

WA Fracking Inquiry 2018

Comments on Appendix 6 -- Water

by Humphrey Boogaardt

iii **Comments on Findings** !!! :

One of the problems I have with the Fracking Inquiry Report (FIR) is that it raises, discusses and describes all the overall issues, but then basically makes findings and recommendations based on the impacts on one well. It is like writing a report about a scenario when a person walks into a swarm of angry bees. Describing and assessing all stings, then as conclusion just noting the impact of one bee-sting. Not taking into account the total impact of all the bee-stings on the person. Differently described by someone else that the report is using the “gangster argument : There are many murders, so one extra murder does not matter”.

In the “finding” the words like “low” risk are used. It would be expected that for clarity that there is a **classification of what terms like “low risk” mean. That is an omission in a scientific process.** For example, even in the recent court case in The Netherlands of The Dutch State against Urgenda (environmental group), in the verdict the court always specified percentages of risk in brackets when terms like “likely” where used. All based on IPCC reports, for example the wording “more likely than not” is equal to “chance of more than 50%”.

As said the report notes the risks of mishaps of the various issues as small, low or negligible, and then concludes that the overall risks are low. In these individual findings conclusions are drawn on small issues without linking it to others. This a **misleading use of statistics**, because the risks of all the different aspects of fracking are additive; and not very scientific. To illustrate this point using some arbitrary percentages, let’s have the scenario of a cyclist riding along a busy highway full of road trains. Chance of accident is 1% during a clear day. The darkness of the night gives a 1% risk. The cyclist does not have any lights on his bike, 1% risk. The heavy rain is a 1% risk. The FIR would conclude that the cyclist at night without lights in the rain along the highway has a 1% risk of accident. A “real” scientific report would conclude that the risk would be 4%. This is an incorrect use of statistics. This is a problem throughout the whole of the inquiry.

The FIR describes very well the (hydro)-geological settings of WA, it forms a good overview. From a hydrogeological viewpoint fracking maybe safe. However, data from the oil and gas industry itself (as discussed in my fracking submission; see attached) show an increasing rate of leaking of gas wells when they get older. On top of that is the problem of exploiting shale gas wells, very many wells have to be drilled. Every time an aquifer will be intersected there is a chance of leakage problems. To illustrate this with an analogy, ask any roof plumber the chance of a corrugated metal roof will be leaking. Comparing it with the same roof but now with one extruding vent, after that comparing it with the same roof but now with 10 extruding vents. Their answer will certainly be “the roof with 10 vents”, and adding “every hole cut into a roof for a vent needs to be sealed and adding increased chances of leaking”. That is the same when drilling through aquifers; and when comparing

conventional gas exploration with exploitation of unconventional shale gas. The number of fracked wells is hundreds of times higher than for conventional drilling. For example, in rough figures, the Canning Basin is 430,000 km²; assuming a 10% prospectively for the basin that means an area of 43,000 km². A fracked well covers at most 10 km². To frack the prospective area 4,300 wells are needed. Using conservative numbers like these it is obvious that the total volumes of emissions will be enormous.

Below comments listed according to page number in the report, text extracted from report in italics.

P102 :

"..., despite the significant increase in knowledge gained from systematic groundwater investigation over the last 60 years (Allen 1997). Many of the submissions to the Inquiry referred to Western Australia as 'the driest state', or even 'our State is one of the driest places on earth' ..."

The amount of groundwater resources have nothing to do with if WA is the 'driest state'

"The sandy soils common to the Perth and Canning Basins provide a pathway for pollutants to reach and contaminate groundwater, and there is a legacy of contamination plumes from industry, horticulture and septic tanks in the Perth area."

"Groundwater supports culturally and ecologically important wetlands on the Swan coastal plain and the Canning Basin, as well as contributes to the maintenance of Fitzroy River wetlands in the dry season."

P267

"A low level of trust was expressed by participants concerning the adequacy of regulations, observance by petroleum companies, and the ability of government to enforce them both during operations and over the long term, post-abandonment."

That **low level of trust** is the result of companies like Exxon and Shell knowing for nearly 50 years about the climate impact of fossil fuel emissions. Then hiding this information and even worse actively campaigning against climate change. There has been no apology from either of them no a real change of action. It is a bit rich to expect that the public now trusts gas companies.

