Scientific Inquiry into Hydraulic Fracture Stimulation in WA
Perth Public Meetings – 28 February 2018

1. INTERESTS REPRESENTED

- Agricultural research and management
- Community health
- Community natural resource management
- Capel Gas Free South West Alliance
- Doctors for the Environment Australia
- Engineering
- Environmental advocates
- Environmental consulting
- Farming
- Frack Free WA
- Fracking industry
- Gas Field Free Metro Action Group
- Geology and Petro-physics
- Indigenous community
- Knitting Nannas
- Local Government
- Lock the Gate
- Medical Students Association
- Mineral sand mining
- Oil and gas industry (exploration and production)
- Pastoralists & Graziers Association
- Sustainable Energy Now
- The Wilderness Society
- Uniting Church

2. SCOPE OF DISCUSSION / ISSUES TO ADDRESS

a) Scientific analysis of risks: environmental, health, agricultural, heritage and community.
b) Describe regulatory mechanisms that may be employed to mitigate or minimise risks to an appropriate level.

3. CONCERNS / RISKS

3.1 Water

- Aboriginal people say No to impacting artesian water resources
- Threat to Perth’s groundwater supplies
- Biggest issue, water (Yarragadee aquifer)

- Severity of impacts too great on water and water use
- We need to save water, a precious commodity
- Competing uses - fracking takes good water away from the communities and water used by fracking is contaminated and cannot be re-used
- Dry state - concern about water resources impacts, particularly in food bowl area
- Swan Valley, Caversham, Chittering are over a reserve of water which is very pure; concern that this water would be contaminated and destroy ability to live there, to grow grapes, citrus and other produce, and that their properties would be taken over without any say in the matter

Water quantity
- Water licensing - concern regarding the amount of water required for fracking, especially in horizontal wells, considering the current state of water resources, especially in food bowl and farming areas
- Huge amount of water used when we have water restrictions
- Water use, water drawdown, industry acknowledges that this is a water intensive process
- Concerns regarding the amount of water to be used, 30 million litres per well; a single shale gas frack uses 11.34 million litres of water; 14000 wells in Perth basin, 41720 in Kimberley (Frogtech 2013)
- Perth Hills – water drying up in groundwater bores; concerned that this is going to happen
- Yanchep National Park: Perth water/bore field; water levels dropped significantly after borefield installed; dry lake – extinction of species
- Water shortage - desalination too expensive

Water quality
- Groundwater contamination, particularly of potable aquifers
- Fear of water pollution from fracking fluids and breaching aquifer
- Surface water contamination from spills
- Flow-back water saline impacting the human population and wildlife
- Canning Basin fracking likely to be kilometres deep, below groundwater, making contamination highly likely, both below ground and on surface, and then into other parts of the environment
- Some fluid causes flow-back; numerous reports of water contamination by people living close to gas fracking areas.
- The massive volumes of waste water not necessarily properly treated; then reinjected underground or into waterways
- Queensland has claimed that contaminated water could be treated, but now know that it has to be dumped
- If fracking proceeds, whole artesian basin will be destroyed and will rely on desalination
- Already have the example of salinity messing up water

Water experiences

- Water contamination – low probability of happening; no pathway for fluid to water table; baseline and continuous monitoring – zero evidence of contamination
- Industry doing groundwater monitoring after fracking to check if the barriers have broken down and the aquifer compromised
- Numerous offences by petroleum companies using unlined waste pits, discharging water into creeks, killing vegetation and contaminating water.

3.2 Amenity

- Visual impacts on landscape
- Impact on tourism
- Aesthetics

Air quality

- Exposure to pollutants especially in air, volatile organism compounds fine silica, oxides of nitrogen, hydrogen sulphide, formaldehyde, ground level ozone and diesel fumes; corrosion inhibitors, toxic and carcinogenic compounds
- Methane emissions - see studies in Whan literature review
- Literature - between 2% and 17% of gas from wells is leaking and methane is lost through harvesting
- Industry is not monitoring wellhead methane releases.
- How much Hydrogen sulfide and methane?
- Vent pipe to release gas (methane and others) - odours, exposure, fire
- Commonwealth Scientific and Industrial Research Organisation has shown that contaminants at a fracking site in Australia are significantly less than an Australian urban environment
- Dust

Greenhouse gas

- Fugitive emissions/gas released by fracking adds to greenhouse gas emissions
- Paris Agreement and COP23 require reduction in carbon emissions

Noise

- trucks, drill rigs, machinery, 24 hour pumping
- Increased trucking movements with transport of gas and chemicals

3.3 Human health

- Short and long-term impacts on human health and well-being is the ultimate issue
- Correlation with pre-term births, asthma, cardiology, neurological, severity with proximity

- Psychological health, socio-economic – DEA 550 paper
- Degradation of farmland – suicide
- Farmers stress – mental health issues
- Biopsychosocial impacts
- Indigenous (remote) community disproportionately affected
- Impacts on food, water, air and climate will impact human health
- Interrelated public health risks at each step of the process; there will be chemicals harmful to people, contamination will occur (related to spills, etc) in community; difficult to ensure safety
- Individual chemicals may not be a problem, but in quantity and mixed may be a problem; overseas experience shows many problems
- Release of chemicals into environment, poorly quantified and difficult to predict; unforeseeable events; unknown toxicity of components, if identified; hence unknown timing and quantity of release, public exposure and danger to public; chemical toxicity involved with fracking and exposure to affected water; several public health bans overseas because of inability to ensure safety, e.g. Scotland
- Hydrocarbons, heavy metals are carcinogenic and endocrine disruptors; testing is not fit for purpose for exposures which can't be mapped, and can't predict vulnerable populations.
- Benzene is found in some of the effluent; it is carcinogenic
- The products resulting from the combination of chemicals from fracking and flow-back are not biodegradable; they can be taken up the food chain
- Concerned that fracking wastewater may be used for dust suppression; children climb through this environment
- Concerns about organic compounds, what is disturbed and what comes out, the release of heavy metals and the resultant contamination and what is released back into the environment. The remote areas are suffering from a high percentage of kidney disease because of the exposure to nitrates in drinking water. Bore water has a high level of nitrates.
- Cardiovascular illnesses near gas fields, higher stress and emotional impacts due to chemicals, gas emissions, noise and industry lack of honesty
- Exposure to high levels of methane, causing respiratory, eye, nose irritations; when methane is burnt, it produces ozone, and breathing it is like putting acid down your airways, it almost acts like radiation and we have no idea if this will be passed on to offspring and future generations
- Public health and medical organisations are calling on governments to protect people's health, Doctors for Environment of Australia, Public Health of Australia, Australian Medical Association, national toxics network, Australian Phycological Association, Australian College of Nursing, Australian research alliance for children and youth
- Reports of requirements for secrecy by medical practitioners (New South Wales, Victoria, Queensland, United States) not allowed to report the illnesses of presenting patients

