



PUBLIC HEALTH

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10.1 Introduction

The Panel has assessed two broad categories of public health risk arising from any onshore shale gas industry:

- first, the induction or exacerbation of specific diseases, or induced dysfunction of critical organs and physiological systems; and
- second, the negative effects on wellbeing, including mental health.

In common with all of the other potential risks associated with onshore shale gas extraction, there has been a rapidly increasing coverage of public health over the past five years in the peer-reviewed literature.¹ There have been entire issues of journals that have addressed the topic² as well as review papers³ and reports.⁴ Most of these reviews analyse data from US operations, however, similar issues have been canvassed for unconventional gas extraction activities in the UK.⁵ Submissions to the Panel, previous reports prepared for various government authorities, and recently published articles, suggest that more than 700 papers on the specific topic of the impact of the unconventional gas industry on public health have been published in recent years. The Panel has taken into consideration the most significant of these published papers, reports and submissions, in order to address the key risks identified by the Panel that impact upon public health.

Public submissions specifically relating to public health impacts included a 2017 critique by Professor Melissa Haswell from the Queensland University of Technology⁶ of the issues raised in reports from WA Health in relation to unconventional gas exploration in WA,⁷ and a 2015 critique of the report on CSG by the Chief Scientist of NSW.⁸ Other submissions⁹ addressed reports of adverse health outcomes associated with conventional and unconventional gas extraction (including from CSG reserves) in the US and Queensland. Some of these submissions and reports are discussed in more detail in Sections 10.3.3.1 and 10.3.3.2.

While comments and submissions made after release of the Draft Final Report in December 2017 were largely positive or neutral in relation to the Inquiry's assessment of public health risks, there were some exceptions. These included further criticism of:

- insufficient weight given to reports from the US and south-east Queensland,¹⁰
- insufficient weight given to psycho-social factors affecting individual or public health,¹¹
- inappropriate weight given to the use of Human Health Risk Assessment (**HHRA**) reports commissioned by the gas industry to address concerns about public health impacts,¹² and
- insufficient weight given to the impacts of climate change on public health.¹³

The Panel's response to these criticisms is found in additional discussion in this chapter.

In terms of the risk assessment methodology outlined in Section 4.5 in Chapter 4, the environmental value addressed in this Chapter is the avoidance of adverse public health impacts associated with the hydraulic fracturing processes. The environmental objective is the

1 Costa et al. 2017.

2 Bamberger and Oswald 2013; Stern et al. 2014; Barcelo 2016.

3 For example, Carpenter 2016; Finkel 2015; Hays 2016; Meng 2017.

4 Zucker 2014; Physicians for Social Responsibility 2016.

5 Kibble et al. 2014; Prpich et al. 2016; Watterson and Dinan 2016; Saunders et al. 2016; UK Task Force on Shale Gas 2015.

6 Haswell 2017.

7 WA Department of Health; WA Report.

8 Dr Wayne Somerville, submission 1170 (**W Somerville submission 1170**).

9 For example, Doctors for the Environment Australia, submission 96 (**Doctors for the Environment submission 96**); Doctors for the Environment Australia, submission 477 (**Doctors for the Environment submission 477**); Public Health Association of Australia, submission 107 (**PHAA submission 107**); Prof Madelon Finkel, submission 94 (**M Finkel submission 94**); Ms Pauline Cass, submission 33 (**P Cass submission 33**); Ms Pauline Cass, submission 192 (**P Cass submission 192**); Ms Pauline Cass, submission 463 (**P Cass submission 463**); Dr GERALYN McCARRON, submission 53 (**G McCARRON submission 53**); Dr GERALYN McCARRON, submission 501 (**G McCARRON submission 501**); Dr GERALYN McCARRON, submission 508 (**G McCARRON submission 508**); K Marchment submission 438; Ms Helen Bender, submission 144 (**H Bender submission 144**).

10 For example, Health Professionals Against Fracking, submission 1179; Ms Helen Bender, submission 632 (**H Bender submission 632**); NT Greens, submission 1209.

11 For example, H Bender submission 632; issues raised at Darwin Hearings and community forum 6 and 10 February 2018.

12 Health Professionals Against Fracking, submission 1179.

13 For example, Doctors for the Environment, submission 1180.

identification and mitigation of specifically identified risks in order to maintain good health in potentially affected communities.

The key issues addressed here are whether any of the potential public health impacts identified can be attributed to specific causal factors in the environment resulting from activities associated with hydraulic fracturing to recover gas from deep shale deposits in the NT. The Panel notes that much of the information on health risks to the general public derives from studies and formal health risk assessments undertaken primarily in the US or in relation to the CSG industry in Queensland and NSW.

Many of the Panel's recommendations relating to protection of water quality (Chapter 7), protection of the land (Chapter 8), prevention of fugitive gas emissions (Chapter 9), avoidance of social impacts (Chapter 12) and strengthening of regulatory measures (Chapter 14) are also relevant to the protection of public health and are not repeated here.

10.1.1 Human health risk assessment and public health impacts

Public health impacts are generally measured in terms of adverse health changes in large exposed groups or populations. This is because it is usually too difficult to attribute a causal relationship between exposure to an environmental factor and adverse health effects in an individual, in a small group such as an individual family, or in a small community.

An important conventional tool for assessing public health impacts from environmental sources or activities is to conduct a formal HHRA. The methodologies for conducting an HHRA are well established. The 2012 enHealth¹⁴ (the National Environmental Health Standing Committee) guidance normally takes precedence in the Australian context, but the Panel notes that HHRA guidance specific to processes associated with extraction of CSG have been developed by the Australian Government Department of the Environment and Energy¹⁵ (discussed further in Sections 4.6.1, 7.4.2.3 and 10.1.1.4). This CSG guidance has been developed to be consistent with enHealth methodologies.

The two critical elements of an HHRA that must be present in order to aggregate and characterise the risks (the term 'risk characterisation' is used in enHealth guidance to describe this final component of an HHRA) are described below. They are, first, identification of and knowledge about the chemicals of concern, and second, identification of the potential exposure pathways.

10.1.1.1 Hazard risk assessment

Hazard risk assessment requires identification of 'chemicals of concern' (see Section 10.1.1.3) and knowledge of their intrinsic toxicity (toxicological profile). That is, what health effects might occur if the exposures are high enough in either the amounts of chemical in the exposure media or associated with a sufficiently long period of exposure. This knowledge is generally gained from a number of sources. Important among these sources are epidemiological studies of human populations, where different patterns of adverse health effects can be categorised according to some degree of measured exposure. Other types of studies compare disease incidence in groups that can be identified as having been exposed to a chemical, compared to those not having been exposed. Another source of human data, although generally more subjective and less reliable, is the accumulated experience of usage patterns where extensive human exposures have occurred. Because of the intrinsic difficulties of interpreting epidemiological data, the main source of quantitative data for HHRA purposes is conventionally drawn from experimental studies in animals, where the exposures can be controlled in relation to both dose and duration. The data from these studies may be used to demonstrate a level of exposure where the risk of adverse health effects is negligible, or unlikely, after incorporation of conservative 'safety factors' that address the inherent uncertainty of extrapolating from effects seen in animals to those likely to

¹⁴ enHealth 2012.

¹⁵ Australian Department of the Environment and Energy 2017a.

occur in humans.

In this context, it should be noted that the 'hazard potential' for individual chemicals, as opposed to an estimate of risk (or 'likelihood'), is usually only able to be demonstrated in studies where the exposure is orders of magnitude higher than those expected to result from exposure to environmental sources. Risk estimates derived from a conventional HHRA are therefore based on an extrapolation of these dose-response relationships to a level of exposure associated with the environmental scenario under investigation.

10.1.1.2 Exposure assessment

A key element of the HHRA process is to identify and quantitate all of the potential exposure pathways by which chemicals could reach members of the general public. Exposure pathways relevant to this Inquiry include:

- the ingestion of contaminated drinking water or food;
- the breathing in airborne gases, vapours or dusts; and
- the direct skin contact with soil or other contaminated media, such as water.

In this context, it is conventional to construct a Conceptual Site Model (**CSM**) detailing all such potential pathways from a contaminated site to individuals or collectives of humans around that source (termed 'receptors' in the terminology of HHRA). Such a CSM is described graphically in **Figure 10.1** (Section 10.1.1.4 below). The CSM should include an assessment of how likely those exposure pathways are to be 'complete', that is, exposure has actually occurred, as opposed to a theoretical possibility. The Panel has been critical of the industry-generated HHRA reports (see Sections 7.4.2 and 10.1.1.4) that have generally failed to include risk estimates associated with exposure pathways they have assessed to be 'incomplete' based on an assumption that process controls and risk mitigation mechanisms are fully effective.

The exposure pathways that can result in broad community exposure are likely to be quite different to those by which onsite workers (occupational exposure) might occur. The magnitude of such exposure, and the consequent health risks, are likely to be higher for workers who are directly handling these chemicals, or are exposed to greater 'doses' as a result of their proximity over the longer term, to the construction, drilling and gas extraction activities.

The Terms of Reference of this Inquiry focus on the potential impacts of hydraulic fracturing activity on the general community of the NT. Managing the risks associated with on-site occupational exposures are considered to be industry responsibilities, and beyond the scope of this Inquiry. The Panel notes that the WA Health HHRA,¹⁶ and the HHRA for the Amungee drilling program prepared for Origin by consultants AECOM¹⁷ (detailed in Section 10.1.1.4 below), also excluded on-site workers, while the HHRA prepared by consultants EHS Support Pty Ltd¹⁸ for the Santos Gladstone Liquefied Natural Gas (**GLNG**) project in the Bowen and Surat basins in south central Queensland addressed only some on-site health risks for workers.