P102

"Groundwater in the Perth and Canning Basins has been shown by carbon dating to flow slowly, typically at rates of a few metres (m) per year. Discharge from the aquifers in the Perth Basin is mostly offshore, though there is minor inland spring discharge. Discharge from aquifers in the Canning Basin supports dry season flows in the Fitzroy River. Over most of Western Australia, annual evaporation far exceeds annual rainfall. Salts in rainfall are concentrated by evaporation from vegetation and the soil zone, hence groundwater in Western Australia generally has a significant salt content. Salt content typically increases along the groundwater flow path. ..."

P267

"Groundwater along the eastern margin of the Perth Basin is also saline owing to southward groundwater flow from the Yarra Yarra salt lakes which are fed from the paleodrainages on the Yilgarn Craton. ..."

P268

"Since much of the literature on the impacts of hydraulic fracture stimulation is from the United States, it is pertinent to note that the state of California refers to the protection of freshwater containing 3,000 milligrams per litre (mg/L) TDS or less, ..."

P269

"An aquifer may be unconfined in one locality and confined elsewhere, where it is overlain by impermeable sediments."

Therefore, unless very detailed hydrogeological studies have been carried out, there is no certainty that an aquifer is confined.

P269

" 'the definition of aquifers, referring to the use of Yarragadee aquifer in the Department of Water and Environmental Regulation (DWER) water allocation system, was not satisfactory and further identification and classification was needed. The tight gas at Warro is in the lowermost part of the 4,000 m thick Yarragadee Formation, where the formation water is saline. The deepest water production bores in the Northern Perth Basin are 600 m deep in the Yarragadee aquifer at Eneabba. However, the Yarragadee Formation in the Warro hydrocarbon exploratory wells is sufficiently consolidated at a depth of 4,000 m so it holds tight gas reserves. This indicates that groundwater circulation at the base of the Yarragadee Formation is highly restricted' – submission from Latent Petroleum"

But if low rates are very slow why would the water move up, also the more TDS the heavier so naturally they are at the base. Could fracking change these flow patterns? That would have been a good scientific question.

p272

"Indigenous knowledge of water in the north-west of the Great Sandy Desert has been documented by Yu (Yu 1999) in a report to the then Water and Rivers Commission. The Karrijarri concept of 'living water' refers to permanent groundwater connecting various water sources. They distinguish 'jila', permanent water sources, from 'iirri', seasonal soaks, 'pirapi', claypans and 'wirrukuja', rockholes. Understanding the nature of these sources was critical to survival and Traditional Owners are responsible for looking after those water supplies."

p273

"Detailed groundwater studies have been carried out, only in the extreme South-West (West Canning Basin), along the coast and around Broome (LaGrange Sub-area and Dampier Peninsula), near Derby, and along the Fitzroy River Elsewhere conditions are inferred from pastoral bores in the Fitzroy Trough and along the coast and inland from widely spaced petroleum exploration wells and shallow bores and wells ..."

P273

"The pools in the dry season represent the only permanent water source for terrestrial, aquatic and avian wildlife, and they also support fringing vegetation. The river and pools are culturally significant for the local communities."

Therefore it is even more important that these areas do not get disturbed.

P287 Fig 9.10 :

Why this low quality map? Is there something to hide?

P288

"The Perth Basin contains Western Australia's most important groundwater resources. The northern part of the basin contains extensive Mesozoic (Triassic, Jurassic and Cretaceous) sandstone aquifers and locally significant superficial aquifers. There are extensive areas of fresh groundwater, the soils are sandy or gravelly allowing direct recharge from rainfall; and the water table is commonly deep below the surface. Groundwater is used for public water supply, mining, stock and domestic use on farms, and for irrigation (development of which has been hampered by the depth to water)."

Any surface pollution would therefore affect the aquifers below.

P288

"The basin contains two major aquifers: the Leederville-Parmelia aquifer, and the Yarragadee aquifer in which low salinity groundwater extends to depths of around 3,000 m (Figure 9.12). The Lesueur Sandstone and Eneabba Formation also contain significant fresh groundwater resources where they crop out at the surface in the Hill River area east of Jurien."

Therefore these aquifers should not be intersected by the many proposed fracking wells. The more wells the more chance of leakage and so pollution of the aquifers.

P290

"Figure 9.12: North to south geological cross-section, showing depth of low salinity groundwater (light blue) and shale gas targets (grey), groundwater investigation bores (red) and petroleum exploration wells (black). Source: Geological Survey Western Australia (GSWA)"

P292 Fig 9.13 :

How come companies are interested drilling near Badgingara, but the maps in the report indicates prospective areas well away from there?

