.

The mechanism by which gas migrates into shallower aquifers as a result of hydraulic fracturing has been explored in a number of studies (e.g. Jackson et al, 2013b; Vengosh et al, 2014) and include:

1. Leakage of stray gas originating in deep formations along poorly sealed gas production wells (see Figure 1 below, taken from Bair, 2010).

2. Leakage of gas along legacy/abandoned water, oil or gas wells which create a connection between geological formations

3. Migration of gas from deep reservoirs along fractures and faults, which may be enhanced by hydraulic fracturing

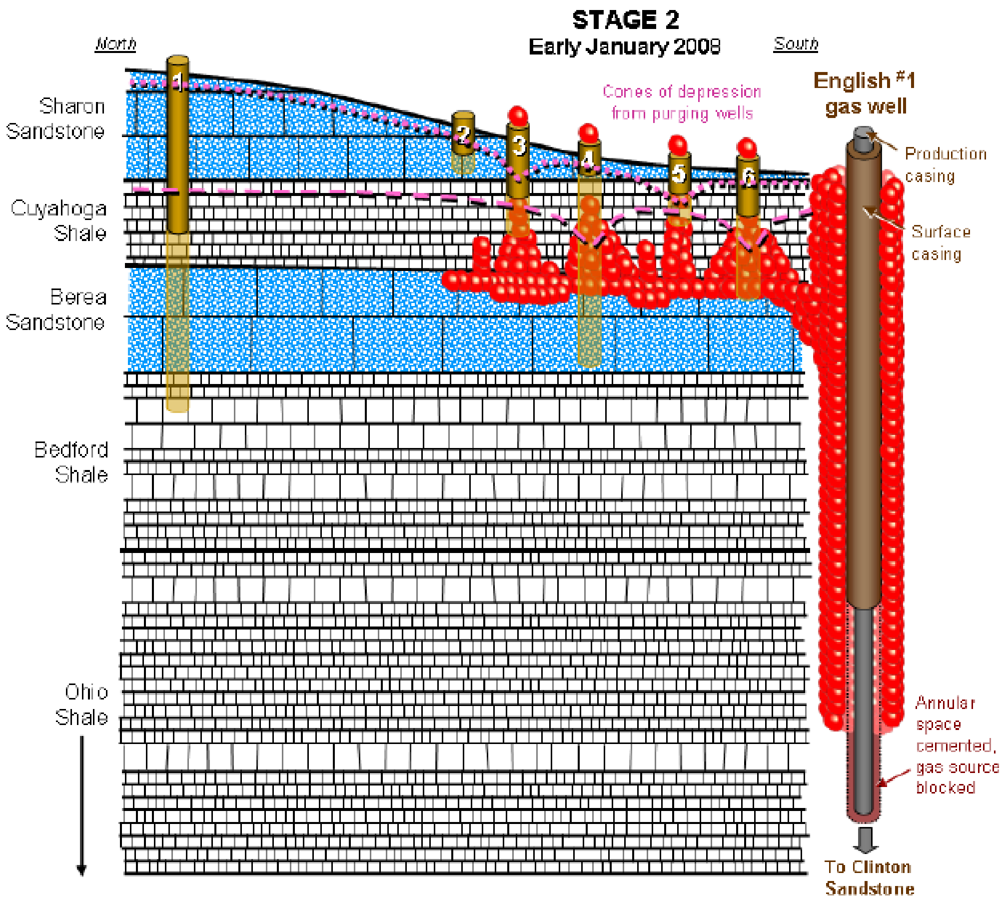

Figure 1: Schematic diagram showing the mechanism of gas contamination of shallow aquifers, based on case study in Ohio (Bair, 2010).

Of these mechanisms, the strongest evidence to date is for 1 & 2; the migration of gas along poorly sealed wells (Fig 1; Bair, 2010; Darrah et al, 2014; Vengosh et al, 2014; Jackson et al, 2013b). This underscores the importance of proper well construction, maintenance and full life-cycle care for gas, oil (and water) wells in areas of unconventional gas.