10.1.1.3 Sources of chemicals of concern

The chemicals of concern (**CoC**) in an HHRA associated with extraction of gas from shale are likely to be those added to the hydraulic fracturing fluid (**HFF**), as well as those extracted from the shale deposits and brought back to the surface in flowback and produced water. The need to identify these chemicals and to match them with information that could inform their potential health effects was recognised as early as 2014 in reviews¹⁹ of the toxicology of chemicals used in HFF (see also the discussion in Chapters 5 and 7).

The information on the chemical composition of HFF and flowback water is now generally much more extensive than it was only two to three years ago. Industry submissions indicate that, while the specific composition of HFF may depend on the technical requirements of the specific site, the common elements (proppant, pH adjusters, biocides, corrosion and scale inhibitors, and foaming/de-foaming agents (see Table 1 Pichtel²⁰ and Section 5.7.2 and 7.6) are now generally well identified. An example of the disclosure of HFF chemicals is seen in **Table 7.7**, the list

¹⁶ WA Department of Health 2015.

¹⁷ Origin 2017.

¹⁸ Santos 2016b.

¹⁹ Goldstein et al. 2014; Wattenberg et al. 2015.

²⁰ Pichtel 2016.

of chemicals used to stimulate the Beetaloo Project Hydraulic Fracturing Risk Assessment Amungee NW-1H.

A component of the NCRA²¹ for CSG prepared by the Australian Government Department of Environment and Energy includes information identifying chemicals used in HFF in Australia and their toxicological profiles. Of the 113 chemicals used in for the extraction of CSG in Australia at the time of the assessment (2012), the NCRA reports²² differentiated between 44 chemicals whose toxicological profiles were sufficiently low to be of no real concern for human health, and did not therefore require any further assessment. They summarised the available toxicological information on the remaining 69 chemicals that could be hazardous to human health. The Panel notes that the suite of chemicals used in HFF is likely to have been refined since 2012, and that more contemporary information on chemicals actually used in current HFF require disclosure to the regulator in the NT.

Chemicals extracted from shale and brought back to the surface in flowback and produced water (Section 5.7.3) are potentially of greater concern to human health. These can include inorganics (for example, heavy metals) and organics, such as aromatic hydrocarbons (for example, BTEX), other hydrocarbons, and naturally occurring radioactive material (**NORM**). These 'geogenic' chemicals were not included in the NCRA reports, or in the risk assessments undertaken by Santos for its GLNG project.²³

Other CoC might be airborne chemicals, such as volatile organic carbon (**VOC**) gases and vapours, diesel fumes associated with transport and drilling equipment, and airborne dusts generated by land-clearing and other activities.

10.1.1.4 Examples of formal HHRA reports

Five formal HHRA reports describing the risks associated with unconventional gas extraction in Australia were available to the Panel. Only one of these related to hydraulic fracturing for shale gas in the NT,²⁴ with another addressing water-related risks associated with shale gas extraction in WA.²⁵ The third addressed water and airborne chemical risks associated with gas extraction from coal seam deposits in Queensland,²⁶ the fourth was a health impact assessment for the CSG project around Narrabri, NSW,²⁷ and the fifth was a formal HHRA of BTEX in flowback water from wells in the Gloucester Basin in NSW.²⁸ All five reports provide useful information supporting the risk assessments undertaken by the Panel in this Report, and they are consistent with the Panel's consequence and risk assessment of 'low'. However, all five HHRA reports suffer from some significant limitations, principally that the Origin and Santos HHRA reports omitted potentially important exposure pathways on the grounds that they are likely to be incomplete due to operational controls. These, and other elements of the HHRA reports, are discussed below.

Origin

Origin commissioned consultants AECOM Australia to undertake an HHRA of its exploration program at the Amungee well in the Beetaloo Sub-basin.²⁹ As part of its identification of CoC, this report quantitated the concentrations and toxicological characteristics of chemicals used in HFF at the site, as well as some chemicals recovered in flowback water. Relevant drinking water guidelines and other health-based guidelines against which exposure could be compared in the risk characterisation phase were determined. A suite of exposure pathways were considered as part of the development of a CSM, including water-borne, airborne and direct ingestion or skin deposition pathways, along with the potential location(s) of human receptors likely to be exposed via these pathways.

The most lacking feature of this HHRA was that all but one of the potential exposure pathways (deliberate entry by trespassers into storage ponds) was considered by the consultants to be incomplete, based on OHS and operational procedures designed to limit exposures, and therefore, were not included in the risk estimates.

21 Australian Department of the Environment and Energy 2017a.

22 Australian Department of the Environment and Energy 2017a.

23 Santos 2016a.

24 Origin 2017.

25 WA Department of Health 2015.

26 Santos 2016a.

27 Santos 2016b.

28 EnRiskS 2015.

29 Origin 2017.

Santos

Santos commissioned consultants EHS Support Pty Ltd to undertake an HHRA of its gasfield developments in the Surat and Bowen Basins in south-west Queensland.³⁰ The HHRA report was peer-reviewed by an independent consultant (Environmental Risk Sciences, or **EnRiskS**). While the report relates to gas recovery from CSG sources, it does contain information on CoC from drilling fluids, including HFF, flowback water, and on-site water treatment processes. The report included relevant drinking water guidelines and other health-based guidelines against which exposure could be compared in the risk characterisation phase.

The conceptual exposure model (**CEM**) (analogous to a CSM) used was comprehensive for water and soil, but it did not address airborne contaminants because of the suggested low volatility of the identified CoCs. The model explored potential exposure pathways through transport, onsite storage and the use of drilling chemicals, with different classes of human and ecological receptors (for example, transport workers, accident first responders, landholders, agricultural workers, trespassers, livestock, aquatic and terrestrial fauna, and users of surface and groundwater resources) exposed under the different stages of the process (transport, spills, drilling and gas production).

However, similar to the Origin HHRA discussed above, not all of the potential exposure pathways were deemed to be complete and, therefore, included in the quantitative HHRA. In particular, exposures of human and ecological receptors resulting from accidental spills during transport and drilling fluid preparation, accidental releases of stored water (including geogenic chemicals in produced water) and the use of treated produced water for irrigation were the main pathways considered. Pathways leading to contamination of surface water and impacts on drinking water quality were deemed incomplete.

Santos also commissioned a health impact assessment (**HIA**)³¹ and chemicals risk assessment for its CSG development in Narrabri, NSW.³² The HIA was a desktop assessment prepared by EnRiskS, while the chemicals risk assessment was conducted by EHS Support Pty Ltd. The EnRiskS HIA represents a more limited assessment of public health risks associated with potential impacts on water, soil and air quality, as well as potential impacts of noise, fire and explosion hazards, and social and community wellbeing. The assessment was reasonably thorough, drawing on a range of associated technical reports on air and water quality, and social impact studies. However, it noted that the assessment relates to a project primarily in the development phase. The EnRiskS report relied on exposure information developed by other consultants addressing water quality, as well as the potential for surface and groundwater contamination. The assessments of health risks associated with airborne dusts associated with construction activities and airborne dispersion of gases and VOCs from the gas processing and power generating facilities were informed by air dispersion modelling. The modelling predicted that no health-based air quality guidelines would be exceeded. The assessment of water-borne chemical risks addressed interconnections with groundwater sources and surface spills for both HFF and produced water, with predictions that pathways would be either incomplete, or would result in exposure concentrations below health-based guideline value.

The chemicals risk assessment report for the Narrabri project had the same overall structure as the HHRA for the Gladstone project described above, and used the same methodologies. It specifically addressed CoC from drilling fluids, including HFF, flowback water and on-site water treatment processes. However, the conceptual exposure model for this project was more comprehensive, and extended coverage from that used in the Gladstone report to include the reuse of treated water for irrigation and dust suppression. Like the Gladstone HHRA, pathways involving contamination of groundwater and surface waters were found to be incomplete for all of the human receptors under consideration. Moreover, no off-site airborne pathways were considered.

The overall conclusion from both the HIA and chemicals risk assessment was that the health risks to surrounding communities were low and manageable. However, the HIA acknowledged that this was dependent on effective implementation of the process controls and environmental management measures outlined in the environmental impact statement.

³⁰ Santos 2016a.

