**Review of the Northern Territory Government's Scientific Inquiry into Hydraulic Fracturing *Interim Report* (July 2017)**

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The following is a review of the Interim Report published by the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory (Interim Report), prepared at the request of the Environment Defender's Office NT. Due to my expertise being primarily in hydrogeology and geochemistry, I have primarily assessed the sections of the report relating to these particular areas.

***General comments:***
Overall the Panel have considered a large amount of scientific information relevant to assessing water and other environmental-related risks from hydraulic fracturing for shale gas, and have surveyed a wide array of literature, mostly from the United States. This includes peer reviewed academic literature, government reports and policies, and oil and gas industry literature. Many of the key environmental risks have been acknowledged and analysed on the basis of this survey, such as risks to surface water and groundwater quality and quantity, land contamination and greenhouse gas emissions. However, there are some areas where the evidence base for conclusions about the level of risk from particular mechanisms (such as well integrity failures, wastewater spills and fugitive gas contamination of groundwater and the surface atmosphere) is questionable, and should in my view be further investigated and developed. Additionally, a more comprehensive review of the baseline data requirements and mechanism for ensuring adequate baseline data are collected, should any further shale gas activity be permitted, is needed. This was identified as a key community concern during the initial phases of the Inquiry; however the report does not provide much detail about what a comprehensive baseline data collection program and monitoring regime might look like.

***Chapter 5***
p.27: The source(s) of data or information underpinning the claims about well integrity improvements and rates of well integrity failure should be carefully interrogated (see below).

Section 5.3.2: There is clearly a large discrepancy in the rates of well integrity failures reported in the academic literature (e.g. the Ingraffea et al. 2014 and Jackson et al. 2014 studies cited in the Interim Report), and literature produced by the oil and gas industry (e.g. the APPEA submission). The Inquiry's interim report quotes well failure rates ranging from as high as 6% of wells, based on academic sources, to as low as 0.004%, according to petroleum and gas industry sources. The reasons for this discrepancy should be thoroughly investigated and resolved by the Inquiry, prior to any judgement about the level of risk from this contamination pathway, as there is a more than 1000-fold difference in the expected failure rates depending which source(s) is relied on. Additional recent reviews on the topic from the peer-reviewed academic literature (e.g. Davies et al., 2014; Kiran et al., 2017) and the Australian Government's Independent Expert Scientific Committee (IESC, 2014) should also be considered by the Inquiry in forming a view on this matter.

The 0.004% failure rate figure quoted in the APPEA submission is based on a study (King and King 2013) published in an oil and gas industry publication (Society of Petroleum Engineers) which is not readily available to the public or academic community. An argument is made in the submission that there are a number of barriers and 'lines of defence' in a gas well, which mean that complete 'well barrier failure' is a relatively rare occurrence. The data sources, specific types of wells and assumptions used to arrive at this conclusion are however not clear. Other estimates in the peer-reviewed academic literature, which were not considered by the Inquiry, indicate that rates of well-integrity failures, including complete 'well barrier' failures, are consistent with those cited by the Jackson and Ingraffea studies – e.g., on the order of 5% or wells. For example, Davies et al., (2014) found well integrity failures had occurred in a significant percentage of oil and gas wells from a range of conventional and unconventional operations worldwide on the basis of numerous databases, with a total number of wells exceeding 1 million (including databases from Australia, Europe, South America, Canada and the US). Their assessment included 'well barrier failures' as defined in the King and King (2013) study. In some of the settings examined, well barrier failures exceeded 10% of wells – far higher than the rates quoted by APPEA.

The Davies et al (2014) study indicates that the rates of failure quoted in the previous academic studies (e.g. Ingraffea and Jackson) of between 1 and 6% are applicable and correct for unconventional shale gas wells in the Marcellus Shale (where the largest datasets for unconventional gas wells are available). The distinction between a 'well integrity failure', where one or more parts of the casing fail, and a 'well barrier failure', where multiple failures occur and lead to escape of fluids, does not appear to explain the discrepancy between these data sources and the King and King (2013) study. Both categories of failure are examined in the Davies et al, 2014 study, and the King and King (2013) study is reviewed and cited within their study:

> "Using the Pennsylvania state database, a well barrier or integrity failure rate of 6.3% is identified for the years 2005 to 2013. This includes failures noted in inspection reports that were not recorded as a violation, following the methodology of Ingraffea (2012). Without including these reports, the failure rate would be 5%. This is higher than the 3.4% well leakage figure reported by Vidic et al. (2013) for the period 2008-2013, and close to the well failure rate of 6.2% reported by Ingraffea (2012)" (Davies et al., 2014)

They also note that most instances of well casing or cementing failure showed measurable impacts – in terms of leakage of gas or other fluids:

> "The online database collated by the Department of Environmental Protection (DEP) in the US state of Pennsylvania allows oil and gas well records to be searched by various criteria, such as well status, operator and drilling date. The unconventional hydrocarbon wells included in that database are those that were drilled to target the Marcellus Shale Formation. From these data, Vidic et al. (2013) derived a figure of 3.4% well barrier leakage for shale gas production sites in Pennsylvania (219 violations for 6466 wells) between 2008 and 2013. Using the same database, Ingraffea (2012) argued that 211 (6.2%) of 3391 shale gas wells drilled in Pennsylvania in 2011 and 2012 had failed. More recently, Considine et al. (2013) identified 2.58% of 3533 individual wells as having some form of barrier or integrity failure. This consisted of 0.17% of wells having experienced blowouts (4 wells), venting or gas migration (2), and 2.41% having experienced casing or cementing failures. Measurable concentrations of gas were present at the surface for most wells with casing or cementing violations." (Davies et al., 2014)

This appears to contradict the claims in the APPEA submission regarding the much lower likelihood of 'well barrier failures' (ie, failures that result in the escape of gas or other fluids to the surface).

The other source of data relied on in the APPEA submission is the Ground Water Protection Council (2011) study. This study relates to two states in the U.S., and onshore conventional oil fields (not unconventional shale gas). Quoting from the recent Kiran et al (2017) review of well integrity issues, it is clear that unconventional oil and gas resources present particular challenges with respect to maintaining well integrity – far more so than traditional oil and gas fields, from which most of the industry data cited in the APPEA submission appears to be derived:

> "The complexity of many unconventional reservoirs poses many well integrity challenges such as severe pressure and temperature conditions, the irregular chemical behavior of formation rocks. Therefore, more comprehensive tactics are required to facilitate high-quality well integrity in the unconventional reservoir. Unconventional shale reservoirs often encounter specific problems due to unpredictable geological behavior during drilling operations. Oil-based mud (OBM) is the most common drilling fluid used in these reservoirs (Guo et al., 2012). The solubility of hydrocarbon gasses in OBM is considerable. This

characteristic of OBM causes the evolution of dissolved gas when the mud reaches the bubble point pressure during circulation. This process provides a pathway for gas migration to shallower, uncased zones. This phenomenon can also result in sustained casing pressure in certain zones of a well during shale drilling operations." – Kiran et al., (2017).

These specific challenges appear not to have been considered by the Inquiry at this stage. It appears that the Inquiry has placed greater weight on the submission from APPEA with respect to well integrity issues than the peer-reviewed academic literature at this stage. This has led to (in my opinion) the Inquiry forming a premature view about the level of risk that this mechanism might pose if an unconventional gas industry were to operate in the NT (See further comments below in relation to Chapter 7 of the report).

While the Ground Water Protection Council report does indicate that regulation of the oil and gas industry can significantly reduce the incidence of groundwater contamination due to well failure (and other mechanisms – see below), the representativeness of the study for predicting well failure rates in areas of hydraulic fracturing for shale gas  should be carefully considered. In particular, the issue of conventional vs. unconventional gas wells and of who collects well integrity data (e.g. is the industry self-reporting incidents of well failure, or are these independently verified by a robust monitoring regime) are critical. Industry reported well failures may only represent some fraction of the actual number of failures taking place if there is no independent verification through a robust monitoring regime. This point is important, as there is independent evidence that well integrity failures have indeed resulted in contamination of aquifers with fugitive methane in the United States in multiple areas (Bair, 2010; Jackson et al., 2013; Darrah et al., 2014).

Regarding baseline data for methane in groundwater (discussed with reference to the WA case in the second last paragraph of p.27), due to natural variability in $CH_4$ levels being typically quite high even under baseline conditions (see Ground Water Protection Council, 2012), the isotopic composition of methane is an important additional requirement to adequately characterise baseline conditions. Even if $CH_4$ concentrations deviate from a 'baseline', there is likely to still be uncertainty (and potential controversy) over its source, unless the different possible source(s) ofgas in groundwater are well-characterised, for example using isotopic analysis of a range of baseline samples. This also requires that gas companies collect and report data on the isotopic composition of the natural gas deposits they are producing from, so that this source can be identified in the case of any leakage/spillages affecting groundwater resources (see Osborn et al., 2011; Jackson et al., 2013a; Parliament of Victoria, 2015; Currell et al., 2017).