Proponents of the unconventional gas industry argue that with adequate controls and protocols on well construction and maintenance, problems of this nature can be avoided. However, Jackson et al, (2013b) cited petroleum industry data which showed that in some areas of intensive oil and gas production (e.g. Alberta, Canada; Gulf of Mexico, U.S.), on the order of 5 to 20% of historically drilled wells show evidence of poor seals and therefore may act as pathways for gas migration. The risk of this pathway increases with both the number of wells drilled and with the time since drilling and development took place. Whether all wells (water, gas, oil, active, inactive, abandoned) can be effectively monitored and prevented from acting as pathways for methane contamination in a given area of mining is a question of critical importance to the future viability of the onshore gas industry worldwide. There are serious doubts about whether well-integrity can be ensured for long enough periods of time and in a large enough number of wells to prevent gas migration and contamination over the long-term.

Other issues associated with uncontrolled gas releases resulting from accidents during well construction have also been documented. A major incident involving uncontrolled methane release into shallow groundwater wells occurred due to a well 'blow-out' in Bainsbridge, Ohio

(US EPA, 2015; Bair et al 2010), affecting private water wells in the township. Such incidents underscore that even when good procedures are followed and maintained by most of the industry, accidents can and do happen, and these can have detrimental impacts on human and environmental health.

Fugitive methane to the surface atmosphere

In addition to risks of contaminating water supply aquifers with gas, emissions of methane to the atmosphere may increase as a result of hydraulic fracturing or gas development generally. Methane is a potent greenhouse gas, and any increases resulting from unconventional gas require careful monitoring. Howarth et al, (2011) proposed that fugitive methane to the atmosphere was increased by shale gas development, and that rates of fugitive methane due to well, pipeline and other leaks were under-estimated by national inventories of greenhouse gases.

Subsequently, a number of studies looked to quantify fugitive methane to the atmosphere in areas inside and outside unconventional gas fields, including Australian coal seam gas fields (e.g. Kort et al, 2014, Leifer et al, 2013; Maher et al, 2014; Day et al, 2014).

In Australia, Maher et al (2014) monitored near-surface methane concentrations in northern New South Wales and southeast Queensland, comparing areas within coal seam gas development (the Tara gas field) with areas outside gas fields. They showed that near surface methane concentrations were elevated in coal seam gas fields (up to 6.5 parts per million, and consistently above 2ppm) relative to areas of no coal seam gas development and similar geology. Possible explanations are either increases due to leaks around gas well production and collection infrastructure; increased soil gas emissions, or de-gassing from produced water stored in above ground ponds containing dissolved methane.

Follow up work by Day et al., (2014), examined gas leaks in some of Queensland’s coal seam gas fields, using similar technology. They targeted gas production wells and pipelines, looking to identify leakage to the atmosphere. They found that the majority of operating CSG wells showed little or no evidence of any methane leakage, and that in general gas contents were at background atmospheric levels. However, one well was identified with increased levels, associated with a valve on the production well which periodically vented methane.

Radon and other hazardous gas emissions

A recent study conducted in the United States by Casey et al, (2015) examined large numbers (nearly 1 million) of measurements of radon gas (Rn^{222}) from the basements of houses situated above the Marcellus Shale, where hydraulic fracturing has been extensive. They found that there was a statistically significant increase in levels of radon in basements above areas of hydraulic fracturing compared to areas without shale gas development, posing a potential lung cancer risk. Increased levels of radon into basements as observed in this study indicates an increased overall flux of soil gas from underlying geology to the surface in areas of hydraulic fracturing. This indicates that hydraulic fracturing has an impact on the transport of gases from underground to the surface.

These findings are consistent with work carried out in Australia by Tait et al, (2013) who also showed that areas of intensive coal seam gas development (e.g. Tara gas field, Surat Basin) in Australia were characterized by higher fluxes of radon, as well as CO_2 from soil gas.

b) Pollution risks associated with ‘flow-back’ or ‘produced’ water

During unconventional gas development, large volumes of waste water are produced. This comes from one or both of the following sources:

- Water injected into the well at high pressure during hydraulic fracturing which then returns back to the surface (‘Flow back water’)
- Water extracted from the coal or other geological formations in order to reduce pressure and release gas from the deposit to the surface in wells (‘produced water’).