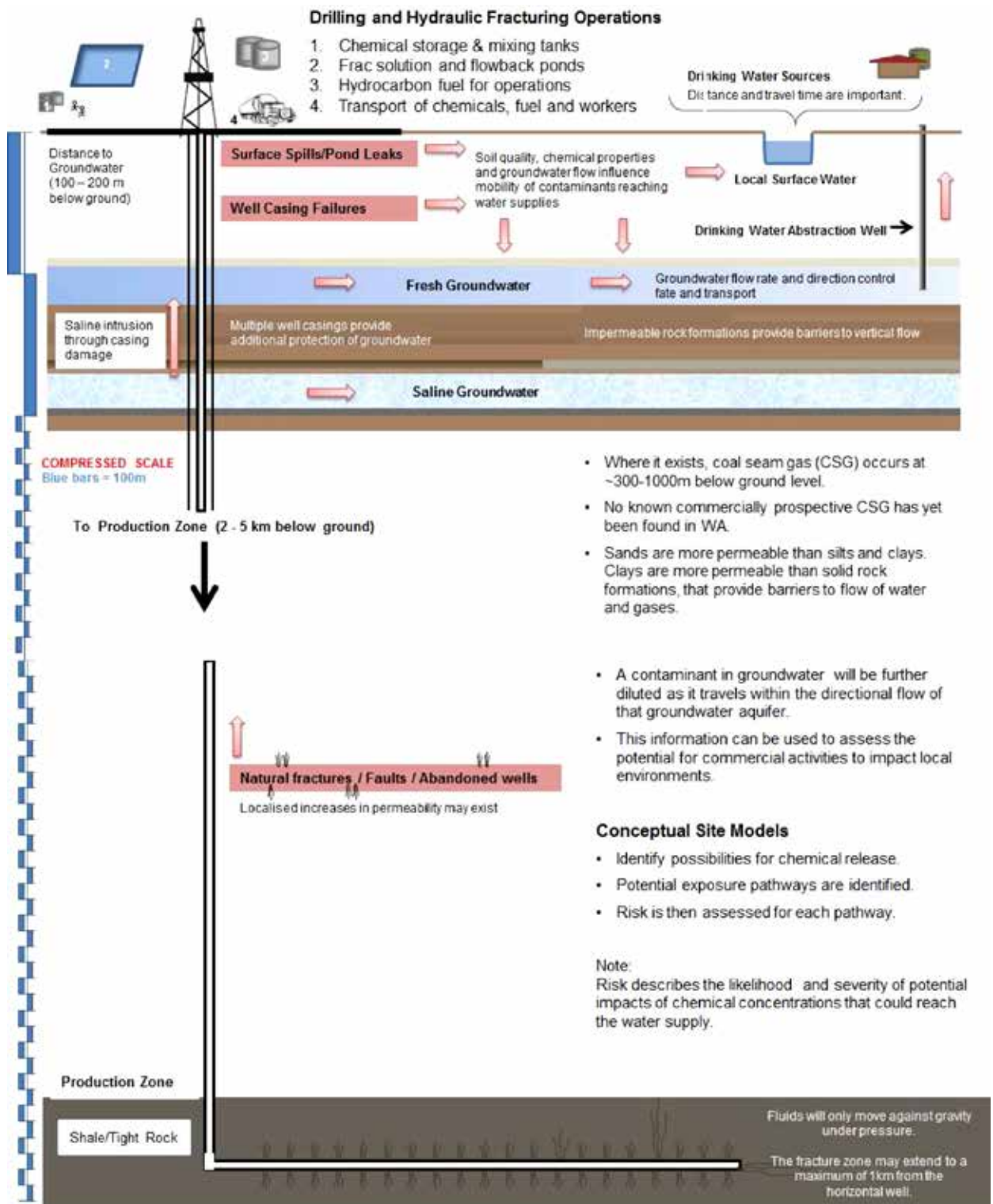
³¹ The difference between an HIA and an HHRA is explained in enHealth 2012. In essence, an HHRA is a process that aims to identify and quantify health risks associated with a specific exposure scenario. An HIA is a broader systematic process by which a policy, program or project may be judged as to the effects it may have on the health of a population. An HIA assesses actual, potential, direct and indirect effects, as well as potential benefits and is usually undertaken at an early stage of a project so that a risk manager has options to avoid negative impacts on health, and to promote more positive health benefits.

³² Santos 2016b.

WA Department of Health

The HHRA report from the WA Department of Health specifically addressed the potential for groundwater contamination with the chemicals employed, or generated, in hydraulic fracturing processes used to extract gas from shale or other tight deposits. In common with the NT, WA relies on a significant proportion of its drinking water by extraction from groundwater aquifers. The CSM utilised in the WA HHRA is shown in **Figure 10.1**.³³ It depicts all of the potential exposure pathways noted in the introduction to this Chapter and discussed in Chapters 5 and 7.

Figure 10.1: Conceptual Site Model. Potential pathways for hydraulic fracturing chemicals to have an impact upon drinking water supplies. Source: WA Department of Health.³⁴



33 WA Department of Health 2015, Figure 8, p 29.

34 WA Department of Health 2015.

The WA Health HHRA was hampered by the lack of local measured/reported data on the concentrations of the chemicals identified in HFF and produced water, so it primarily used data sourced from US operations to estimate likely exposures. It further noted that elevated levels of some chemicals found in drinking water around some sites in the US may not necessarily be attributable to hydraulic fracturing, due to their natural (or background) presence in some regions. The WA Health HHRA did not identify any specific human receptors or their proximity to drilling sites, although it did acknowledge that distance and travel time from the well head to the drinking water source are key parameters influencing such an assessment.

The approach taken in the risk characterisation component of the HHRA merely compared the concentrations of chemicals reported in US flowback water with relevant health-based guideline values (for example, the Australian Drinking Water Guideline values³⁵), of which there were very few indicators for the chemicals in hydraulic fracturing fluids or any other available benchmarks. This represented a 'worst case' analysis because actual exposures by drinking would not be at overly high concentrations due to the dilution effects occurring over the distance between the source of the chemicals and where the water was extracted for drinking (see Section 7.6).

The overall conclusions of the WA Health HHRA were that:

"under the right conditions, hydraulic fracturing of shale gas reserves in WA can be successfully undertaken without compromising drinking water sources... Firstly, in WA, shale and tight gas reserves have been identified at depths of between two and four kilometres below ground level which are a considerable distance below potable groundwater sources. Secondly, the risks to drinking water sources associated with hydraulic fracturing can be well managed through agreed industry and engineering standards, best practice regulation, appropriate site selection (including consideration of Public Drinking Water Source Areas) and monitoring of the drinking water source."³⁶

AGL Upstream Investment report

AGL Upstream Investment commissioned EnRiskS to assess the human and environmental health risks associated with BTEX in flowback water from wells WK12 and WK13 in the Gloucester Basin of the Waukivory CSG project in NSW. The report specifically addressed the potential for BTEX vapours from the holding tank to have an impact on nearby residential areas, with the closest residences located 490 m, 570 m and 600 m from the tank. The assessed risks only covered airborne transfer from the holding tank, and not leaks or spills to surface of groundwater, on the basis that there had been no reported spills at this site. Exposures were modelled based on measured BTEX concentrations in tank water, the surface area available for evaporation, and conventional air dispersion models to estimate the maximum 1 h BTEX concentrations that site workers and nearby residents might experience. The estimated workplace exposures were generally five times higher than those at the nearby residences. In all cases, the maximum predicted 1 h and annual average exposures were at least two orders of magnitude lower than relevant health-based guideline values, with benzene exposure the more critical of the estimates.

NCRA reports

Another significant document outlining an agreed Australian approach to risk assessment for CSG sites is the series of NCRA reports submitted to the Inquiry by the Australian Government Department of Environment and Energy.³⁷ A more detailed discussion of these reports is included in Sections 4.6.1 and 7.4.2.3. The reports include information on potential exposure pathways, proposed best-practice methodologies for carrying out a formal, site-specific HHRA, and a series of data sheets on 69 drilling and HFF chemicals where such HHRA were prepared.³⁸ The Panel notes that the risk assessments addressed health risks to both on-site workers, where there is a potential for higher exposures, and to the general public, when exposed through off-site contamination of water used for drinking or recreation. While geogenic contaminants of flowback water were identified in one of the reports,³⁹ they were not included in the formal risk assessments outlined above.

³⁵ NHMRC 2016.

³⁶ WA Department of Health 2015, p 1.

³⁷ Australian Department of the Environment and Energy 2017a.

³⁸ Australian Department of the Environment and Energy 2017a; Australian Department of the Environment and Energy 2017c.

³⁹ Australian Department of the Environment and Energy 2017a; Australian Department of the Environment and Energy 2017d.

The recommended NCRA approach is in contrast to that outlined in the Origin - and Santos - commissioned HHRA reports described above, where off-site water pathways were considered to be incomplete, and therefore, were not included in the risk estimates. The generic guidance⁴⁰ on HHRA for CSG sites does recommend that a more comprehensive range of potential exposure pathways be considered, including off-site transport through surface and subsurface waterways, as well as airborne transfers by dusts, vapours, or gases.

In a comprehensive review of the risk assessment methodologies used by the gas industry in the US, the challenges associated with making meaningful estimates of probabilities for barrier failures, spill, leaks, and the associated volumes and exposure pathways were acknowledged.⁴¹ The uncertainties inherent in determining data inputs for formal risk assessments for shale gas extraction, particularly at the early stages of the project, were also highlighted in a review that proposed a weighted qualitative assessment model covering technological and environmental sources of risk.⁴²

The Panel therefore acknowledges the difficulties in including the off-site and early-stage exposure pathways that have been considered incomplete in industry-sponsored HHRA reports, but emphasises the importance of addressing the potential health impacts of such pathways in the unlikely event of the failure of process control measures designed to prevent such incidents.

10.2 Key risks

The issue of water security of aquifers essential in the NT for drinking water and for support of horticultural, agricultural and pastoral activities was consistently raised in public consultations and submissions as the primary area of concern (see Chapter 7). Protection of ground and surface waters from contamination associated with hydraulic fracturing and gas extraction activities is essential. The impact of unknown interactions and interlinkages between aquifers was also raised. The view consistently expressed in public consultations and submissions was that any contamination of an aquifer would be unacceptable and that it would result in 'poisoning' of the environment and people. There was also scepticism that flowback and produced water could be effectively collected and treated, or transported safely to other locations.

A more balanced view is that aquifer contamination would only be likely to become a real issue to public health or horticultural, agricultural, pastoral, and cultural activities if the amount of contamination is high enough to result in adverse health effects to people or fauna consuming the water, or if the level of contamination is such that it compromises organic farming certification of an affected landholding.⁴³ These issues are addressed below and are also discussed in detail in Chapter 7, along with the Panel's assessment of the level of several risks relating to water quality.