- Statistics collected by a local General Practitioner in Tara Queensland in relation to fracking;
- Peer review study which talked about increased hospital admissions in Toowoomba; spread of wells in farmland, impacts on farms, land devaluation
- This is a new industry in terms of completeness of health information; now seeing hundreds of papers regarding health risks, documented increased risk of cancer near wells, baby abnormalities, pre-term birth, supportive of a relationship with toxicity from wells
- Should learn from experience of Wittenoom, a no-go area
- Data shows increase in levels of chemicals in the air, and lack of government response; many years ago, we used lead everywhere, and then it was discovered to be an issue; we used asbestos, until people got sick. In all these situations, it took so long for issues to be evident. This seems to be similar. We had better be sure that if we are going ahead with fracking, that we will not have the same issues. No water to drink and no food to eat. Nothing is convincing that there will not be the same issues.
- From personal risk analysis perspective, I spend 50% of time on subsea engineering; a lot of engineering expertise goes into managing risk sub surface; this is applied throughout the industry
- People in industry show no health affects – Australian Petroleum Production and Exploration Association website has studies on health
- It took about two years to get approval for a pilot program; rigorous monitoring showed no impact. The traditional owners took part in the monitoring and the results were made public. Air quality monitoring by consultants showed a marginal increase in methane (same as being a couple of kilometres from a landfill). Fracking fluid was tested by an ecotoxicological and environmental assessment company and it came up as below toxicity, less toxic than swimming pool water. Flow-back water almost met stock-water guidelines; it was above drinking water guidelines with radioactivity
- Experience in a community associated with the industry; oil and gas workers concerned for their own safety
- Experience of mining areas with health problems (Midland, WA); dealt with asthmas due to air conditions, kidney disease, mesothelioma, cancer due to genetic and environmental factors, lung from coal mining and chronic health sufferers
- Experience of having to use a water filter because working in a highly damaged environment
- Workers are getting silica contamination with lung problems

3.4 Environmental health

- Fracking meets the definition of ‘environmental harm’

- Concerned about scale of industry; 400m tractor width seismic survey; disgusted with size of exploration area
- When you see maps in the Terms of Reference people think that it's an enormous area that is all going to be fracked. This is not the case. Impact environmentally is constrained and contained. Small pad sizes 150 m^2 can drill 20-30 wells from one location. Risks of scale are low. Starts with small scale to prove project.
- Threat to highly sensitive environments, ecosystems (including groundwater dependent ecosystems), soil profile
- Concerned about interconnection of Ramsar wetlands and surface and groundwater
- Habitat fragmentation from clearing and linear infrastructure
- Roads being put through floodplains affecting watercourses
- Midwest soil disturbance, fragility of environment, geological instability, soil disturbance of any kind
- Fractured land
- In the great west woodlands, infrastructure caused landscape fragmentation, altered surface hydrology by erosion, pooling 5 and 6 times higher on road. Effects flows and natural overland flows, changing moisture regimes, dry and saturated areas. Soil degradation. High well density in unconventional fields, 100-1000s times higher than conventional gas. Restoration not possible; Allred et al NA Ecosystem lost to oil and gas. 2015 Science study, demonstrated that accumulating land degradation has resulted in continent wide impacts in the United States, loss in carbon absorbed by plants.
- Western Australia has a legacy of environmental impact from processes and destruction from mining
- We need to save land
- Drilling may cause sink holes
- Olympic size pool evaporation ponds
- Land impacts, Whicher Range will be ruined after moratorium

Climate change

- Climate and the impacts to climate change - honour our agreement to the Paris Agreement; climate and health are interconnected
- Climate impact/life-cycle
- Large industry – will it allow Australia to meet climate targets
- The Australian Institute quotes that methane emissions in unconventional gas are largely underestimated; Melbourne University has recorded methane gas leakages
- Methane global warming capacity is 20 times that of CO_2; already too much methane emitted, even before fracking; would represent a vast contribution to global warming
- Studies in the United States show that methane emissions and the total carbon footprint as a whole are higher. Lafleur 2016 study of the US

- The footprint of methane is higher than coal in this process.
- Climate change concerns, methane 86% more potent from wells; should be left in the ground.

Cumulative impacts
- Cumulative impacts of water usage and cumulative contaminations
- We need to look at the long-term effects not the short-term benefits.

Reserves
- Limited areas under conservation, unlike proposed exploration release areas
- Kimberley proposed conservation estate needs review
- Heritage listed areas

Invasive species
- Introduction of weeds and invasive species that cannot be managed (prickly pear, rabbits, foxes, cane toads)
- Biosecurity

Biodiversity/terrestrial flora and fauna
- Dingo death; cause unknown; there had been dog baiting at the time
- Eneabba area has most number of flora per hectare in the world
- Concern all flora in Kimberley will be gone in whole area; new moth species in exploration area
- Aboriginal flora picking will be impacted
- Linear infrastructure – predator highways
- Still discovering species in Kimberley; we don’t know enough about biodiversity
- Local hydrology critical to local flora/fauna
- Lights and impacts on birds
- Detrimental to livestock and animals, mainly due to water contamination; by accident, negligence and normal operations; manifested in deaths and failure to breed

Fire/safety
- Gas flaring during total fire ban
- Flaring methane raises concerns; permitted during fire bans
- Flaring in summer

Seismic activity
- Damage done through seismic activity
- Oklahoma is now experiencing earth quakes as a result of fracking and has had to stop fracking

- Has seen beautiful land put aside for seismic monitoring in Midwest. Carneys feeding nearby. Just vandalism for exploration. Seismic work is very destructive.
- Induced seismicity - Globally – evidence of seismic effects
- Most of activity recorded in Badgingarra originated in Asia
- In the Coorow/Meckering earthquake, the watercourses were changed, and water wells dried up. If fracking is occurring where watercourses are, wouldn't it change the watercourse, and potentially be consumed by the public

3.5 Fracking process

Retention ponds

- Overflowing retention pond in the Kimberley in 2013
- Fauna perishing in the waste water ponds
- Risk of effluent dispersal from a cyclone or natural flood event
- Industry - pumps out the excess after rain to prevent overflow, approved by Department of Mines and Petroleum; covers ponds with netting to prevent animals being trapped

Well integrity

- Well integrity issue in Dongara noticed by a member of the public
- A gas leak in the Kimberley believed to have been leaking for over two years
- Industry statistic, about 5% of wells leak immediately, 51% after 15 years and 60% after 50 years. Over 9% of shale gas wells leak over the first 5 years
- 75% of wells have integrity failure (Davis et al 2014)
- Well head leaking an hour out of Broome; investigation result was that the valve was deliberately bent, a person was charged
- Evidence of well leaks in Whan literature review, confirmed by industry, which admits the risks
- Are wells susceptible to earthquake stress?