Regarding the well blow-out in Baldwin-1 well (last paragraph of p.27), based on this incident and the number of shale gas wells drilled to date in the Northern Territory, a preliminary rate of well integrity failure for wells in the NT can be calculated (on the basis of NT-specific data).

p.28: Would 'inward pressure gradients towards the gas reservoirs' (in the Pangaea submission) apply in the case of a well fault with respect to gas phase contaminants (e.g. residual $CH_4$ and other hydrocarbons) or only liquid-phase fluids? This should be clarified.

p.28-29: In light of the uncertainty about flowback fluid composition in the NT, some regulatory requirement to report raw flowback water chemistry data for any exploration wells would be valuable (as is perhaps foreshadowed in the Interim Report).

p.31: Regarding wastewater management and spills, the currently active oil and gas wastewater spills database in the US: http://snappartnership.net/groups/hydraulic-fracturing/webapp/spills.html should also be referenced, and these data should be used in any risk assessment for ground and surface water contamination due to hydraulic fracturing related wastewater spills. These are the largest publicly available datasets on wastewater spills due to shale gas hydraulic fracturing worldwide. They indicate spill rates of between 2-16% of oil and gas wells per year, according to the Patterson et al., 2017 study.

The relatively common nature of wastewater spills and other groundwater contamination mechanisms is also highlighted in the Ground Water Protection Council 2011 report (which was cited in the APPEA submission although not discussed in this context): http://fracfocus.org/sites/default/files/publications/state_oil__gas_agency_groundwater_investigations_optimized.pdf.

In this report, the GWPC notes that in a 25 year period (1983-2007), 185 groundwater contamination incidents due to historic or regulated oilfield activities occurred in Ohio, and in a 16 year period, 211 groundwater contamination incidents took place in Texas (1993-2007) (Figures 1 & 2 below):