There was a common concern that the injection of large quantities of unknown chemicals into the ground would be an inevitable outcome of hydraulic fracturing, with an associated potential for contamination of groundwater. This anxiety was not assuaged by information indicating that many of the chemicals would be recovered with flowback water and that this water could then be treated to remove the chemical residues, including the chemicals leached from the shale (for example, BTEX, metals, minerals, and NORM).

The Panel's initial assessment in its Interim Report, confirmed in this Final Report, is that any evaluation of human health risks associated with contamination of drinking water resources can only be meaningful if it is carried out on a site-specific basis. This requirement for a site-specific HHRA, identifying the sources, exposure pathways and location of human receptors (as outlined in Section 10.1.1.2) is a crucial element of any HIA. It has been acknowledged in the submissions from Origin⁴⁴ and in the NCRA reports.⁴⁵

40 Australian Department of the Environment and Energy 2017c; Australian Department of the Environment and Energy 2017f.

41 Torres et al. 2016.

42 Veiguela et al. 2016.

43 Barkly Landcare, Submission 241.

44 Origin submission 153, pp 123-125.

45 Australian Department of the Environment and Energy 2017c.

The importance of site-specific factors in evaluating risks to groundwater resources has also been well documented in the recent US EPA Report on the potential impacts of hydraulic fracturing activities:

“Evaluating potential hazards from chemicals in the hydraulic fracturing water cycle is most useful at local and/or regional scales because chemical use for hydraulic fracturing can vary from well to well and because the characteristics of produced water are influenced by the geochemistry of hydraulically fractured rock formations. Additionally, site-specific characteristics (e.g., the local landscape, and soil and subsurface permeability) can affect whether and how chemicals enter drinking water resources, which influences how long people may be exposed to specific chemicals and at what concentrations.”⁴⁶

The Panel reaffirms its view that a site or region-specific HHRA should be part of the HIA for any onshore shale gas project seeking approval in the NT. Such a site or region-specific HHRA should cover operations at the exploration and production stages and also consider any health risks associated with decommissioned wells.

Recommendation 10.1

That formal site or regional-specific HHRA reports be prepared and approved by the regulator prior to the grant of any production approvals. Such HHRA reports must address the potential human exposures and health risks associated with the exploration for, and the production of, any shale gas development, off-site transport, and the decommissioning of wells, as recommended in NCRA guidance. The HHRA reports must include risk estimate assessments for exposure pathways that are deemed to be incomplete.

Among the concerns raised in some public submissions was whether knowledge of the toxicological profile of many of the chemicals used in HFF is incomplete (see Chapter 5 and the comment above). However, there may have been misconceptions on this matter based on the early use of HFF in the US. A quote from a report to the WA Government summarises this point:

“There is much misinformation in the public domain regarding the types of chemicals that are routinely used in Australia for hydraulic fracturing. The Committee distinguishes between the chemicals used overseas (specifically, in the USA) and those which are used in Western Australia.”⁴⁷

The Panel notes that where adequate toxicological information is available, the majority of HFF chemicals that are used routinely appear to have low toxicity.⁴⁸ At the concentrations used in HFF, ingestion would be unlikely to represent an acute health risk, although direct exposure to some of the chemicals in pure form prior to formulation would represent a much greater potential health risk to industry workers. In the case of the low concentrations that are present in HFF or in flowback water, there would need to be continuous exposure to these lower concentrations over a much longer period to constitute a chronic health risk.

Industry submissions emphasised the technological developments that have occurred in the hydraulic fracturing industry in recent years, and confirm that the disclosure of chemicals used in HFF is now more common, including in Queensland and the NT, where it is mandatory. In the NT, specific information regarding the chemicals used in HFF must be released to DPIR and the general public. However, there is no requirement to report the composition of flowback water, noting that this is also the case for the FracFocus database in the US.⁴⁹ The Panel is of the opinion that this information should be publicly available. The Panel therefore recommends requiring the collection of information on the chemical composition of flowback and produced water from unconventional gas wells in the NT (see **Recommendation 7.10**) and on the management and treatment of these waters (**Recommendation 5.5**).

A consistent theme in many of the public submissions and community forum comments was that it is crucial that adequate baseline data on public and environmental health be collected ahead

⁴⁶ US EPA 2016a, p ES42.

⁴⁷ WA Report, p 103.

⁴⁸ Stringfellow et al. 2017; Elsner and Hoelzer 2016; Department of Environment and Energy 2017a.

⁴⁹ FracFocus chemical disclosure registry; available at <https://fracfocus.org/>.

of any onshore shale gas development so that the future impacts of any industry can be reliably assessed. This point has also been raised in some published papers.⁵⁰ It is also an important element for informing claims for compensation for environmental damage by the holders of land upon which the activity takes place. The Panel has confirmed the importance of having a completed bioregional study of baseline health and environmental data before any onshore shale gas production occurs in the NT (see Chapters 15 and 16 and **Recommendation 7.4** in Chapter 7).

Other public health issues raised in submissions and during consultations relate to impacts associated with noise, trauma associated with increased road traffic, and impacts on social amenity, wellbeing and mental health. These risks are more difficult to quantitate, but to the extent possible, they are addressed in Sections 10.3.4 and 10.3.5, and Chapters 8 and 12 below.

10.3 Assessment of risks

The framework for systematically assessing the potential risks, mitigation measures and the resultant residual risk is outlined in Chapter 4. As stated in that Chapter, this framework essentially involves three steps: first, determining the resultant risk by using the 'likelihood' and the 'consequence' if the particular risk or threat occurs; second, defining possible mitigation measures to reduce the risk further if required; and finally, assessing the remaining, or residual, risk if these mitigation measures are applied.

A link between shale gas extraction activities and a number of adverse health effects has been raised in several submissions to the Panel, as well as being addressed in some published papers. The nature of the evidence and its relevance to any onshore shale gas development in the NT is crucial. In some cases, the Panel notes that the allegations are related to health effects associated with CSG extraction in Queensland.⁵¹ Due to some crucial differences between the processes for extracting gas from shale and coal seams (as described in the Issues Paper and see also Chapter 5), in particular, that hydraulic fracturing has, until recently, been infrequently required in Queensland for CSG extraction, some of the alleged health risks associated with CSG extraction may not be directly relevant to gas extraction from onshore shale deposits using hydraulic fracturing. The health risks from Queensland that are more likely to be relevant to the NT are those associated with:

- contamination of groundwater and surface water from geogenic chemicals (Chapter 7);
- airborne gases and VOCs (addressed in Section 10.3.3); and
- socio-economic factors outlined in Chapter 12.

Although the NT environment and social structure has both similarities to, and notable differences from, those in Canada, the Panel observes that its overall assessment of the risks associated with hydraulic fracturing of shale for gas extraction are consistent with those reached by two expert panels reporting to the Nova Scotia Department of Health⁵² and the Council of Canadian Academies.⁵³

10.3.1 Assessment of risks related to contamination of water

The Panel's assessment of the water-related risks of shale gas development is discussed in detail in Chapter 7. Whether the source of human exposure is through contamination of surface waters or aquifers through any of the pathways described above, the overall risk estimates have generally fallen into the 'low' category for 'likelihood', with some of the estimates of 'consequence' falling into the 'low' to 'medium' categories. In some cases, the Panel has been unable to make a definitive assessment of the risks due to a lack of data, background information or understanding of the particular system.

These risk assessments are consistent with predicted risks from HHRA reports discussed above in Section 10.1.1.4. In the specific context of impacts on public health, the Panel's assessment of consequence is also in the 'low' to 'medium' category, except for geogenic chemicals, where a lack of specific information on potential flowback water concentrations at this time make the risk estimate 'unknown'. The Panel's risk estimates stand in contrast to the opinion expressed in many of the public hearings and submissions, that an outcome was that drinking water would be 'poisoned'.

50 For example, Schmidt 2011; Korfmacher and Elam 2014; Steinzor et al. 2013.

51 For example, Ms Katherine Marchment, submission 259 (**K Marchment submission 259**).

52 Wheeler et al. 2014.

53 Council of Canadian Academies 2014.

The limited available evidence does show that, even for flowback water, the water concentrations of many of the HFF and geogenic chemical constituents could be lower than the conservatively set health-based guideline values (for example, the Australian drinking water and recycled water guidelines,⁵⁴ or other similar toxicity reference values). Where the concentrations do exceed guideline values, or where there are no relevant health-based guideline values, human health may still not be significantly affected where dilution and attenuation occur between the emission source and the site where human ingestion can take place, or where a credible exposure pathway does not exist (see Section 10.1.1.2). A further factor is that conservatively set guidelines generally assume that ingestion occurs consistently over a lifetime, whereas exposure scenarios associated with surface or groundwater contamination, should it occur, would be of a shorter duration.

The six most likely pathways (see also Chapter 7) by which aquifers may be contaminated by chemicals used in HFF, or in the produced water that flows back after hydraulic fracturing has occurred, are:

- direct contamination of contiguous aquifers through fractures induced in the shale deposits;
- direct leakage from single or multiple steel and concrete-encased wells at a particular site, where the drill casings pass through an aquifer either during drilling, gas production, or after well decommissioning;
- reinjection of treated or untreated wastewater into aquifers where there is possible connectivity between aquifers;
- leakage of onsite storage of HFF chemicals, pooled flowback water, or a rain event leading to the overflow of storage ponds;
- overflow, or escape from containment ponds where the flowback water is stored; and
- spillage from HFF mixing sites, during transport of chemicals to sites, or during transfer of wastewater for treatment.