Materials/chemicals used and managed

- Chemicals used are toxic; they come to the surface and are held in tanks
- Heavy metals and materials going through aquifers with these processes
- Concern about the nitrates used; will be present in the water and go down into the bedrock
- Fracking fluids react with natural substances
- Found nitroquinoline-1-oxide; is a concern
- The chemicals going into wells are likely to be the same everywhere, but the flow-back fluid can be different
- Risks associated with the land transportation of the fracking fluids

- Whicher range – exploration previously has left diesel in the wells and they have just capped it. Concern about leak. Conventional techniques didn't work; tried diesel and left down there
- Impacts from treatment of wastewater
- Concern about use of chemicals in areas that support the food industry
- Methane coal seam and fracking is being confused. South of Dongara a private British company owns patented fracking product. No problems fracking but can be improved in terms of safety to make it 100% safe

Regulation experience

- Monitoring of gas exploration is less rigorous than monitoring of gas production
- Poor and non-existent control of the industry
- No faith in regulatory bodies, resourcing to do job or legislative requirements
- Industry - environmental management plans and monitoring are constructive and adequate for fracking to continue; the current Department of Mines, Industry Regulation and Safety regulations are fine; demonstrated by experience of Dongara and Eneabba field, Woodada well, Senecia well
- Incidents found by community members and reported publicly by community (3rd parties)

Risk assessment

- Is a new industry in Western Australia, treat with caution
- Key issue is risk; risks are permanent to the environment, not mitigated over time, especially any damage to an aquifer
- Fracking poses an unaccepted health risk
- Industry says the practice has moved on and improved, but the risk is still there
- Community is not willing to pay for it; knowledge not there to do risk assessment; even with better geology; concrete and steel are not enough; legitimately we cannot afford the risk
- Risk of individual well failure is low, but with thousands of wells, failure is a certainty and consequences of a contaminated aquifer are catastrophic. Risk analysis needs to be accurate and at this level. Failures are difficult to detect and can take 30-40 years to happen/be noticed, when industry is long gone, and the contamination may take another 50 years to correct
- Not unless guaranteed water source protection, no harm to others and without challenging other economic opportunities of other West Australians
- Invoke precautionary principle (as it has been overseas) and principle of intergenerational equity, key planks of the Environmental Protection Act (EP Act)
- Precautionary Principle. "If in doubt, don't". Australian Medical Association has suggested that this principle should be adopted

- No advanced research regarding risk analysis; minimal understanding of geo mechanics; not well mapped; may exacerbate existing faults in aquifers. Large methane leaking in deep aquifer in Woodada Deep
- Companies should be compelled to prove that fracking is safe; people don't trust that regulation will control and reduce risk; the risks are too high
- Scientific risk analysis by geologist and petro-physicist in the industry who has worked worldwide: never seen conformance issues, never seen impacts outside zone of design, no evidence to suggest cross flow, industry best practice procedures are well established; enquiry should not just focus on Western Australia as world experience has a lot to inform this process.

3.6 Country/community

- Heritage listed areas
- Connection to land spiritually; scientific nature counters spiritual terms of Aboriginal peoples; disconnect from country; songlines disrupted; loss of access to sites – doesn't quite fit framework of big picture; everything relevant
- Although the terms of reference don't include the social component, it has to be a government decision that satisfies the social project - people; can't ignore evidence from other jurisdictions
- Damage to rural communities
- Loss of farm land
- Landholder rights – farmers, Traditional Owners
- Darling Downs was best agricultural land in Australia; now it is ruined for life; farmers lost livelihood; bores ran dry; led to suicide; gas miners knock down fences; can't get bank loan; farmers treated with contempt
- Infrastructure interferes with the efficiency of food production
- Draw attention to communities to be affected; huge difference in power between companies and grass roots communities; people in city don't realise importance of what people are fighting for – their communities
- Kalamunda local producers (vineyards, white asparagus, oranges, organic farms) concerned that risk to water quality will impact the produce, taint the brand, impact exports
- Industry program in 2015 - a couple of hours out of Noonkanbah - Fitzroy Crossing; undertook an independent review of the risks to water; funded the community to get independent advice on the groundwater; community undertook the work; company provided employment and training and the community seemed happy with how it went. The community released a media statement saying that from their perspective the program went well and that they liked how we worked with them. They don't have many opportunities and they are very keen for another one
- Native title and pastoral lease over the area (Noonkanbah); industry negotiates a land use agreement with Noonkanbah for the oil field and fracking. It outlines royalties to the land owners, Department of Mines,

Industry Regulation and Safety, and the native title holders. The community is more keen for work than royalties

Sense of place

- Must consider whole sense of place, and what it means for well-being and mental health
- Agricultural people end up living in industrial estates

Economics/jobs

- Without fracking and economic expansion, jobs may be lost
- Sold as job creation proposal – is not the reality
- Do harm and go - ruined
- Tourist industry harmed
- Gas helps jobs – No, inflates economy and leaves
- The renewable industry is real
- Economics of the industry are marginal; business cases are poor and probability of success low; leads industry to cut costs in design and materials, then maintenance and rehabilitation, pushing the risk profile through the roof
- Kalamunda community would prefer investment in wind and solar
- Call for a rigorous and thorough cost benefit analysis comparing gas and other energy supply alternatives such as wind and solar
- Capel – historic mining town, not much local employment from fracking; concerned that no unskilled employment
- Fracking is a minute amount of short term money, which will have long term impacts also on employability and profit in these areas by making these areas unusable
- Queensland government socio-economic report: 10 fracking jobs – 18 agricultural jobs lost; key concern would be Midwest
- Fracking operates at the expense of other industries, such as agriculture, tourism
- Sum of all activities - water contamination, infrastructure, roads/pipelines through farmland, fragmentation of farmland, noise, light, air pollution, human health and decrease in agricultural productivity

3.7 Philosophy/ethics/natural justice/policy concerns

Ethics and natural justice

- There is an assumption that gas industry should have the right to do this, and the onus is on the public to prove they shouldn't; on the other hand, pharmaceutical companies are required to prove safe. Whatever the arguments, the industry can do it anyway
- Address rights of people and property owners to say no, and human rights in general

- Disempowering aboriginal rights/land claims; no respect for land rights/sacred site
- It should be more about consent rather than consultation, so that landowners have the power to consent or say no, rather than just be consulted
- Northern Territory holders, landholders and community should have right to say No
- Yawuru people said No – wells were drilled anyway
- Process currently favours companies because land owners do not have authority over the land below ground level; need constitutional change to property ownership
- Property worthless due to mining licence; no respect; right of refusal; can refuse wind towers – why not gas
- Companies are underinsured, yet farmers have been refused insurance to cover the risks from fracking
- Australia was mining asbestos when medical students were being told of its dangers; and yet the Australian Government continued to mine asbestos. The history the company responsible - went overseas to avoid their responsibility from asbestos mining
- We will be told that everything is safe, but don't have confidence in the industry or government; there are too many knowledge gaps and too much literature warning of the risks
- Gas companies don't have a history of honesty;
- Experience resulted in a general lack of trust in the government regulatory framework
- Two main petroleum company players pay zero corporate tax, so we get nothing back from this and they get all of their underground water for free; so there is nothing for Western Australia
- If a consenting neighbour is adjacent to non-consenting party, then the latter should not be impacted by the fracking activity
- Issues with accessibility and resources for Land Court - Family thought they had to go to land court, ran out of money, signed land access agreement; Access agreement deceptive, hard to understand for land holders
- Intergenerational equity – responsibility to leave environment in a good state