P292 :

"Groundwater in the Yarragadee aquifer is recharged by rainfall and local runoff on the outcrop."

Because the importance of Yarragadee as a source of drinking water, no drilling should intersect it.

P298 :

"Wireline logs from some oil exploration wells indicate that low salinity groundwater extends to the base of the aquifer which is formed by the Cadda Formation aquiclude, suggesting that the meteoric flow reaches depths of 3,000m (Figure 9.12)."

P302 :

"The Northern Perth Basin contains mainly sandy soils and sediments and therefore groundwater is at risk of contamination by surface activities. The relative importance of these factors was taken into account to produce a 1:500 000 scale map of the Northern Perth Basin with a five-fold ranking of vulnerability to contamination"

p303 :

"Groundwater with dissolved contaminants usually has a higher density than the surrounding uncontaminated groundwater, and so sinks towards the base of the aquifer. A 'plume', rather like an inverted smoke plume, ..."

The contaminants will go to the bottom because they are heavier, while do this travel they have to down from top down to bottom and so pollute the intermediate layers.

p303 :

"Petroleum liquid hydrocarbon contaminants, including chlorinated hydrocarbons (called LNAPL – or Light Non-Aqueous Phase Liquids) may float on the water table, owing to low density and low miscibility with water."

There must also be contaminants that happily flow with the water and so can be found anywhere

p305 :

"Some chemical compounds have a very low mobility in soils and although they may be highly toxic, they may not pose a great threat to groundwater quality. However, a large percentage of the compounds released to the environment as a result of human activities are mobile to some degree in soils. The relative mobility of potential contaminants has not been taken into account on the groundwater vulnerability to contamination map."

Why were not taken into account, or could be represented in a different map?

p306 :

"The DRASTIC score of an area is the sum of the weighted factors. DRASTIC is an acronym for the following factors:

- x Depth to water table;*
- x Recharge (net);*
- x Aquifer media;*
- x Soil media;*
- x Topography;*
- x Impact of the vadose zone; and*
- x Hydraulic Conductivity of the aquifer."*

p306 :

"The DRASTIC scores were used to generate five classes of vulnerability to contamination: very high; high; moderate; low; and very low. These are colour coded from red (one - very high vulnerability) to dark green (five - very low vulnerability) on the map."

p307 Fig 9.17 :

Looking at the large areas groundwater vulnerability only answer to fracking would be NO.

p311 :

"Submissions to this Inquiry from Latent Petroleum, the operator of the Warro gasfield, and the Australian Petroleum Production Exploration Association (APPEA) questioned the classification of aquifers in the Warro area."

Why was the classification questioned? What was your response?

p312 :

"A subject that requires consideration is the identification and classification of aquifers in the Warro area. In the resources description paper, an all-encompassing definition is used – any geological formation that holds and can yield useful quantities of water. Such a definition could be construed to encompass not only the shallow water bearing units but suggest much of the Yarragadee should be considered an aquifer. ..."

You can sub-classify aquifers with levels of TDS. But to suggest that a body of water that behaves like an aquifer is not an aquifer because of level if TDS is wrong. Who determines the boundary? Who defines the boundaries, humans, cattle, sheep or microbes? On top of that it is **immoral** to say we can pollute high TDS aquifers.

p315 :

"The guidelines outline the following principles ...

-- Polluter pays; ..."

Polluter pays what and for how long?

p317 :

"Mineral processing with chemicals is listed as incompatible with P1, P2 and P3 areas ..."

Where is the map that shows the P1, P2, P3 areas?

p317 :

"The case illustrates the necessity of land use controls in the groundwater catchment, especially in a highly vulnerable superficial aquifer; the efficacy of regular monitoring of nitrate levels (which were rising but did not exceed the Australian Drinking Water Guidelines); and the rate of flow and attenuation of contaminants which allowed time for an alternative supply to be implemented."

What was the fine?? Not mentioning it does not give confidence in the process.

p318 :

"Baseline groundwater monitoring is used to establish groundwater conditions before petroleum activities commence and, when transitioned into surveillance monitoring, can determine whether groundwater has been affected by petroleum activities."

So no exploration should be started until all the baseline studies have been carried out. Groundwater monitoring should be done all the time, no exceptions.