The opinion consistently expressed in industry submissions is that such risks are manageable, and that contamination of aquifers from the process of hydraulic fracturing is improbable because of the spatial separation between the deep shale deposits and the beneficial use aquifers, which are typically much closer to the surface. The latter issue of low probability of contamination by virtue of large separation is supported by the conclusions from the published literature (see Chapter 7 for more detail).

Some of the CoC reported in flowback and produced water may be more of a health concern than those initially added to the HFF. In particular, BTEX,⁵⁵ and other VOCs extracted from hydrocarbon deposits in the shale can reach concentrations that would exceed health-based water quality guideline values. However, a number of risk-mitigating factors, including dilution, adsorption on the rock matrix, delay in moving further along the aquifer and microbiological breakdown processes, all contribute to reducing the concentrations of these chemicals in an aquifer to a level that would not be of concern for exposure through ingestion.

The Panel's recommendations to mitigate the potential risks of contaminating a beneficial aquifer are addressed in more detail in Chapter 7 (see **Recommendations 7.9, 7.11 and 7.16**).

In relation to the potential for contamination of surface waters, an analysis of incidents of surface water contamination associated with recorded spills and well failures in the US suggest a higher level of likelihood and risk and consequently, a greater need for effective risk management.⁵⁶ See **Recommendations 7.12, 7.14 and 7.17**, which address mitigation of the potential risks of surface water contamination.

However, the Panel recognises the need for site-specific HHRA to better inform the management of risks associated with groundwater and surface water contamination.

The Panel acknowledges that there is generally insufficient definitive data on the presence and concentrations of NORM in flowback and produced water, although preliminary data in flowback water from the Amungee well indicates that the levels are at the low end compared with experience from US and international wells (see Section 7.6 for more detail). The presence

⁵⁴ NHMRC 2016; NRMCC 2008.

⁵⁵ Gross et al. 2013.

⁵⁶ Mrdjen and Lee 2016.

of NORM in flowback water was also incorporated into the AECOM HHRA discussed in Section 10.1.1.4, although it was acknowledged that further testing would be needed to refine the risk assessment.

While there are some US reports that suggest discharge of radionuclides to local streams can result in significantly increased levels in stream sediments relative to background⁵⁷, there are also estimates that the efflux of this amount of NORM would be a somewhat rare event. Another report has suggested that such discharges to natural groundwaters in the UK could be less than those associated with other power-generating sources and that they would be unlikely to exceed the 1 mSv annual allowance for radioactivity exposure in the UK⁵⁸ or the 1.5 mSv annual background level for Australia.⁵⁹

Accordingly, the Panel has concluded that the level of risk to public health from NORM, while difficult to determine in advance of any onshore shale gas development, would need to be considered on a site-specific basis. The likelihood of exposures, the level of consequence to human health, and the overall level of risk will be subject to the same constraints and respond to the same mitigation factors that apply to other geogenic chemicals from such sources.

10.3.2 Assessment of risks relating to contamination of food

During many of the community forums, concerns were raised about the potential for HFF and geogenic chemicals to contaminate local food sources (such as beef and fish), especially Aboriginal 'bush tucker'. There is relatively little published information about the potential for farm animals and crops to be contaminated by onshore shale gas recovery activities, and much of what has been published is based on conjecture or case studies of health impacts on farm animals.⁶⁰

The Panel has noted the difficulty of estimating the risks of contamination through the food chain. This difficulty has also been acknowledged in the NCRA report⁶¹ on HHRA for CSG-related chemicals, where the following was said:

"Exposure to these chemicals is also possible through the consumption of foods such as meat, milk, vegetables and cereals contaminated via uptake of contaminated water and/or direct airborne deposition of chemical particulates. However, currently no data are available on levels of chemical residues in food which could be linked to contamination by drilling and hydraulic fracturing operations. Therefore, because of the difficulty in establishing likely levels of contamination of foods linked to these operations, public exposure to drilling and hydraulic fracturing chemicals via food is not quantified in the current assessment".

The Panel has assessed the risks of food contamination as 'low', although this will need to be confirmed by relevant site-specific HHRA. The initial assessment is based on an expected 'low' likelihood of contamination of nearby surface waters (see Chapter 7) and a 'low-medium' consequence, depending on whether the specific HFF chemicals, or those released from flowback or produced water, or in airborne plumes, would not be bioaccumulative, be degraded in the environment over time, or be subjected to metabolism in plant and/or animal tissues with a resultant reduction in toxicity. It is acknowledged that NORM and heavy metals of geogenic origin in flowback water are less likely to be detoxified by metabolism, although it is possible that they will be sequestered in tissues (for example, liver and kidney) or plant components less likely to be used in the conventional food chain.

57 For example, Warner et al. 2013.

58 Almond et al. 2014.

59 ARPANSA 2015.

60 Bamberger and Oswald 2012; Bamberger and Oswald 2015; Haswell and Bethmont 2016; Catskill Mountainkeeper.

61 Australian Department of the Environment and Energy 2017f.

10.3.3 Assessment of risks relating to airborne contaminants

The potential health risks associated with airborne chemicals from shale gas developments have been summarised in Goldstein et al.⁶²

Table 10.1: Potential health effects of air pollutants associated with shale gas development.

Airborne pollutant	Potential health effects
Methane	Explosion and fire; asphyxiation in confined space; impact on global climate change.
VOCs (including BTEX)	Ozone precursors; haematological toxicity (including leukaemia - mainly from benzene); upper respiratory tract inflammation; central nervous system effects (mainly in confined spaces).
Oxides of nitrogen (NOx)	Ozone precursors; asthma and other acute respiratory irritancy effects.
Ozone and other photochemical oxidants	Asthma and other acute respiratory irritancy effects; effects on lung function; premature death.
Particulates (including diesel exhaust fumes)	Asthma and other acute respiratory irritancy effects; chronic respiratory diseases; premature death; cancer.
Silica dust	Silicosis and other chronic lung diseases (particularly among workers exposed onsite).

The epidemiological evidence relating to the public health impacts of many of these airborne pollutants is mixed (see further **Table 10.2**).

The Panel's assessment of the risks of shale gas development relating to airborne chemicals generally falls into the 'low' to 'medium' category for likelihood, and the 'low' to 'medium' category for consequence. In accordance with **Tables 4.2** and **4.3** and **Figure 4.1**, the overall risk category is 'low' to 'medium', with risk mitigation actions such as the clear identification of potential exposure pathways, and the establishment of buffer zones or setbacks likely to reduce the residual risk to 'low'.

Exposure pathways most likely to lead to potential impacts on public health would involve emissions of VOCs and NORMs from flowback water, whether through volatilisation from unenclosed on-site storage ponds, emissions of extracted gas (mainly methane), or the combustion products from 'gas flaring'. Other airborne emissions include diesel and petrol exhaust fumes from trucks and drilling equipment. The potential impacts of windborne particulates (dusts) from well heads and other land clearing sites are considered below in Section 10.3.3.1.

Methane is a non-toxic gas.⁶³ It is unlikely to pose a direct health risk at concentrations associated with fugitive emissions from leaking shale gas production fields or abandoned wells (see Section 7.6.1.1), pipelines or processing facilities. The Panel's assessment is that, while there is a relatively 'medium' to 'high' likelihood of there being fugitive methane emissions around gas wells and processing facilities, the consequence of such emissions directly affecting public health can be categorised as 'low' because of the intrinsically negligible toxicity of methane.

A more significant risk to public health may, however, occur if methane concentrations reach levels high enough to pose a flammability or explosion risk. Methane concentration in water cannot exceed its saturation concentration (28 mg/L at atmospheric pressure) and becomes flammable in air at around 5% by volume.⁶⁴ The likelihood of such a risk is discussed in more detail in Chapter 7 (Section 7.6.1.1), with US recommendations that methane concentrations in water between 10 and 28 mg/L or 3-5% by volume in air represent levels that should be monitored in order to reduce the flammability or explosion risk.

Submissions to the Panel emphasised the risks associated with methane emissions and the contribution of burning natural gas for power generation on global climate change, especially the significant impact of climate change on public health. Risks associated with greenhouse gas impacts on climate change are discussed in detail in Chapter 9 (Sections 9.1.4 and 9.9), including identifying some impacts of climate change on human health. The Panel did not attempt to categorise the specific risks to public health in the NT, because implementation of **Recommendation 9.8** should seek to ensure that there is no net increase in the lifecycle GHG emissions emitted in Australia from any shale gas produced in the NT.

62 Goldstein et al. 2014, Table 2, p 277.

63 US EPA 2016a, pp 9-47.

64 Eltschlager et al. 2001.

In common with the public health impacts of water-borne chemicals, the health risks associated with airborne contaminants depend on there being credible exposure pathways to nearby human receptors that can deliver chemicals at concentrations sufficiently high to have immediate or delayed adverse health effects. The Panel notes that distance from the emission site is likely to be a critical factor, not only in regard to the likelihood of exposure pathways being 'completed', but also the extent of concentration dilution that could occur as the emissions move away from the source.

The assessment of airborne risks is substantially informed by the published literature on experience with unconventional gas extraction overseas (mainly in the US) and from more recent Australian experience with CSG in Queensland and NSW. However, the Panel reiterates its view that the exposure scenarios described in the examples below (in Sections 10.3.3.1 and 10.3.3.2) are unlikely to be closely representative of any onshore shale gas extraction activities in the NT, because of the much closer proximity and higher density of habitation to the gasfields in the US and Queensland compared to any shale gas developments in the NT.