Policy

- Concern about political influence by gas industry; Mining departments speak as if they are industry
- Mines and Petroleum seem to take precedence over environmental significance
- Competes with irrigated Agriculture and 'Water for Food' policy
- Insecurity of a moratorium rather than legislation
- Discussion of risk mitigation and risk minimisation focusses on the risks of mining rather than considering not mining at all.

- Government departments that are there to protect environment (Department of Environment Regulation, Environmental Protection Authority, Department of Water) all seem to favour a mining outcome; Western Australia supports mining above section 75 of the Mining Act in relation to public interest
- Current State legislation says that oil and gas are priority resources. I argue that they are not priority resources or they won't be soon and therefore the petroleum act should not have priority over the EP Act. All mining should be considered the same under the same legislation
- Northern Territory terms of reference are better than the Western Australian terms of reference; they mention sustainability and precautionary principle
- This is a political matter about land use; fracking conflicts with the state's water security and agricultural land purposes
- Long term water security is of concern; increases reliance on desalinisation
- Why are we working towards increasing gas production when there is a surplus in the state? Have more than enough gas – sold overseas – based on money not needs
- Sustainable energy modelling has looked at gas supplies and future gas needs; conclusion is that gas from fracking not needed as there is sufficient gas from conventional sources (for domestic and export purposes) until the renewable industry is developed
- Unconventional gas will be uncompetitive because of the extra costs involved; United States experience is that fracking is uneconomical
- A lot of our gas resources are offshore, and how much of this is being exported; we have a 15% reserve for Western Australia.
- Gas may address energy needs, but increases greenhouse gas emissions
- Focus is on money and GST
- Consider economic and social risks of not developing industry
- Modelling done to characterise energy needs - advocates moving to 85% renewable energy and 15% non-renewable to provide for business as usual energy. What is the need for the use of the gas?
- World trend to reduce investment in oil and gas; International trend of gas prices falling over the past few years

3.8 Information/communication matters

- Lack of transparency by industry and government, misleading of the public
- Rural community does not trust regulators and government is not visible to the community on the ground
- Examples of misleading and false information, and intimidating behaviour by industry
- Scientific evidence is around but not heard
- No confidence in scientific inquiry - Information for meeting shows the outcome is pre-determined – information and regulation
- Truth

- Uncertainty
- Not able to find through Freedom Of Information, unable to take evidence away; Not transparent process
- Unable to access environmental documents
- Information must be made public, e.g. biodiversity survey done by department but not available; no information on land clearing
- How to make decisions as a society if information not available to everyone
- Make information on water licence approvals public
- What happened to 2015 senate inquiry
- Concern is this has become an emotional discussion and not a technical discussion and therefore the facts are not being properly conveyed and not properly heard or understood by the public

Knowledge gaps

- Data would seem to be an issue; takes many years to acquire
- How rigorous is the current data? Is it sufficient for assessments? Is there a gap in information and can it be bridged by further research?
- Difficult to gather evidence on a new concept, so should take information from other country/world literature
- Community health knowledge; concern that there are a lot of gaps in information related to human health and the impacts of the chemicals used
- Intergenerational human and environmental health impacts
- WA data on gas seepage/methane leakage
- Inadequate vegetation and legitimate fauna work
- Independent research on well integrity
- Understanding of the broader hydrogeology/geological structure, there should be assistance to landowners so that they can have two sides of the story, so that they completely understand the consequences and the pros and cons of fracking, presented to them by an independent body
- Life cycle of emissions, cumulative emissions and climate impacts; how emissions are measured; total emission scenarios - research
- Modelling for WA’s future gas needs
- Requirement for research and investigations undertaken independently (not company or government), independent monitoring of wells – quantity and quality; need more understanding of water in the fracking process, leaks and spills

4. Regulatory considerations; What regulatory mechanisms may be employed to mitigate or minimise risks to an acceptable level?

4.1 Regulation framework

Critique of current framework

- Current regulatory structures found wanting; not confident that impacts of fracking can be managed
- Regulation should be a national issue, not a State issue; water trigger in Environment Protection and Biodiversity Conservation Act as a matter of national environmental significance multinational enterprise; undertook investigation of coal seam gas in Victoria, New South Wales and Queensland on compliance with federal legislation; why is most diverse flora area not a federal issue?
- Big issue is PAGER (Petroleum and Geothermal Energy Resources) Act 1967; concern that government literature states lead agency is Department of Mines, Industry Regulation and Safety (DMIRS); it operates under petroleum legislation; DMIRS' role is to promote and develop industry; Act has issues – access requirements, compensation, bonds, rehabilitation
- PAGER Act needs updating
- General history of lack of enforcement for non-compliance Part IV mining and clearing; failure of government to monitor existing wells
- Concerns regarding regulations, there are none; concerned that regulations won't go far enough; organisations will do what they want.
- Worried about "best practice"; ALARP (as low as reasonably practicable) inappropriate; want to see limits
- If Department of Mines and Petroleum (DMP) grants licences, and DMP is supervising the environmental effects, isn't this a conflict of interest? Puts forward mining as a commercial benefit. Supervision should be given to a strong environmental authority
- Current regulatory framework is robust, but takes too long for approvals
- Government is working well and industry should not be asked to go further than government requirements; problem is perception

Needs of new framework

- Establish legislation before industry develops; too late after mistakes; companies must prove safe
- Need WA State policy on greenhouse gas emissions before we go further; risks from greenhouse gas will need to be mitigated
- Rewrite regulatory framework, not patch old one
- Don't need a new framework, just one that is more efficient
- Rules and regulations should be legislated so that they can't be changed; not just recommendations
- Review existing legislation (PAGER Act, EP Act Pt IV and V, Aboriginal Heritage Act, Contaminated Sites Act, etc) to identify gaps in fracking assessment, regulation and management
- DMIRS should not be the regulatory body as they issue the permits; it should be an entirely independent body to oversee
- EP Act ultimate body; clearly outline the legislation hierarchy, i.e. the mining act is only secondary to the EP Act; Environmental Protection Authority (EPA) needs more clout/respect; Barnett considered EPA decisions as guidelines; Public still needs to be able to challenge the EPA