P320:

"Before the production stage of an oil and gas development, a Field Management Plan must be submitted, including details of how produced formation water will be monitored, managed and disposed"

What is difference between the two?

p321 : Recomm 5 :

"That baseline and routine surveillance groundwater quality monitoring, including methane concentrations, should be included in an enforceable Code of Practice and results made publicly available before commencement of drilling operations and thereafter."

What effect do the results have on further drilling?

p321 :

"Average fluid use in hydraulic fracture stimulation in North America has been typically 20 ML per well, but can be as much as 48 ML ..."

Why the lower level and not two scenarios of lower and upper estimates, ie 20ML and 45ML?

p322 :

"These amounts appear astronomical to domestic consumers using around 300 kL/a, who are paying up to \$3.17 per kL, ..."

Could be 100 households per year. With a well using 30ML that would only be \$95,000, which is light of size operation not much.

p322 :

"As this is 75 to 150 times the annual domestic gas demand in Western Australia the Panel did not consider this size of development to be realistic (Section 6.8)."

Why not?

p322 :

"If the wells required re-stimulation every five years, this increases to 11.5 GL over a 20-year period, or just over 0.5 GL/a."

Why this referring to per annum, just because it looks smaller to fool the opponents?

p323 :

"These estimates are somewhat greater than those given in the submissions by Buru Energy (in which they state the expected water use over the 20-year lifetime of their proposal is 1.065 GL) and by FINDER Shale (whose maximum water use over the same period is expected to be 6.720 GL). MC Resources did not give a projected water use."

All companies should give projected estimates of water use, which should form part of their application and assessed accordingly. Is this part of the robust regulations the inquiry is so proud of? What about the usage by companies not on this list?

p323 :

"None of the company submissions accounted for the possibility of re-stimulation during the lifetime of the project. If the wells are re-stimulated every five years, and not accounting for re-use, the overall water use would be around 60 GL over twenty years, or 3 GL/a. .."

Many unconventional gas wells do not last 5 years of production. "**Could also use**" another **weasel word** used in the report. Stipulate that they 'must' use the saline water.

p323 :

"-- Adopting a flexible approach to the production of a water resources operating strategy to satisfactorily address issues related to the taking of water from a particular water resource at a specific location; "

"-- Increasing the licensee's awareness of their responsibilities and their participation in managing the water resources and specifically managing the impacts of taking and using water;"

What does "**flexible approach**" mean, sounds like "**free for all**"?

"Increasing Licensee's awareness"? If they are not aware of their responsibilities they not be able to get their license and they should be more than aware, i.e. they should understand and being prepared to adhere to their responsibilities.

p324 :

"-- Supporting the principle of water conservation where water taken is used in an efficient and productive manner; ..."

What does "**Supporting the principle**" mean?? Shouldn't they just follow this principle?

p324 :

"Edwards et al (Edwards et al. 2017) quotes flowback water as ranging from 10 -30 percent of water used during hydraulic fracture stimulation, the balance being imbibed into the shale matrix. However, in his submission Dr Vogwill quoted Vengosh et al. (Vengosh et al. 2014) who

points out that waste water may be highly saline (up to seven times the salinity of seawater) and contains a large number of toxic chemicals and gases making hydraulic fracture stimulation water reuse difficult."

What is actually the volume increase of a fracked shale? What does it displace?

p325 : Finding 13 :

"Excessive groundwater use is not permitted under the Department of Water and Environmental Regulation (DWER) water licensing regime."

What is "**excessive**" and who decides how much it is?

p326 :

".....Halliburton provided information on the development of innovative products for use in hydraulic fracture stimulation, which the company stated will provide economic and environmental/health benefits by reducing the volume of chemicals required as well as utilising lower toxicity chemicals....."

"Lower toxicity" how low is low?

The FIR quotes (too) many "scientific" reports by companies like Halliburton, the inventor of fracking. It is **like tobacco companies reporting "scientifically" on smoking.**

P326 :

"Large volumes of fluids are used in hydraulic fracture stimulation, which can mean the loads of chemicals may be significant over time, even when they are present at low percentages in the fluids."

This statement should make you concerned!!

p326:

What about NOT commonly used chemicals?

p328 : Finding 14: *"...Currently the DoH only reviews information when asked by the Department of Mines, Industry Regulation and Safety (DMIRS) or the Environmental Protection Authority (EPA) when there is a specific issue/concern...."*

DoH is only asked when there is a specific concern. This shows a lack of "Duty of Care" approach to any chemical used in any industrial process.