10.3.3.1 International health impacts in respect of unconventional gas extraction

A number of published papers have addressed the potential public health impacts of VOCs and other airborne chemicals in dusts that may travel off-site. Much of the evidence linking airborne emissions with adverse human health effects is based on surveys and reviews of health effects relating to unconventional gas extraction from shale gasfields in the US, particularly around Pennsylvania, Texas and Colorado.

There is strong evidence that proximity to unconventional gas activities is a crucial factor,⁶⁵ with a survey of health effects showing that residents living beyond 0.8 km of wells had a lower incidence of a range of health effects than those of closer residents (see below for more detail).⁶⁶ This is not surprising because airborne, dust-borne, and water-borne contamination can be expected to undergo dispersion as it spreads away from the site of release, resulting in a lower potential for human exposure.

However, the Panel has concerns that the US findings will not have the same relevance to any proposed onshore shale gas development in the NT. The Panel notes that most of the areas with shale gas development potential in the NT are in relatively remote areas distant from established communities, while most of the unconventional gas activities assessed in the US are in relatively close proximity to established residential communities. In this context, it should be noted that in the US, the national average offset distance of a shale gas extraction well from other land use activities is only 94 m.⁶⁷ Based on the study by McKenzie et al.,⁶⁸ described in more detail below, Webb et al.⁶⁹ have recommended a shale gas well setback distance of at least 1 mile (1.6 km) from occupied dwellings, including schools, hospitals and other sites where children and infants may spend a substantial amount of time. The current NT guidelines for permitting of such activities merely exclude close proximity to residential areas, and a range of defined land uses and are not, in any event, enforceable.⁷⁰

This point is reinforced in a review by Watterson and Dinan of the UK experience with unconventional gas extraction in which they stated that, "*globally accurate estimates of the human populations exposed to UGE [unconventional gas extraction] chemicals, by-products, and contaminants do not yet exist.*"⁷¹

The strength of the US evidence on the health effects of airborne contaminants is mixed. **Table 10.2**, adapted from a recent review of health studies around Colorado,⁷² illustrates this point. While there has been some criticism of the citation of this review,⁷³ the Panel found it to be a useful summary by a competent US Public Health authority of the weight of evidence behind such adverse health effects.

65 Meng and Ashby, 2014; Meng 2015; Meng 2017.

66 McKenzie et al. 2012.

67 Rogers et al. 2015.

68 McKenzie et al. 2012.

69 Webb et al. 2016.

70 DPIR submission 226, Appendix H, pp 335-336.

71 Watterson and Dinan 2016, p 486.

72 McMullin et al. 2017, Table 2.

73 Health Professionals Against Fracking, submission 1179.

Table 10.2: Summary of overall strength of evidence for epidemiological studies by health effect. Source: McMullin et al.⁷⁴

Health Effects Categories	Number of studies*	Health Effects	Evidence
Birth outcomes	4	Preterm birth	Mixed
		Low APGAR	Mixed
		Small for gestational age	Mixed
		Birth weight (low birth weight and mean)	Mixed
Birth defects	1	Congenital heart defects	Insufficient
		Oral clefts	Insufficient
		Neural tube defects	Insufficient
Respiratory (eye, nose and throat (ENT) and lung)	6	Multiple, self-reported symptoms	Mixed
		Hospitalisations	Failing to show an association
		Asthma exacerbations	Limited
Neurological (migraines, dizziness)	5	Hospitalisations	Mixed
		Multiple, self-reported	Insufficient
		Migraine/severe headache	Mixed
Cancer	4	Overall childhood cancer incidence	Insufficient
		Childhood haematological (blood) cancers	Mixed
		Childhood central nervous system tumours	Insufficient
		Hospitalisations	Mixed
Skin (irritation, rashes)	2	Multiple, self-reported	Limited
Psychological (depression, sleep disturbances)	4	Multiple, self-reported	Failing to show an association
		Hospitalisations	Insufficient
Cardiovascular (heart)	2	Hospitalisations	Insufficient
		Multiple, self-reported	Insufficient
Gastrointestinal (nausea, stomach pain)	3	Hospitalisations	Insufficient
		Multiple, self-reported	Failing to show an association
Musculoskeletal (joint pain, muscle aches)	2	Hospitalisations	Insufficient
		Multiple, self-reported	Mixed
Blood/immune	2	Hospitalisations	Mixed

* A total of 12 studies were included with some studies evaluating multiple health effects

Werner et al.⁷⁵ have also commented that the strength of the epidemiological evidence of health impacts associated with unconventional gas extraction remains tenuous, with many studies of health outcomes lacking methodological rigour. However, they also note that while the evidence is somewhat weak and is focussed more on acute health effects, rather than chronic ones, it is not possible to rule out a relationship between hydraulic fracturing and adverse health impacts. They point out that there are clear gaps in the scientific knowledge that require urgent attention, especially with respect to adverse health effects that may have a long latency.

74 McMullin et al. 2017, Table 2.

75 Werner et al. 2015.

The point is further reinforced by another recent review, concluding that:

"though many epidemiological studies used robust statistical methods to estimate changes in health outcomes associated with unconventional oil and gas development, all had shortcomings that were most often significant. These studies furthermore reported contradictory results for each impact. Some studies, for example, found increases in preterm birth, while others found decreases or no association. As is illustrated by the Community Risk-Benefit Matrix, all impacts had inconsistent findings across the literature for that outcome. Where the results did not contradict each other, the impact was only analyzed by a single study... As a result, even where good evidence is offered for a link between unconventional oil and gas development and health, the causal factor(s) driving this association are unclear".⁷⁶

It is common for health impacts of unconventional gas extraction activities to be assessed by self-reporting questionnaires. For example, a questionnaire-based study of residents around unconventional gas extraction developments in Pennsylvania showed an apparent association of unconventional gas extraction with nasal and sinus symptoms, headache and symptoms of fatigue. While the overall response rate was low (only 7,785, or 33%, of 23,700 survey recipients) and only 23–25% of these respondents reported symptoms, the calculated odds ratios (**OR**) achieved statistical significance for some of the outcomes. These OR (95% Confidence Interval) of 1.49 (0.78, 2.83) for chronic rhinosinusitis (**CRS**) plus migraine; 1.95 (1.18, 3.21) CRS plus fatigue; 1.84 (1.08, 3.14), for all three outcomes, suggested an association, presumably related to airborne VOCs.⁷⁷ Consistent with the hypothesis that distance is a significant factor influencing the dose-response relationship, the spatial distribution showed higher rates of response in areas closest to unconventional gas extraction activity.

McKenzie et al.⁷⁸ carried out a conventional HHRA for both cancer and non-cancer effects around unconventional gas extraction sites in Garfield County, Colorado. The risks were primarily driven by airborne VOCs released mainly during well creation activities (trimethylbenzenes, xylenes and aliphatic hydrocarbons, none of which are part of the HFF used and which were presumably derived from flowback water). The calculated Hazard Indices (**HI**) (where a value greater than 1 represents a likelihood that the combined exposures exceed conservative health-based guideline values thought to be protective of population health) were 1 for residents living less than 0.8 km from a gas well, and 0.4 for residents living greater than 0.8 km from a gas well. The estimated cumulative lifetime cancer risks were 10 in a million and 6 in a million respectively, for distance from source, driven primarily by exposure to benzene.

These findings were confirmed to some extent in a different type of study. Bunch et al.⁷⁹ collected air monitoring data for VOCs at seven fixed sites around Dallas-Fort Worth, analysing these airborne VOCs in comparison with health-based guideline values. The nearby Barnett Shale deposits comprise one of the largest active onshore gasfields in North America, with an estimated 15,870 producing wells across 500 sq miles (1,295 km²). The seven monitoring sites were clustered around the heaviest density of producing wells. None of the measured VOCs exceeded acute health-based guideline values, and none of the annual averages entered into probabilistic and deterministic HHRA programs suggested that the unconventional gas activities would represent a chronic health risk.

By contrast, community-generated air sampling at sites around unconventional gas sites in Wyoming revealed that of the 75 VOCs measured, eight of these (for example, benzene, formaldehyde, and hydrogen sulfide) exceeded Federal health-based air quality guidelines over different operational conditions.⁸⁰

In a review of potential respiratory health risks to children and infants around US unconventional gas sites, Webb et al.⁸¹ cited the extent to which airborne emissions of ozone, benzene and formaldehyde exceeded relevant US air quality guidelines (1 h and 8 h averages for ozone and, chronic exposure (>365 d) Minimal Risk Levels for benzene and formaldehyde). They also cited measured airborne levels of ozone, benzene and formaldehyde from various US studies where acute respiratory effects, including exacerbation of asthma, had been reported. In a more recent

76 Krupnick and Echarte 2017, p 1.

77 Tustin et al. 2017.

78 McKenzie et al. 2012.

79 Bunch et al. 2014.

80 Macey et al. 2014.

81 Webb et al. 2016.

paper, Webb et al.⁸² singled out a group of five pollutants associated with the unconventional oil and gas industry in the US (the metals arsenic and manganese, particulate matter, polycyclic aromatic hydrocarbons, BTEX and endocrine-disrupting chemicals), and speculated on the health impacts these chemicals could have on the developing brains of newborns and young children. The Panel notes that much of this air monitoring data in the above US studies is comparable with, or mostly somewhat higher than, monitored airborne VOCs around gasfields in south-west Queensland (discussed further in Section 10.3.3.2).