This water is a waste product which requires careful management, as it is usually highly contaminated. It poses a risk to surface water and shallow groundwater systems located close to where the water is produced and stored. This is in my opinion the biggest risk associated with unconventional gas production at present in Australia. There is a growing body of evidence that significant impacts to the environment are associated with flowback and/or produced water, both in Australia (e.g. see Currell, 2014; Khan and Kordek, 2014; Hannam, 2015), and internationally (Warner et al 2013; US EPA, 2015).

For shale gas, there are three major issues associated with water used in hydraulic fracturing: 1. a local water source must be found for conducting the fracturing, and in some cases this creates conflict with existing users; 2. during mixing and preparation of the ‘frack water’, there is the potential for spills and accidents which can contaminate the site of the well; 3. When the water comes back to the surface following hydraulic fracturing, this water is contaminated and needs to be managed on and off-site until it is returned to the hydrological cycle (usually following treatment).

The recent US EPA analysis of unconventional gas’s impacts on drinking water in the US estimated that while water requirements per well were often significant (on the order of 5ML per well), water shortage/conflicts due to unconventional gas were rare in the US except for some particularly water scarce regions.

Significantly the report also noted that spills of ‘frack water’ were relatively widespread across the United States, occurring at a rate of between 0.4 and 12.2 spills per 100 wells. Given approximately 30,000 new wells were drilled and fracked in the US between 2011 and 2014, this means thousands of pollution incidents have probably taken place over this period (US EPA, 2015).

Volumes of wastewater produced from gas development are typically larger for coal seam gas wells than other unconventional gas types (shale gas, tight gas). For example Queensland Government statistics indicate that the total volume of produced water from CSG wells in the Bowen and Surat Basins in the 12 months from June 2013 to June 2014 was 26.7GL, a significant volume with major implications for wastewater treatment and disposal, and catchment salt balances (Biggs et al, 2012). This compares to lower (but still significant) amounts of water produced from shale gas (e.g. Warner et al, 2013; US EPA).

Unconventional gas waste water usually contains high levels of hazardous contaminants which are either associated with:

a) natural elements found within coal seams or shale beds

b) fluids used during hydraulic fracturing and brought back to surface as ‘flowback’

Contaminants typical of produced water from coal seam gas include high levels of heavy metals, radio-nuclides (radium, barium, uranium and thorium); high levels of salinity (e.g., total dissolved ion contents of >5g/L, in some cases up to 30g/L); high levels of ammonia and fluoride (up to 10 mg/L), organic carbon, sulphides and sulphate reducing bacteria (APLNG, 2012; Biggs et al, 2012; Kahn and Kordek, 2014).

Contaminants typical in 'flowback' water produced by shale or tight gas hydraulic fracturing include salts, acids (hydrochloric and acetic acid) organic chemicals (biocides, gelling agents, surfactants and corrosion inhibitors), caustic soda and other additives used to control the density and viscosity of the fluid (e.g. Halliburton, 2015). Shale formations usually also contain saline formation water, which in some cases contains high levels of radionuclides such as radium and strontium (Warner et al, 2013), and this mixes with fluids used in hydraulic fracturing before returning to the surface as flow-back.

In Queensland and New South Wales there are some policy arrangements and infrastructure which have been developed in recent years in an attempt to manage the large volumes of produced water from CSG (e.g. Biggs, 2012), however there still exists a large gap between the ideal scenario –involving the safe storage and treatment of all production water to a high quality before selling water to nearby water users – and the reality of how this water is actually managed in practice, which often involves:

-Extended periods of storage in dams, which can be subject to leaks, spills and overflows, that can contaminate groundwater (e.g. Khan and Kordek, 2014);

and/or

-Disposal into waterways or sewers, which occurs in contradiction to the wishes of environmental regulators such as EPAs (Hannam, 2015).