How often do DMIRS or EPA ask for assessments? **Very convenient if you do not have to ask because then you do not have to take action.**

p329 : Finding 15 :

"Benzene, Toluene, Ethylbenzene and Xylene (BTEX) have not been proposed to be used for drilling of wells using hydraulic fracture stimulation in Western Australia since 2009. Hence, banning use for this purpose should not be of concern to the industry but would assist in alleviating community concern."

Because they have not been used recently, does not guarantee they will not be used in the near future, but when banning there is a certainty.

p330 :

"A communication plan for notification of incidents with potential to impact public health and drinking water sources to be incorporated into ongoing stakeholder engagement; "

Beside notification plan, any plan to stop the activity that caused the incident? What is the time frame after the contamination? Is causing activity stopped straightaway?

p330 :

"A risk assessment approach considers the potential or likelihood to the chemical to be present in drinking water supplies, the toxicity of the chemicals at the concentrations that may be present, and the risks posed to the public should the water be consumed as drinking water"

How can DoH do a proper assessment if there is no compulsory testing and recording of chemicals?

It is not the task of DoH to assess if there is a possibility of contamination, they should only assess if the chemicals used pose a health risk

p332 :

"In relation to potential exposures to the public, the risk assessment identified a range of chemicals where there is a high degree of confidence that the chemicals are of low concern for human health. A number of other chemicals were identified where there is the potential for concern, however, these would need to be assessed on a site-specific basis...."

Why do medical doctors stake their reputation to indicate that there is health issues associated with fracking? They use internationally collated medical databases as a reference. So how is it possible that CSIRO can say there are no risks? Were their research project sponsors proponents of the oil / gas industry? Compared that with what is the financial or career gain is for doctors to oppose fracking?

p335 :

"A number of technical reviews and submissions have referenced a review conducted by Gradient for Halliburton: National Human Health Risk Evaluation for Hydraulic Fluid Additives (Gradient 2013)..."

Halliburton is a proponent of fracking because it is one of its inventors. **Too many "scientific" reports by companies are quoted in this inquiry!!!** It is like tobacco companies reporting "scientifically" on smoking.

p337 : Finding 17 :

"Without an amendment, ruling or clarification, it is inferred that biocides used in shale or tight oil and gas production will need to be registered for this use by the Australian Pesticides and Veterinary Medicines Authority (APVMA)."

There seems to be a lot of inconsistencies between the assessment regulations of the various regulatory bodies. This needs to be sorted out to close any loop holes which there will be because of the inconsistencies.

p338 : Finding 19 :

"Currently, there is no requirement for the Department of Mines, Industry Regulation and Safety (DMIRS), nor any other regulatory agency involved in the assessment and approval of hydraulic fracture stimulation activities in Western Australia, to check if a chemical is approved for any use in Australia."

How it is than possible for the inquiry to conclude that fracking is safe?

p340 : Recommendation 6 :

"The regulations governing the use and assessment of chemicals associated with hydraulic fracture stimulation should be strengthened and clarified, specifically: ..."

No fracking should be allowed until this regulatory system is complied with. In addition baseline studies have to be done before hand.

p341 :

"The U.S. EPA (U.S. Environmental Protection Agency 2016) has reported on a number of these instances and where a cause could be determined the incident was found to be due to one or more of the following: ..."

This are the risks at any well drilled

p341 :

"Edwards et al. (Edwards et al. 2017) concluded that it was not physically plausible for induced fractures to create a hydraulic connection between deep shales and other tight formations to overlying potable aquifers, based on the limited amount of height growth at depth, and the common rotation of the least principal stress to the vertical direction at shallow depths..."

That is disputed by Mullen (2017). Also after studying Zoback (2007) I disagree with their arguments.

p343 :

"Bense et al. (Bense et al. 2013) describe the process of smearing and drag of sand and clay along fault planes in unlithified siliciclastic sediment. They considered it an important mechanism to generate a strongly anisotropic fault core in which sand will act as along-fault conduits while the clay smear will strongly hamper across fault flow. They considered faults in unlithified siliciclastic sediments are likely to behave in a combined conduit-barrier system,

though they depict very low permeability along the fault plane, but in lithified siliciclastic sediment, where cataclasis (fracture, crushing and rotation) plays an important role, fault planes are likely to have much reduced permeability and behave as efficient barriers to fluid migration."