By contrast, Brown et al.⁸³ used measured airborne VOC and particulates (PM 2.5) around a Washington County, Pennsylvania, unconventional gasfield to model possible human exposure at a specific residence surrounded by three unconventional gas facilities (1 km, 2 km and 3 km distances) over different stages of activity and different timeframes. The modelled residence was based on data showing a typical distribution of residences around the field (214 homes with 1–7 well pads, 2–5 km away; 85 homes with 1–17 well pads, 1–2 km away; and 31 homes with 1–7 well pads, within 1 km). Modelled peak exposures occurred 83 times over 14 months of simulated emissions, with drilling, flaring and finishing and gas production stages producing higher intensity exposures compared to the hydraulic fracturing stage. Exposures were episodic, with peaks occurring at different times of the day, the highest tending to be at night when air mixing is least likely. This indicates the critical importance of when, and over what period, monitoring is done. The conclusion from this study is that human exposures leading to adverse health effects are possible in the scenarios described, although the authors made no attempt to compare the estimated peaks and average exposures to health-based guideline values.

In a review of 1.1 million birth records from Pennsylvania over the period 2004 to 2013, Currie et al.⁸⁴ found that in utero exposure to fracking activities resulted in poorer infant health outcomes, including lower birth weight, and that the distance from these activities was again a crucial factor. The highest impacts were noted where mothers lived less than 1 km from fracking sites, with effects also noted at up to 3 km, although the effects, as measured by an infant health index, were quite variable between 2–4 km from hydraulic fracturing sites.

Bamberger and Oswald,⁸⁵ in a longitudinal study of the health impacts in humans, companion animals, and food-producing animals around US unconventional gas extraction sites (21 human cases across five states), noted that the reported effects in humans (mainly neurological, respiratory, vascular, dermatologic and gastrointestinal) and animals were variable over the 25 months from first to second interviews. In humans, there was an overall decline in symptoms that had been attributed to the drilling operations (50% of cases), while those attributable to wastewater management (33% of cases) were unchanged. The reduction in reported symptoms was strongest where exposure to drilling operations was reduced, either by reduced operational activity or by families moving away.

The issue of an appropriate distance for well heads and well pads to be 'setback' from human habitation was addressed by Haley et al.⁸⁶ They noted that previous attempts to regulate setback distances⁸⁷ were not based on data analyses or historical events. Rather the regulation was the outcome of compromise between governments, the gas industry, landowners, and environmental/citizen interest groups. They analysed health risks associated with blowouts, thermal modelling and air pollution around three major shale plays (Barnett, Marcellus and Niobrara) in the context of relevant State regulations in respect of setback distances from buildings: 200 ft (61 m) in Texas; 500 ft (152 m) in Pennsylvania; and 500–1000 ft (152 m – 305 m) (high-occupancy dwellings) in Colorado. These setback distances contrast with the 2000 ft (610 m) recommended in the Maryland health study,⁸⁸ the 1,500 m setback recommended by Webb et al.⁸⁹ to protect children and infants living in nearby dwellings and the average setback of 447 m estimated for houses in the UK.⁹⁰ The overall conclusion of Haley et al.⁹¹ was that the setback distances analysed were inadequate to protect public health. While they were unable

82 Webb et al. 2017.

83 Brown et al. 2015.

84 Currie et al. 2017.

85 Bamberger and Oswald 2015.

86 Haley et al. 2016.

87 For example, Fry 2013; Maryland Institute for Applied Environmental Health 2014.

88 Maryland Institute for Applied Environmental Health 2014.

89 Webb et al. 2016.

90 Clancy et al. 2018.

91 Haley et al. 2016.

to recommend more generous setback allowances on the basis of the analysed data, they noted that distance is not an absolute measure of protection, and that other risk mitigation measures (for example, regulatory controls over all aspects of the processes: see Chapter 14) are needed to address public health concerns.

The issue of setback distances from unconventional gas facilities (from drilling or producing wells, pipelines, gas plants, to dwellings, rural housing developments, urban centres or public facilities) has also been addressed by the AER in Alberta, Canada.⁹² These distances range from 100 – 1600 m, depending on the estimated gas release rates and H₂S content of the gas (odour impact).

Recommendation 10.2

That in consultation with the gas industry, landholders, Land Councils, local government and local communities, the Government mandates an appropriate setback distance from all gas well heads, pipelines and gas processing facilities to a habitable dwelling (including all buildings or premises where people reside or work, schools and associated playgrounds, permanent sporting facilities and hospitals or other community medical facilities) in order to minimise risks identified in HHRA reports, including potential pathways for waterborne and airborne contaminants. Such setback distances should not be less than 2 km and should apply to all exploration and production activities.

The distance of 2 km represents a reasonable upper limit of setback distances established in gasfields in overseas regions based on protection of human health from airborne chemicals. In the Panel's view, it represents a reasonable compromise to the 5 km setback proposed in the submission from the Northern Territory Cattlemen's Association (NTCA), based primarily on protecting the amenity of pastoralists.⁹³

10.3.3.2 Queensland health impacts experience with unconventional gas extraction

A number of submissions drew attention to alleged public health impacts associated with unconventional gas extraction in Queensland.⁹⁴ The Panel also obtained further information through interviews and site visits to Dalby, Roma and Miles in July 2017, and through meetings in relation to these impacts from with the Queensland Government, CSIRO, the University of Queensland and GISERA (see Chapter 2 for more detail on these visits).

The information provided to the Panel⁹⁵ described a range of health effects, from skin irritation and rashes to spontaneous nosebleeds, eye irritation, headaches and other relatively non-specific symptoms. More concerning were reports of deaths of livestock and serious development toxicity in farmed pigs.⁹⁶ Many of these reports are consistent with those documented in a survey of human and animal health impacts around US shale gas developments, although these resulted from a mixture of gas flaring events and exposure to contaminated surface waters.⁹⁷ The symptoms are consistent with exposure to irritant gases and vapours, and the impression given by the Queensland experience was that these events were more likely to be associated with gas flaring events.

However, there is a difficulty in correlating the incidents with atmospheric concentrations of any chemicals known, or likely to be, associated with gas flares⁹⁸ or with fugitive emissions from gas wells. During consultations with Queensland regulators in July 2017, the Panel's attention was drawn to ongoing real-time monitoring of a number of criteria air pollutants (carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide and particulates) around CSG installations in south-west Queensland. The online air monitoring data (generally updated on an hourly basis) from monitoring stations at Burncluth, Miles airport, Hopeland and Tara provides some information on air quality in relation to health-based guideline values from the ambient air quality National Environment Protection Measure (**NEPM**).

92 AER 2015.

93 Northern Territory Cattlemen's Association, submission 639 (**NTCA submission 639**); Northern Territory Cattlemen's Association, submission 1203 (**NTCA submission 1203**).

94 For example, P Cass submissions 33, 192 and 463; G McCarron submission 53; K Marchment submission 438.

95 Interviews with Dr GERALYN McCARRON and Mr JOHN JENKYN in July 2017; P Cass submissions 33, 192 and 463; G McCarron submission 53.

96 Interviews with Mr JOHN JENKYN and Ms HELEN BENDER, July 2017.

97 Bamberger and Oswald 2012.

98 Origin submission 469, Appendix E.

The Panel notes that the alleged health effects around Tara were investigated by Queensland Health, which concluded that, *"in summary, the most that can be drawn from the DDPHU⁹⁹ report is that it provides some limited clinical evidence that might associate an unknown proportion of some of the residents' symptoms to transient exposures to airborne contaminants arising from CSG activities."*¹⁰⁰ Queensland Health also noted comments from an independent clinical assessment of the reported symptoms that:

"The reported symptoms, if due in any way to CSG emissions, are more suggestive of intermittent exposure to low-level irritants and odours, rather than exposure leading to significant systemic toxicological effects. It appears clear the reported symptoms are rapidly reversible based on the reports that symptoms improved when residents were away from the area."

The DDPHU report noted that, *"as of 12 November 2012, there were no reported hospital admissions related to CSG exposure."* However, in submissions to the Panel,¹⁰¹ reported hospital admission data over the period 2007 to 2014 showed a sharp increase from around 2010–11 onwards. This upswing in acute hospital admissions (around 133% for circulatory conditions and 142% for respiratory conditions) appeared to coincide with the development of the CSG industry in the region and was mirrored by local emissions of particulate matter (PM10 and PM2.5), formaldehyde and other VOCs, as reported by CSG industries to the National Pollutants Inventor.¹⁰² One curious aspect of the hospital admission statistics in the McCarron paper (2018) is that they appear to occur across all regions of the hospital catchment area, including areas where CSG development has not occurred (as shown by the graphical distribution of gas wells and flare sites in her paper). Queensland Health notes that, *"further investigation of these statistics is required to determine impacts of other factors such as population growth, changes in demography and other social and environmental stressors"*.¹⁰³

During development of the Santos GLNG project in Queensland, a report¹⁰⁴ submitted to the Queensland Department of the Environment outlined the gaseous and volatile chemicals likely to be emitted from CSG sites, including chemicals likely to result from gas flaring. The report included baseline data from two monitoring stations installed at Fairview and Roma, comparisons with air quality data from Toowoomba, along with modelling data for air quality in the region attributable to background and to gas compression, production wells, vehicle emissions and flaring activity. The modelling included estimates of air quality up to 5 km from the sites, and showed that estimated one hour averages for nitrogen dioxide and carbon monoxide were below relevant air quality standards, even when background emissions were included. The report also noted that airborne emissions would be highly variable, with emissions associated with well construction, decommissioning and rehabilitation being temporary.

While the air monitoring data suggests that the level of criteria air pollutants is well within NEPM guidelines, the Panel acknowledges the difficulties in matching the air monitoring data with any known flare events or other emissions from CSG sites.