The recent controversy over AGL's Gloucester coal seam gas project is illustrative on this issue:

- Contaminants were found in the flow back water produced from AGL's four pilot wells that were hydraulically fractured at Waukivory, with levels of some contaminants (BTEX, Monoethanolamine, THPS) found exceeding ANZECC guideline values (AGL, 2015).
- The company spent many months trying to find a water utility willing to accept this wastewater under a trade waste agreement, and were refused repeatedly by Hunter Water and Mid Coast Water, due to concerns that high volume of water would create excessive pressure on treatment plant capacity (Hannam, 2015).
- Eventually, water was disposed of through the sewer system at Newcastle. This type of disposal option is considered to be of low desirability by the EPA, and it is not sustainable for large volumes of water that can be expected to be produced at a major gas field.

In my opinion AGL should have determined exactly how the water was going to be stored, treated, and/or re-used, and obtained agreement from all parties involved before they were allowed to conduct any hydraulic fracturing at the site, and this should apply to any unconventional gas development. Clear plans for whole of cycle management of produced water or flow-back water and any associated wastes (e.g. brine produced during treatment of produced water using reverse osmosis) must be a pre-requisite of any approved activity.

Even in cases where water treatment facilities exist to improve the quality of produced water, discharge to the environment of treated water can still introduce contaminants (such as radium and barium) and have detrimental environmental impacts (e.g. Warner et al, 2013). Research which I have supervised at RMIT (Duncan et al, 2014) found that it is extremely difficult to find an appropriate beneficial use and/or disposal method for CSG wastewater that can match the volumes, quality and timing of water production to the needs of the receiving environment. Treatment plants may not always be equipped to deal with high levels of certain contaminants and some, such as boron, are resistant to treatment by reverse osmosis for example. Reverse osmosis plants themselves also produce waste (brine) which also requires safe storage and disposal, so treatment is not a simple 'silver bullet' solution to the problem.

Kahn and Kordek published a report in 2013-14 for the New South Wales Chief Scientist and Engineer on CSG produced water and environmental problems associated with it, documenting the occurrence of numerous incidents of uncontrolled release of coal seam gas wastewater into the environment in Australia, and there is similar research emerging elsewhere worldwide (Warner et al, 2013). Given that CSG production water is far from reaching peak volumes in Australia and that amounts are likely to significantly increase (by at least an order of magnitude) over the next decade, I have serious concerns about the management of this water given the already high number of pollution incidents.

c) Risk of increasing pathways and connections for fluids (including potential contaminants) to travel between different geological layers

While there is still little evidence to date of hydraulic fracturing leading to regional scale mixing of saline and fresh groundwater bodies from different depths or major contaminant migration along fracture/fault zones, the capacity to detect and document these impacts is limited by observation data and monitoring techniques.

This is because of the long times-lag that exists in many groundwater systems, which mean that an impact in one place may not be seen at another location for a significant period of time (decades or longer in some cases, e.g., Currell et al, 2015). Unconventional gas is often extracted in very deep sedimentary basins, where naturally the groundwater flow paths and travel times are very large (thousands of years). Therefore, in many cases it is too early to say whether effects such as regional depressurisation of coal seams may be leading to large scale cross-flow of contaminated fluids to areas where negative impacts may be felt – such as shallow water supply aquifers or springs, wetlands and river systems connected to the groundwater.

Modelling by Gassiat et al., (2013) indicated that there was potential for shale gas brines and associated contaminants to migrate to shallow aquifers over long time scales as a result of hydraulic fracturing, but only under very particular geological circumstances. This work was also challenged by the gas industry as the modelling parameters used contained significant uncertainty.