- EPA has ability to decide not to assess and defer to other agency and not do holistic assessment; but pollution, water, social, greenhouse gas, aboriginal heritage issues need broader environmental impact assessment than specialist agencies; can EPA do it? Is policy up to date?
- EPA needs to assess all applications for exploration and full fracking; not through petroleum legislation; assess proposals cumulatively, not just individually; need consistency in assessment
- Every proposal should be assessed on a case by case basis
- Makeup of independent body - academics, government, interested environmental bodies, industry, landowners, experts, community representatives, indigenous people, medical people, environmental groups, Doctors for the Environment
- Want regulations with prescriptive outcomes
- Include input to regulations from a community health specialist in long-term health impacts, not just specialists in mining and mitigation
- Include regulation of the transport and storage of the fracking fluids; review of Dangerous Goods Regulations
- Include a mechanism that allows community to intervene in the event of inappropriate fracking
- Assessment, regulation, monitoring and compliance bodies need to be resourced, experienced; well-crafted regulations are effectively useless if implementation and enforcement are poorly funded
- Need effective complaints process, that listens
- Full disclosure of chemicals used and chemical interactions
- Any impacts of fracking should not be able to cross the boundary between farms
- Industry would like a clear and streamlined referral and appeals process, thoroughly transparent; streamlined means time; want the ability to reject mischievous, repetitive and unfounded referrals and claims to protect a proposal against activists and environmentalists; no problems with the process, but not repeating it every time for the same proposal; want protection against frivolous referrals and requirement for referrals to have fact-based concerns that are relevant to the proposal; want protection from activist groups using landowners, Native Title owners and government regulations to disrupt activities

No risk option

- No fracking in Western Australia
- No confidence in regulation so should be a complete ban. Ten countries have banned, 4 in United States, and 4 Canadian states have banned. Also, Victoria. We should also do the same
- Support ongoing moratorium
- Doubt that the industry can be regulated so that it is harmless, so that it does not provide an unsatisfactory level of harm to humans, animals, land.

Responsibility

- Government has a duty to protect our most vulnerable, children, the elderly and sick
- Concern that many exploration companies are small and may not have the financial resources to meet their responsibilities
- Who is responsible for well at end of life/decommissioning – deterioration of cement and steel, particularly if water becomes saline
- Someone needs to take responsibility for post-extraction monitoring, management and remediation
- Re insurance - Meat and Livestock Australia has stated that there is a genuine risk that landowners will be responsible for fracking causing contamination of produce
- Individual farmers should have the right to make their own decision and broker their own deal, including compensation, to have fracking on their land
- Fracking can't be isolated as hydrological aquifers and streams are interconnected
- Concerned that if a decision is made by environmental professionals to not go ahead, how easy is this to overturn

4.2 Modelling, baseline studies, monitoring, analysis and public reporting

- A thorough, completely independent, completely comprehensive measurement of local populations, human health, water quality, air quality flora, fauna, local ecology before fracking commences, so there is a benchmark, baseline data by which to measure for long term monitoring
- A thorough, completely independent, comprehensive baseline test of water, air quality, health levels of local populations, flora, fauna, local ecology, etc. to be in place before any licence is issued; this is necessary for monitoring to be meaningful
- Before fracking, modelling and baseline studies need to be done by an independent party from an environmental perspective not an economic perspective: water, air quality, greenhouse gas (lifecycle), community health, environmental health
- Monitoring and compliance auditing to be independent of industry and external to government/regulators
- Post-abandonment monitoring of well health and general environmental health over the long term

4.3 Insurance/penalties/compensation

- Industry (exploration and production companies) should be required to compensate for the water in deep aquifers becoming unpotable, for illness, devalued farms
- Industry should put up bond to cover well integrity and land rehabilitation far into the future so that we in Western Australia are not left with it

- Fracking should not be sustained by tax payers/government; exploration companies should have liability insurance, bonds should be required for all exploration bores, and costing put onto carbon emissions for exploration and investment proposals
- Companies should pay as go/bond/continuous payments to cover clean-up bills
- Environmental bonds should be meaty and last long after the company is there want to avoid companies going onto care and maintenance and not fulfilling post-mining responsibilities
- Polluter pays for any legacy issues such as contaminated land and water
- Compensation should be available for personal cost and loss of land value (through both footprint of fracking and impacts)

4.4 Land access

- Need clarity regarding the legal status of land tenure and what hierarchy prevails; what over-rides what

5 REFERENCES, INFORMATION SOURCES CITED/REFERRED TO

- Allred et al. Ecosystem services loss to oil and gas, 2015 study
- APPEA website studies on health
- British Medical Journal 2017. “the evidence against fracking are overwhelming.”
- CSIRO on contaminants at a fracking site in Australia
- CSIRO paper on flora and fauna
- Davis et al 2014 – well integrity
- DEA 550 paper – psychological health
- Frogtech 2013
- Hays & Shonkoff 2015 – fracking and public health
- IP - gas reservation policy. Have gas oversupply. [may have been quoting this https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/WA_GSOO/2017/2017-WA-GSOO.pdf or West Australian 6 Dec 2017 “Gas glut tipped to last another 10 years”]
- International Association of Hydrogeology – impacts of fracking on groundwater in US
- John Fenton, Wyoming farmer’s experience
- Lafleur et al 2016 US study of methane emissions and the total carbon footprint
- Melbourne University on methane gas leakages
- NE Pennsylvania paper
- Peer review study which talked about increased hospital admissions in Toowoomba
- Schlumberger paper
- Stats collected by a local GP in Tara QLD in relation to fracking;
- The Australian Institute on methane emissions in unconventional gas
- TWS Fitzroy report; peer review 2016

- Uniting A&TSI Christian Congress
- Videos/films of interest: Frackman, The Fractured State, The Fractured Country, Gasland, Promised Land, Frack Nation, Oil - Komand website has lots of films
- Vogwill, R. 2017. On WA's tight gas industry