99 Queensland Health 2013, Appendix 1, Dr Penny Hutchinson. (January 2013), The Darling Downs Public Health Unit (DDPHU) investigation into the health complaints relating to CSG activity from residents residing within the Wieambilla Estates, Tara, Queensland - July to November 2012. This was one of several reports considered by Queensland Health in its 2013 response to the issues raised.

100 Queensland Health 2013, pp 6-7.

101 G McCarron submission 53.

102 McCarron 2018; W Somerville submission 1170.

103 Queensland Department of Health, submission 654.

104 Santos GLNG gasfield development project; environmental impact statement, air quality impact assessment (report no 620.10745-R1, August 2014), cited in Santos submission 168.

10.3.4 Impacts associated with increased road traffic

The Panel notes that risks associated with increased road traffic were addressed in some of the submissions and have been raised anecdotally by some members of the public during community consultations. In particular, it has been noted in some industry submissions that driver training and promotion of safe work practices is a priority for addressing and mitigating this potential risk.¹⁰⁵

The issues are canvassed more broadly in a review by Adgate et al.¹⁰⁶ and are also cited in the submission from the Public Health Association of Australia.¹⁰⁷ However, the Adgate et al. review cites evidence drawn from studies in the US, where the proximity of communities to unconventional gas sites may not be as relevant to the situation in the NT. In particular, the Adgate et al. review notes that an increased incidence of road accidents is primarily associated with increased truck traffic in residential areas.¹⁰⁸ Whether or not increased truck traffic will occur in residential areas of the NT will depend on where any proposed shale gas industry will be located and the routes used to access those locations.



Entry point to the Origin Amungee NW-1H exploration well lease pad on Amungee Mungee Station.
Source: Origin.

The Panel's assessment of the risks relating to increased road traffic is outlined in more detail in Chapter 8 (Section 8.5.2). While the Panel's analysis acknowledges that the lack of data on potential traffic movements makes it difficult to assess the likelihood and consequences of traffic-related impacts on land use and amenity, the potential public health impacts are equally difficult to categorise. The potential public health risks of increased vehicle and equipment transport activities are most likely to be associated with exhaust emissions and road trauma from accidents, although the stress of driving on roads crowded with heavy vehicles may be another factor affecting health. The magnitude of these potential risks will vary according to the scale of any gasfield development and according to the phase of any onshore shale gas development (higher during drilling and exploration, and lower during production). The gas industry provided some data on increased traffic movements related to CSG projects in Queensland, but comment was made that, *"projects in the NT will be less dependent on public roads due to the location of the fields. The findings of QLD assessments may not be directly relevant to the NT. If development was to proceed in the NT, similar modelling would be undertaken based on local conditions and development plans."*¹⁰⁹

105 For example, APPEA submission 215, p 114.

106 Adgate et al. 2014.

107 PHAA submission 107.

108 Adgate et al. 2014.

109 APPEA submission 421, pp 5-6.

The Panel's assessment of the public health risks associated with diesel emissions from vehicles and other particulates (dusts) is that the likelihood is 'medium' (but likely to be of relatively short-term impact during the pre-production phase of well head and facility development), and the consequence is 'low' to 'medium' (which is likely to depend on controls over equipment movements and/or dust suppression measures). The overall risk level is therefore 'low' to 'medium'.

Mitigation of these risks will be addressed through the implementation of **Recommendation 10.2**, namely, the setting of appropriate setback distances.

10.3.5 Impacts on social cohesiveness, mental health, and wellbeing

The Panel notes that this risk has been identified in some of the submissions and was raised by some people during the community consultations. The issues are discussed in more detail in Chapter 12, and in particular in Section 12.3, although the Panel has been unable to find a sufficient amount of cogent evidence that is required to evaluate the magnitude of this risk to public health. Psychosocial and socioeconomic impacts, both positive and negative, were reviewed by Adgate et al.,¹¹⁰ with an emphasis on stressors such as increased truck traffic, noise pollution, accidents and psychosocial stress associated with community change, as well as the impacts of chemical stressors. Ferrar et al. (2013)¹¹¹ also reported on an interview-based survey of health effects and related psychological stress factors in communities around the Marcellus shale development in the US. Impacts of rapid sociological and economic changes have also been reviewed in mainly agricultural communities in the same region,¹¹² but again, the relevance of these largely US-based studies to any onshore shale gas industry developments in the NT is questionable.

However, the Panel also notes that in a recent review of health impacts of unconventional gas extraction, the limited number of available studies on psychological impacts, only allowed the evidence to be graded as either "*insufficient*" or "*failing to show an association*" (see **Table 10.2**).¹¹³

Finally the Panel notes that some of the submissions from the gas industry suggest more positive effects on wellbeing associated with improved employment opportunities and improved social benefits and facilities associated with an onshore shale gas development.¹¹⁴ CSIRO, in collaboration with GISERA, has, for example, reported on the range of community responses to the social and environmental impacts of CSG development in the Western Downs region of Queensland.¹¹⁵ For further detail, see the discussion in Chapter 12, particularly in respect of the need for a separate cultural and social impact assessment to be undertaken prior to any onshore shale gas production approvals being granted.

110 Adgate et al. 2014.

111 Ferrar et al. 2013.

112 Perry 2012; Brasier et al. 2014.

113 McMullin et al. 2017.

114 For example, APPEA submission 465; Origin submission 153; Central Petroleum Limited, submission 99 (**Central Petroleum submission 99**); Central Petroleum Limited, submission 442 (**Central Petroleum submission 442**); Oilfield Connect Pty Ltd, submission 174 (**Oilfield Connect submission 174**); Pangaea Resources Pty Ltd, submission 60 (**Pangaea submission 60**); Santos submission 168; Schlumberger Australia Pty Ltd, submission 460 (**Schlumberger submission 460**).

115 Walton et al. 2014, cited in APPEA submission 465.

10.4 Conclusion

Knowledge of the potential health risks associated with unconventional gas has evolved slowly over time, with some published reviews and reports acknowledging that the risks are still unresolved. For example, the 2015 review by Werner et al. summarises the gaps in knowledge at that time and points out why epidemiological studies had so far been unable to answer some of the key questions relating to health impacts.¹¹⁶ The following quote from a Canadian review also makes this point, although since it was published in 2014, some of the issues have become less equivocal:

*"But the literature on the risks of hydraulic fracturing, while voluminous, is not clear. The most authoritative studies by governmental academies and agencies suggest that more information needs to be gathered, but at present the risks are judged to be modest and manageable with existing technologies."*¹¹⁷

The conclusions of a UK review into shale gas relating to potential public and environmental health impacts were more succinct:

*"Shale gas can be produced safely and usefully in the UK provided that the Government insists on industry-leading standards... The risk from shale gas to the local environment or to public health is no greater than that associated with comparable industries provided, as with all industrial works, that operators follow best-practice. Much of the negativity surrounding shale gas production originates from communities, largely in the US, where operator standards were lax. There is now strong evidence compiled by the Department of Energy in the US that shows that standards have improved dramatically in the last few years. There has been understandable concern – and even fear – as a result of the lax standards. However, the Task Force is convinced that this highlights issues with regulation and enforcement from which lessons must be learned, not issues with the process of hydraulic fracturing itself and subsequent gas production."*¹¹⁸

However, in its Second Interim Report, specifically addressing the impact of shale gas on the local environment and health, the UK Task Force noted that, *"the amount of evidence available is limited and largely based on pre-green completion (US) data. More research needs to be conducted and should continue to be conducted if an industry develops."*

As pointed out in a submission to the Panel,¹¹⁹ the Scottish Minister for Business, Innovation and Energy¹²⁰ reached a similar conclusion about the status of the epidemiological research. This was used, however, to support a 2017 decision to implement a permanent moratorium on unconventional oil and gas development in Scotland.

Other reviews focussing on airborne emissions from unconventional gasfields (VOCs, dusts and methane) have reached similar conclusions about the need for enhanced air monitoring to inform risk management and to better understand the potential for air pollution at different stages of any unconventional gas development.¹²¹

The Panel's analysis and recommendations in this and other Chapters, acknowledges some of the knowledge gaps that will need to be addressed through the SREBA to better inform the HHRAs and predictions of potential impacts on public health. Among these are the need for better baseline information on regional public health prior to any gasfield development (discussed further in Chapter 15) and further information on proposed sites for well pad development, so that the proximity of human receptors in landholder housing and residential communities can be factored into the CSMs needed to inform a detailed HHRA for these specific sites.

This last matter is crucial given the consistent conclusion of the Panel that only HHRA determinations that are relatively site-specific will provide meaningful information on the public health risks to surrounding communities.

¹¹⁶ Werner et al. 2015.

¹¹⁷ Green 2014, p 24.

¹¹⁸ UK Task Force on Shale Gas 2015.

¹¹⁹ G McCarron submission 508.

¹²⁰ Wheelhouse 2017.

¹²¹ Australian Department of the Environment and Energy 2017c.

The outcomes from the NCRA¹²² also highlight the need to conduct site-specific risk assessments for identified higher-priority chemicals, because site-specific factors can either increase or decrease the level of risk that can be posed by their use. These factors include distance from the gas extraction well to the nearest creek line or sensitive surface water body, the permeability of the surface soil horizon in the vicinity of the well, and how well the soil is likely to bind to a released chemical.

The overall conclusion of the Panel with respect to impacts on public health of any onshore shale gas activity in the NT is that the risks associated with chemicals released to groundwater and surface waters will require appropriately robust management and regulatory controls, and that the risks of airborne gases, VOCs and dusts can be mitigated by the imposition of appropriate setback distances.

¹²² Australian Department of the Environment and Energy 2017a-d.