Unconventional gas in Victoria

Two predominant areas of Victoria have been proposed as potential areas of future unconventional gas development; the Gippsland and Otway basins:

The **Gippsland Basin** is a major sedimentary sequence containing significant coal, oil, gas and water resources, which are the subject of inter-sector conflicts. The Strzelecki Group (a series of marine shales, sandstones and other sedimentary rocks) is a known target for potential future gas exploration in the Gippsland basin. Pilot drilling and hydraulic fracturing tests were conducted in gas wells drilled to depths between 1469 and 2106m in the formation between 2004 and 2009 by Lakes Oil NL, a Melbourne Based oil and gas exploration company. These tests indicated potentially economically recoverable quantities of gas and oil from the wells, which are located in the Wombat gas field, in the Seaspray region in PRL2 (Energy News Bulletin, 2005; Lakes Oil, 2009; Lakes Oil, 2012). Lakes Oil also hold Petroleum Exploration Permit 166 in the basin, and have expressed interest in drilling further test wells in the La Trobe Valley and Central Gippsland areas according to information on their webpage. However, they have faced strong community opposition, due to potential impacts of expanding their activities on the valuable land, water and environmental assets.

Significant quantities of gas are known to occur within the Cretaceous rocks of the Waare, Eumeralla and Pretty Hill Formations in the onshore **Otway Basin** (Mehin & Link, 1994). Gas has already been extracted from conventional reservoirs in the onshore basin in the Port Campbell area. Lakes Oil have also expressed interest in further exploration of gas in the Cretaceous rocks of the Otway Group, and currently hold petroleum exploration licenses 163 (Anglesea region) and 169 (Port Campbell region). Origin Energy are also currently drilling a gas well in the onshore basin.

In both of these basins, the target rocks for gas development occur underneath significant water supply aquifers of the Lower Tertiary (La Trobe and Dilwyn Aquifers). These aquifers provide important sources of water for agriculture and domestic use (for example, many of the regional centres in southwest Victoria are dependent on groundwater for supply, managed through Wannon Water). Depending on location in the two basins, the degree of separation between the gas bearing rocks (of Upper Mesozoic age) and productive aquifers (of Lower Tertiary age) can be quite limited (on the order of 100s of meters).

Through the research project I am overseeing at RMIT through DELWP Victoria, I have been involved over the past 12 months in compiling:

a) Information on the geology, hydrogeology and groundwater conditions in these two basins, based on review of all published data and academic literature
b) A baseline groundwater sampling program designed to determine current groundwater quality, including baseline contents of methane and other dissolved gases in groundwater.

The full report is available on request from the Department.

Conclusions & recommendations to the inquiry

There are significant environmental risks associated with unconventional gas development, which should be carefully considered when deciding whether or not an unconventional gas industry should be allowed in Victoria. These primarily include fugitive methane and produced wastewater impacts. The following are some key findings:

1. The US EPA data recently showed that it is very difficult to completely avoid pollution incidents associated with flow-back or produced water if significant unconventional gas development occurs,

and that this has impacts on shallow groundwater and surface water. Similar issues are faced in areas of Australia where coal seam gas development has been significant.

2. Similarly, the US experience shows that fugitive gas migration – while not widespread throughout all regions of unconventional gas – does occur, and particularly this happens due to migration along faulty wells or legacy/abandoned wells. If large numbers of wells are drilled, it is very difficult to ensure that all wells in an area of gas development that may act as conduits can be accounted for and managed over the full life cycle of a gas development.

3. In the Gippsland and Otway basins in Victoria (most prospective regions) gas deposits are mostly located deep in the basins in Cretaceous aged rocks. These rocks are overlain by important groundwater resources of the Lower Tertiary aquifer (Dilwyn and La Trobe Group aquifers) which are significant water resources. In some areas there is not a large amount of vertical separation between these potential target rocks for gas, and the lower tertiary aquifer, leading to possible increased risk of impact (as opposed to where there are significant thicknesses and intervening aquitards between water resources and gas deposits).

4. Fugitive methane emissions to the atmosphere are a greenhouse gas concern. Studies of fugitive gas emission to the atmosphere from Australia and the United States indicate that there may be increased fluxes of GHGs, as well as other gases (like radon) associated with unconventional gas. Life Cycle Assessments have also indicated that future 'high gas' scenarios for the world's energy mix may have limited benefits in terms of climate change mitigation (McJeon et al., 2014)

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