Do not understand the relevance of this paragraph

p343 :

"In a hard rock environment, and visible in the field, faults may be open, and indeed fault zones may be conduits and targets for water bores to produce groundwater. In a sedimentary environment, particularly in the near surface relatively unconsolidated Mesozoic formations in the Perth and Canning Basins, faults are rarely visible and faults are commonly barriers to lateral groundwater flow (Commander 1974)."

Not sure about this sentence. In hard rock faults are open or closed, are conduits or not, and at depths they can re-open when stress field changes (Zoback, 2007).

p344 :

"While there is evidence of faults as lateral barriers to groundwater flow, proving or disproving vertical flow is likely to be very difficult. The low permeability of fault zones mean that a considerable time would be needed to transfer significant quantities of fluid. Crostella (Crostella, 1995) described faulting associated with oil and gas traps in the Dongara, Yardarino and Beharra fields, implying that the faults have remained relatively impermeable for a considerable period of time...."

That maybe true when no additional stress is applied, but if fracking stresses are applied than it is to me contrary to what Zoback (2007) and Mullen (2017) point out.

P346 : Finding 22 :

"The risk of contamination of shallow fresh water aquifers by saline groundwater through hydrogeological faults is moderate, however where activities are undertaken such that faults are avoided, the risk is considered to be low. This is based on the likelihood that the presence of these permeable faults to propagate and create pathways which could contaminate overlying aquifers is rare. Should this event occur, the potential consequences are considered to range from insignificant to major, reflecting the importance of preserving water quality in the upper aquifers in the development area."

They miss the point that fracking fluids can alter the stress fields and subsequently re-open faults. Focussing just on modelling for carbon storage you does not have to take into account high pressured "slickwater" fluids. They are called slickwater because they lubricate the environment they go through and (Mullen, 2017; Zoback, 2007).

p347 :

"These recommendations flow from the risk assessment and mitigations for induced seismicity in the Section 8 ..."

This means quite a few years of research before any commercial fracking can be carried out.

p348 :

"...undertaken by suitably qualified independent experts..."

Who decides on these independent experts? As consultants rely on repeat and referral work they are not really independent. Therefore they have to be government department or government funded experts. Not industry sponsored university departments.

p348 :

"No go zones. Hydraulic fracture stimulation should not proceed wherever hydrogeologically significant structures are identified within two kilometres of a well and should also be avoided where the structures are so complex or poorly determined that predictions of geomechanical behaviours and outcomes are highly uncertain."

But aquifers related to a well can extend more than 2km. This proposal gives a **false sense of security and scientific rigor**.

P347 : Recommendation 7 :

"All hydraulic fracture stimulation operations should be preceded by a comprehensive geomechanical risk analysis according to an enforceable Code of Practice."

Who is doing the analysis? Who is checking this? Who is paying for this? How independent? Peer-reviewed?

p349 : Finding 24 :

"The likelihood of hydraulic fracture stimulation intersecting decommissioned bores and contaminating deep groundwater is low, given the documentation on decommissioned wells, and provided that adequate separation is made."

How well documented are the existence of decommissioned bores?

With previous recommendations of detailed fracture stress studies this should have been assessed automatically.

p350 : Finding 25 :

"The risk of contamination of shallow fresh water aquifers by saline groundwater and chemicals used in hydraulic fracture stimulation from well integrity failure is low. This is based on the likelihood of well failure occurring such that aquifers are interconnected in the study area being determined to be rare. Should this event occur, the potential consequences are considered to range from insignificant to major, reflecting the importance of water quality in the upper aquifers in the development area. "

Contrary to well integrity information from Anthony Ingraffea et al. (2014).

But if low rates are very slow why would the water move up, also the more TDS the heavier so naturally they are at the base. Could fracking change these flow patterns

References in the Inquiry Report :

Ingraffea, AR, Wells, MT, Santoro, RL & Shonkoff, SBC 2014, *'Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000-2012'*, Proceedings of the National Academy of Sciences, vol. 111, no. 30, pp.10955–10960. Available from: <http://www.pnas.org/cgi/doi/10.1073/pnas.1323422111>.

Mullen, F 2017, *Unconventional gas mining risk to deep aquifers Cadda Terrace*, University of Auckland, MEng. Sci. Thesis (unpublished).

Zoback, MD 2007, *Reservoir Geomechanics*, Cambridge University Press, Cambridge. Available from: <https://www.cambridge.org/core/books/reservoir-geomechanics/71717D4521278CE16D1DED0476ACEDBE>.