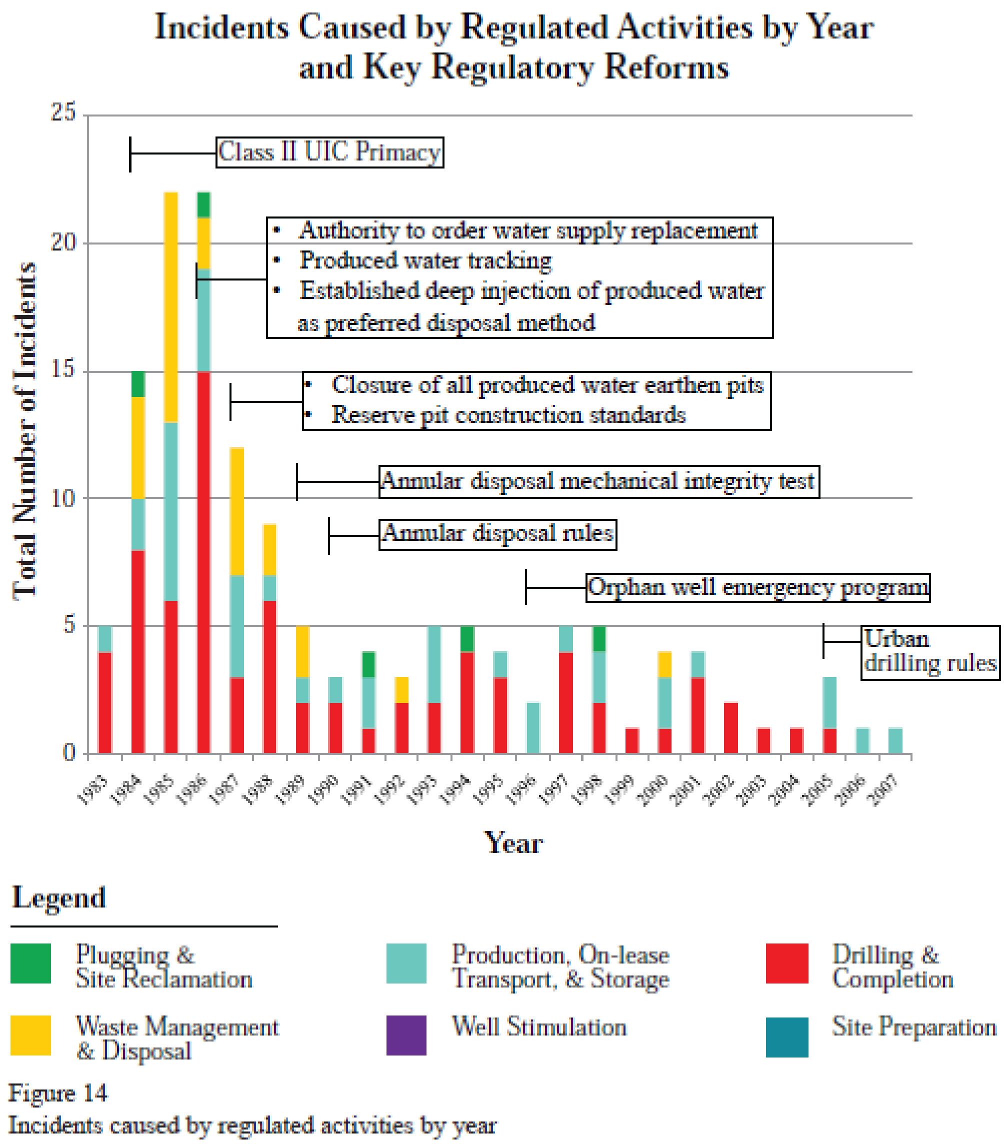


**Figure 1**: Groundwater contamination incidents due to historic or regulated oilfields activity in Ohio, documented by regulatory agency 1983-2007. Source: Ground Water Protection Council (2011): http://fracfocus.org/sites/default/files/publications/state_oil__gas_agency_groundwater_investigations_optimized.pdf

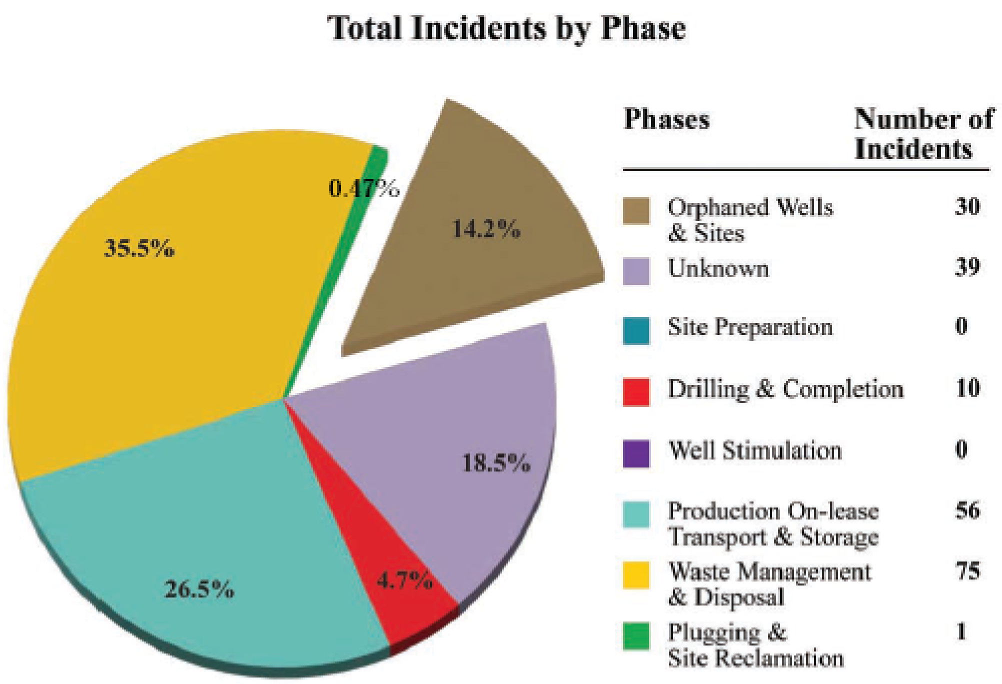


Figure 32
Total incidents by phase

**Figure 2**: Incidents of groundwater contamination in Texas recorded by the regulator, 1993-2008. Source: Source: Ground Water Protection Council (2011): http://fracfocus.org/sites/default/files/publications/state_oil__gas_agency_groundwater_investigations_optimized.pdf

While it is clear (especially from the Ohio data) that regulation of onshore oil and gas activity through a series of compliance measures can reduce the risk of groundwater contamination incidents over time, another important implication of the data is that groundwater contamination incidents are in fact relatively commonplace where oil and gas development is intensive, and that these incidents relate to a range of mechanisms (drilling, production, transport and storage of oil gas and wastewater, abandoned/legacy wells). Note that as discussed above, these data only reflect incidents that are reported to and/or detected by the regulator, which may not encompass all incidents.