6 ATTACHMENTS

6.1 Documents provided at the public meetings

Page	Date	Subject
21	2018	Written comments provided at Perth consultation
28	2018	Whan, Bryan. Review of scientific literature on unconventional gas development (3 papers – introduction, summary, full literature review)
70	2017	Haswell, Melissa. Health concerns associated with unconventional gas mining in Western Australia: A critical review
105	2017	Vogwill, Ryan. Western Australia's Tight Gas Industry – A review of groundwater and environmental risks. Conservation Council of Western Australia.
173	2016	Hays, Jake and Shonkoff, Seth B.C. Toward an Understanding of the environmental and public health impacts of unconventional natural gas development: A categorical assessment of the peer-reviewed scientific literature, 2009-2015
186	2016	Extract from Hansard, Council, Tuesday 15 November 2016, Hon Robin Chapple to Hon Michael Mischin (Attorney General representing the Minister for Mines and Petroleum) and response on gas leak at Buru Energy's Yulleroo 2
189	2014	Map of proposed fracking sites and potential gas fields in the Kimberley. Map provided by The Wilderness Society
190	2017	Map of proposed petroleum exploration and development, overlaid with location of environmental assets. Map prepared by the Department of Mines, Industry Regulation and Safety
191	2013-2015	Photographs of 'incidences with existing Kimberley fracking wells discovered by third party community members'. Provided by The Wilderness Society
192	2018	Pater, Norman. Personal views on economic risks in fossil fuel investment (by government).
203	2018	Sustainable Energy Now (SEN). Summary response to scientific inquiry into hydraulic fracture stimulation
205	2017	Hobbs, Richard J. Environmental impacts of linear infrastructure associated with fracking
207	2016	DiGiulio, Dominic C. and Jackson, Robert B. Impact to underground sources of drinking water and domestic wells from production well stimulation and completion practices in the Pavillion, Wyoming, Field. *Environmental Science and Technology*
201		Vogwill, Ryan. How much 'Water for Food'? New Fitzroy River study warns of need for more information and better processes: Water resources of the Mardoowarra (Fitzroy River) Catchment. The Wilderness Society.
203		Risk matrix
205		Reference list
216		Ivemy, Alan. Notes
217	2018	Whan, Margaret. Notes
220	2018	Additional comments and various attachments
Duplicates not included	See Broome attachments	Series of TGS Fact Sheets Joint statement by Yungngora Association Booklet on Great Sandy Desert Project (EP 493), prepared by Finder Exploration

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table number: 1 Name: [redacted]

Email Address: [redacted]

- Does the State need Gas from fracking - No! There is untapped renewable energy resources state should investigate & develop
- Should follow moratorium of Victoria.
- Secrecy - Medical Practitioners being forbidden to report types of illnesses being experienced by patients eg. NSW, QLD + Wyoming
- Lack of appropriate compensation to landowners
- Baseline Studies - air, water, community health
- EPA take control of entire process not Petroleum + Mines Dept
  - Substantial bond + costs recovered by State

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table number: 2 Name: [redacted]

Email Address: [redacted]

See attached.

Independent Scientific Panel Enquiry into Hydraulic Fracture Stimulation in Western Australia

Public Meetings – Perth 28 February 2018

Notes by Len Bunn – Preliminary Findings from Paper to be Submitted in March

Background

- Thirty years' experience in Oil and Gas facilities and projects across Australia and internationally.
- Founder/director of an engineering consultancy with an international presence (300 FTEs).
- Senior role in the feasibility design and business case for a Queensland CSG project.
- Experience in functional safety and risk analysis.

Overall Risk

- Individual risk events associated with individual wells: low probability per year with low to medium impacts.
- Aggregated risk events for thousands of wells over a 30 year timeframe: statistical certainty with high to catastrophic impacts. Worse over longer timeframes.
- Majority of risk events are difficult/expensive to detect and may not manifest for many years.

Effectiveness of Regulation

- Regulation, no matter how well-crafted, can only be as effective as the inspection and monitoring program supports.
- An effective inspection and monitoring program to cover thousands of wells over an extended period would be prohibitively expensive and resource intensive.
  - Costs for regulation inspection and monitoring have been generally borne by the public (government) and significantly underfunded and under resourced.
  - Oil and Gas companies know this and play the odds to their advantage as the likelihood of being caught is relatively low and penalties are easily included in budgets.

Impact of Marginal Economics

- As with CSG, shale and tight gas projects, on average, are only marginally profitable.
- Marginal profitability drives the industry to implement higher risk projects, resulting in:
  - Cost cutting in design and materials.
  - Poor quality construction.
  - Cutbacks in monitoring and maintenance.
  - Use of overly optimistic well production profiles (ie P30 instead of P50).
  - Lack of funds for end of production shut-in, decommissioning and rehabilitation.
- Higher risk of later insolvency and inability to meet environmental responsibilities when projects do not meet the initial overly optimistic production projections and failure rates are higher than forecast. This outcome may be considered acceptable by a company if senior management/ownership takes a short-term view.

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table number: 4 Name: [redacted]

Email Address: [redacted]

- Past history - Accumulated harms

- Role of the Mining Warden - Individual applications for specific locations / sensitivities for objection.

- Section 75 Mining Act = Public Interest & Alternate proposals - Keating Report

- Contradictions in the literature (Global)

- Subsidies for the Industry - Not Appropriate

- Clarify customer demand in WA.

- Independent compliance for each well and for Fugitive Emissions.

- Value to the State from frack mining Vs alternate energy industries - renewables

- Does the Mining Company have to demonstrate their financial viability?

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table number: 4 Name: [redacted]

Email Address: [redacted]

Can you please advise if the panel is able to recommend a ban or merely focus on regulations?

Thank you.

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table number: 6 Name: [redacted]

Email Address: [redacted]

Need to have a government impartial 'mediator' to discuss issues and to follow up problems.
Should be funded by the companies but must be independent - managed by government
People need somewhere to go, ...

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table number: 6 Name: [redacted]

Email Address: [redacted]

1) Australia is Driest continent on Earth we depend on Bore water which fracting puts At Risk
2) ~~wing~~ windchester well - Still has 2 million litres of Diesel Down it they Can't Recover.
3) Bore field At wanneroo - Gnangalla mound has Been So Affected By the Billions of Litres of water drawn out of it, wastewater Being Injected - Results unknown - Caves Dried out in yanchep National park - Extinction of Rare Crusteans.
4) We don't need onshore fracting in WA, we have Extensive offshore Reserves which does not Affect on Shore Bore water.
5) Human Rights treaty - we're are not Ratified Human Rights treaty And As Such Clean water is A Privelige Not A Right
6) whole Cities in America have had to be moved After Fracking Accidents

WA Scientific Inquiry into Hydraulic Fracture Stimulation in WA
Information for Public meeting – Perth 28 February 2018

Dr Bryan Whan – The Vines, WA

Introduction – my background

I have a PhD and M.Agr Sc. I have a background in agricultural research and management in a career spanning more than 50 years. I have been CEO, Managing Director and Chairman of a number of research groups and institutes, including two Cooperative Research Centres, and a number of commercial companies. I have worked in or with many Universities, State Departments and other research organisations throughout Australia, as well as partnering with a number of major international research and commercial organisations. I have also been a consultant in research and management. I am quite familiar with preparing and evaluating research submissions and reviews.

My interest in the possible development of unconventional gas in Western Australia was prompted when I viewed a video on the topic. Having viewed the assertions, I decided to research the topic myself, in line with my background training and experience. Starting with an open mind, I quickly became appalled at the facts I uncovered. I have since undertaken an extensive literature review and cannot understand how we could be so irresponsible to contemplate this development. Why would we ignore the lessons learnt from USA and Queensland, and contemplate the same destruction in Western Australia?

Scientific evidence from literature review – summary attached

My views are based on an extensive literature review of the impacts of unconventional gas development on water, air, land, human and animal health, the community, and the agricultural industries. It cites over 240 references from the scientific literature, submissions to other inquiries on unconventional gas, reports from industry and Government agencies, personal case studies, videos, TV documentaries, and other press. In many cases the references are extensive reviews and literature databases, so the information indirectly refers to over 1,000 papers and scientific studies. While the reference list is quite extensive, there are many more similar studies that could be cited.

The sources of information are from many authoritative Australian and international organisations, and much of the information has been published in peer reviewed international journals.

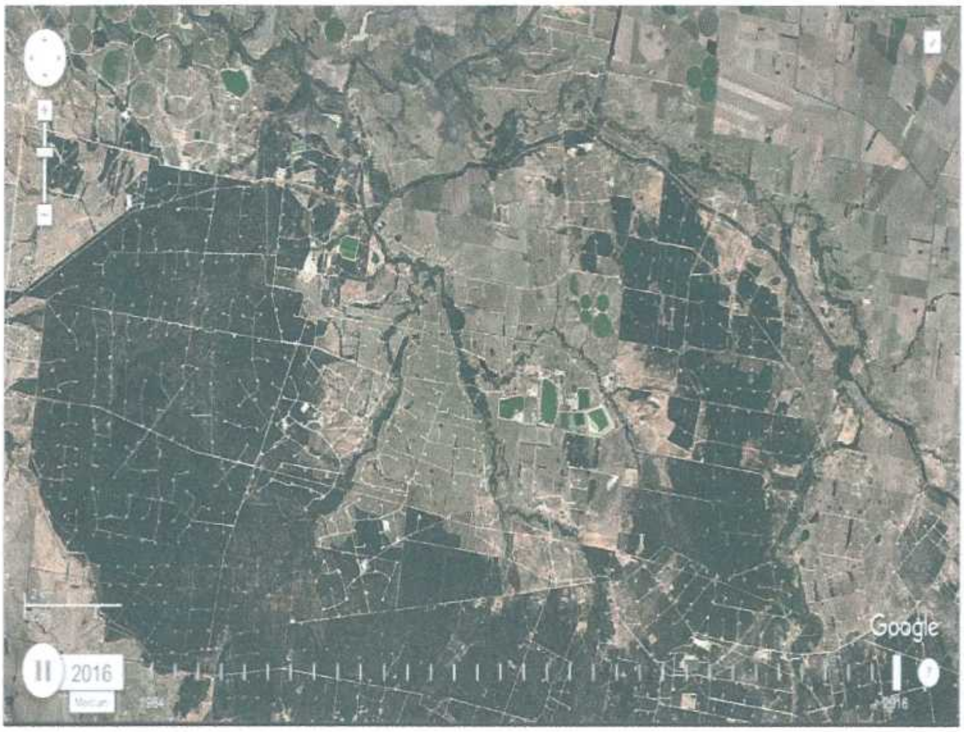
The industry claims that 'concerns about unconventional gas are prompted by false and exaggerated claims, and there is no evidence to show that fracking is not safe'. I find this personally insulting. Opposition to unconventional gas development comes from many people like myself, who have researched the evidence and made responsible conclusions. We know of many who have worked in the industry and seen the issues first hand, and feel strongly that the impacts of unconventional gas are not good. These views are supported with the vast scientific literature from thousands of highly qualified scientific and medical experts world wide.

I trust you treat the information provided in this review seriously.

Key points from information review

1. Industrialisation of prime agricultural land

As an agricultural scientist, I am disturbed to see prime agricultural land being transformed into industrial sites. I was Director of a Wheat Research Institute in Toowoomba, which worked with farmers on the Darling Downs – one of the best agricultural regions in Australia. This is being ruined for agriculture, and it can never recover.



Farmers in these areas have lost their livelihoods. Water bores have run dry, and companies have ignored their obligations to make them good. Stock have been sold because they cannot be managed. Property values have declined, and properties cannot be sold. Banks have refused loans because of the presence of wells. Companies have established gas wells on farmers properties under duress, and would not relocate wells to assist the farmers. Farmers have been treated with contempt.

2. Wells do leak

Contrary to the claims by the industry, there is ample evidence to show that wells do leak – conservative estimates are around 5% to 9%. Leaks increase with age. The question is who will pay for the repairs when leakages are a real problem in 100 or more years? A considerable amount of evidence of well leaks actually appears in industry reports.

3. Water is affected

There are lots of studies from USA and Australia where drinking water has been contaminated, high levels of methane have been found in ground water, and arsenic, heavy metals and salinity have been found in bore water. Fracking fluids have been spilt and surface water contaminated.

4. Air is contaminated

Methane levels surrounding gas mines are up to 3 times normal levels. Studies using an infrared camera demonstrated substantial emissions from vents in Queensland. Emissions of compounds have adverse health effects. In one example of many, data collected by the gas industry showed that emissions of particulate matter known to cause cardiovascular and respiratory diseases were up 6,000% to 1,926t.

The gas industry claims that more natural gas would enhance Australia's ability to meet increasing energy needs while at the same time reduce greenhouse gas emissions. But methane is a more powerful greenhouse gas than carbon dioxide. It has been estimated that, at more than 3% leakage, gas is actually more polluting than coal when used to generate electricity.

5. Human and animal health is affected

The industry claims that unconventional gas activities are safe.

I have cited 40 references, but there are reviews of many hundreds of papers that conclude that unconventional gas operations can have serious consequences for human and animal health and cannot be undertaken safely.

The conclusion reached by the USA Physicians for Social Responsibility from a review of many hundreds of studies is typical: **The health risks posed by fracking are real, significant and unacceptable. No regulatory framework has been shown to adequately protect public health or the environment.** Who should we believe in making decisions on the future of our State?

There are now a number of studies from Queensland showing the impacts of the gas mining on residents living in proximity to mines. There are also worrying reports from a medical practitioner, a clinical psychologist and a Uniting Church minister who work in these communities how the Queensland Government has ignored the interests of its citizens in preference to supporting the gas industry.

6. Communities vs gas companies

The gas industry does not have a good history of being honest or credible. It is the case in USA, Queensland and Northern Territory. It won't be different in WA, and we already know of examples where misleading information has been provided and undue pressure has been applied during negotiations in WA.

Surveys demonstrate the community does not want this development and the risks associated with it. Astute Governments – who have listened to their communities – have banned the development. Irresponsible Governments have proceeded without caution, and disregarded the interests of their communities.

I urge the inquiry to accurately report on the magnitude of the community opposition to fracking. It should not be under played. It is based on a vast amount of scientific information and personal experiences.