***Chapter 7 (water)***
p.52: ‘Probabilistic mathematical modelling of hypothetical scenarios’ will suffer from a high level of uncertainty unless some drilling of monitoring wells and collection of water level and groundwater quality data are conducted in these poorly understood (deeper) aquifers.

Many groundwater dependent ecosystems (GDEs) (such as springs) depend on flow from deep aquifers via natural discharge and/or preferential flow along geological features. These features and dependencies must be assessed using field data in order for proper risk assessments of threats to GDEs to be carried out (e.g. modelling scenarios based on no field data do not provide meaningful input to risk assessments).

Sections 7.4.1.1 and 7.4.1.2: The risk of contamination of surface and groundwater by fugitive gas migration should also be considered one of the primary potential impacts/mechanisms here. Release of fugitive methane and other hydrocarbon gases, and cross contamination of shallow aquifers with these gases due to well integrity failures is not listed as one of the five mechanisms that could be responsible for water quality impacts, nor is it shown in Figure 7.5. This is despite this being a documented impact of shale gas development in the United States (Jackson, et al., 2013a; Darrah et al., 2014). Collecting baseline data on groundwater $CH_4$ contents and isotopic compositions, and monitoring/management strategies for this risk should also be discussed and included here.

p.56: The level of risk that contaminants may reach an aquifer before being detected is entirely dependent on the spatial coverage of the groundwater monitoring network established to monitor groundwater quality in areas of shale gas development and the frequency of monitoring. Wastewater spills or leaks may occur without the operator's knowledge and may only be detected due to monitoring after the fact. This underscores the need to develop clear guidance on the level of monitoring required for protection of groundwater and surface water quality in any areas of prospective shale gas resources.

p.58: Regarding the statement that the risk of well-integrity failures causing contamination of groundwater (or the atmosphere) is 'low', in my opinion this judgement appears pre-emptive. The evidence regarding the likelihood of well-faults occurring and allowing fugitive gas transport to aquifers or the surface atmosphere is only briefly discussed in chapter 5 and appears to rest heavily on the APPEA submission – which is not an independent submission (it was prepared by the gas industry association). More detailed and (in my opinion) more rigorous assessment of unconventional gas well integrity failure mechanisms and rates, such as the Davies et al., (2014) and Kiran et al., (2017) reviews, have not been considered. These studies contradict claims in the APPEA submission about well integrity failure rates and the incidence of gas leakage to the surface. The underlying basis (e.g. empirical data) on which assumptions about well integrity are made needs to be carefully scrutinised before making a judgement on the level of this risk. The Inquiry needs to consider that this mechanism appears to have caused contamination of aquifers in multiple areas of shale gas activity in the United States (e.g., Darrah et al.,2014).

7.5 Knowledge gaps: The section on knowledge gaps needs to stress the lack of baseline groundwater quality (and level) data in most areas of potential shale gas development in the Northern Territory. Such data are needed to conduct a proper risk assessment and detect/monitor any future impacts relating to gas development.

***Chapter 9***

Regarding baseline atmospheric monitoring of methane emissions: isotopic compositions should also be used to attribute methane to its multiple potential sources (as with groundwater). An example is the work done by Pacific Environment (2014) for AGL's Camden gas project.

***Chapter 14***

Baseline monitoring requirements for groundwater and surface water quality and greenhouse gas emissions, if prescriptively regulated (which would be a valuable step), need to be carefully developed to explicitly state what type of data need to be collected, the spatial and temporal coverage of data required (e.g. monitoring network design), and assessment of how to set 'trigger levels' and assess actions if these triggers are exceeded. If these requirements are not clearly documented, then regulation of the industry will suffer from subjectivity and inconsistency in the amount of data and monitoring regimes used and/or deemed appropriate for different projects.

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