Scientific inquiry

While I applaud the initiative of the McGowan Government to conduct an inquiry, I am concerned about some aspects of the inquiry objectives and process. It is emphasised that this is a scientific inquiry. By definition, a scientific inquiry should start with an open mind, and all possible outcomes should be on the table. The starting point should be whether fracking should be allowed at all. In reading the background information, one cannot help but conclude the outcome of the inquiry is already defined. For example, the guide for the public meeting states 'The Panel seeks factual information and evidence that informs an analysis of potential impacts and risk, or how risk might be mitigated or managed through regulation, if possible'. If the inquiry were truly un-biased and open to all outcomes, such a guide should read along the lines 'The panel seeks factual information and evidence that informs an analysis of potential impacts and risks, so all possible outcomes can be considered – from a total ban on fracking in WA to the safe use of fracking by eliminating all risks through regulation or other means'.

Recommendation

Based on the evidence I have gathered, I conclude that unconventional gas development should not be developed in Western Australia, and a permanent State wide ban should be imposed. I do not believe that regulatory mechanisms to mitigate the risks, as identified in the third term of reference, is feasible, and would not be a responsible solution.

Information review for WA Inquiry – Summary

Prepared by Dr Bryan Whan

1. SCIENTIFIC STUDIES SHOWING IMPACTS OF UNCONVENTIONAL GAS *(240 references)*

Australian and international sources:
Universities, Government agencies, Public Health organisations, Think Tanks, Medical groups, Rural R&D organisations, Chief Scientists and Economists, National Toxics Network, Scientific Academies and Associations, Legal groups and Courts.
Papers published in leading Australian and international journals specialising in:
Science, Environment, Ecology, Hydrology, Seismology, Agriculture and Resource economics, Energy, Health, Medicine, Psychology, Epidemiology, Economics, Oil industry.
ROGER: Repository for Oil and Gas Energy Research (PSE) – 1400 papers
Compendium of Scientific, Medical, & Media Findings Demonstrating Risks and Harms of Fracking – 900 papers

2. SOME BASIC FACTS *(25 references)*

- Unconventional gas is highly invasive. Whole regions are industrialised.
- Valuable agricultural and horticultural land is lost. Native forests and wild life are impacted.
- Fracking is a water-intensive practice, using 11-34 million litres of water per frack.
- Wastewater is brought to the surface during gas production. It may contain heavy metals, salts, radioactive materials and volatile organic compounds.
- There could be over 41,700 gas wells in the Kimberley and 14,500 in the Perth Basin.
- The unconventional gas industry has impacted on the health of families living close to Queensland gasfields.
- Governments across the globe have halted shale gas development due to the growing evidence of actual harm, and the potential environmental and health risks.
- Australian surveys show that the community does not want unconventional gas.

3. INDUSTRY CREDIBILITY – PERSONAL CASE STUDIES *(30 references)*

The industry claims it is transparent, consultative, and honest, and is committed to relationships built on trust and mutual respect. Many case studies show how the unconventional gas development has affected the health and ruined the livelihood of people living in the vicinity. The gas companies have been dishonest and treated farmers and land owners with contempt.

4. CHEMICALS USED IN HYDRAULIC FRACKING *(23 references)*

The industry and supporters of fracking argue that only a small amount of chemicals is used in fracking, and the chemicals used can be found in household products.

- While chemicals comprise only 0.5 to 2.0% of fracking fluids, 80 to 330 tons can be used in a frack.
- WA requires companies to disclose chemicals used, but hardly any have been officially assessed.
- The argument that many are used in households is quite misleading. It does not follow that they are safe in the amount and processes used in fracking, and in various untested combinations with numerous other chemicals. Even common salt can be harmful used in the wrong way.
- The risks associated with added chemicals and naturally occurring chemicals returning from underground sources (volatile organic compounds and naturally occurring radioactive materials) are identified.
- Many volatile organic compounds that are carcinogenic, neurotoxic, or affect breathing have been found around homes in the vicinity of gas fields in Queensland. Heavy metals, chemicals like methylene chloride, caesium 137, and radioactivity have been found in drinking water tanks.
- Emissions from one example gas field reported by industry included 1,900 tons of oxides of nitrogen and 1,500 tons of carbon monoxide. Of great concern is the amount of particle matter that was produced.
- The Australian Chemical Regulatory system is quite inadequate at protecting the rights of the community.

5. WELL INTEGRITY AND FAILURE *(13 references)*

The industry claims there is no risk of wells leaking, as well casings are thick and made of concrete and steel.

Oil and gas wells routinely leak – gas and other substances migrate into the groundwater and atmosphere.
- Conservative estimates of well failure rates are between 4.6% and 8.9%. Higher rates of 12%, 20% and up to 75% have been reported.

- An industry paper published by Schlumberger admits about 5 per cent of wells leak immediately, 50 per cent leak after 15 years, and 60 percent leak after 30 years.
- Risks identified by the industry are documented and hidden in mandatory corporate returns.
- A number of incidents in Australia are documented.
- Horizontal or inclined wells are observed to have significantly higher failure rates than vertical wells.

It is not possible to have a zero per cent well failure rate during production let alone post abandonment. Wells deteriorate with age, and they remain after they go out of production. If Regulations only apply to the title holder during production, the rest of the community, who do not get any financial benefit, will have to bear the costs of maintaining the wells forever.

Even strict regulations are simply not capable of preventing harm.

6. IMPACTS ON WATER - Ground water and Surface water *(31 references)*

The industry claims that the risk of groundwater and surface water contamination is very low.

The gas industry claims that because shale and tight gas extraction involves deeper rock layers, they are safer than gas extraction from shallow coal seams. A European Commission report refutes this.
Examples of peer-reviewed literature showing serious unconventional gas impacts on groundwater, regardless of the industry's insistence that there are no impacts.
In USA:

- Private drinking wells contaminated.
- Elevated levels of methane in groundwater.
- Methane detected in houses.
- Spills of fracking fluid and contamination of surface water.
- High levels of arsenic, heavy metals and salinity in bore water close to shale wells.

In Australia:

- Numerous reports of water contamination by people living close to coal seam gas mines.
- Spills in NSW's Pilliga Forest contaminating groundwater with uranium and arsenic.
- Gas bubbling in Condamine river Qld.
- Numerous offences by Origin Energy, Santos and Eastern Star Gas in NSW, NT and Qld for waste water spills, using unlined waste pits that then flooded, leaks from all parts of the operations, discharging polluted water into a creek, polluting an aquifer with radioactive uranium and toxic heavy metals, and killing vegetation and wildlife with untreated toxic coal seam gas wastewater. Significantly, the penalties imposed were a joke.

7. IMPACTS ON AIR *(24 references)*

The industry states that the most common well integrity risk is slow leakage of methane around the external casing, but the consequences of such leaks, although negative from a climate change perspective, do not threaten health because natural gas is not toxic, the frequency of substantial leaks is low, and the leakage rates are low as well.

- Methane levels surrounding gas mines are up to 3 times higher than background values.
- There is considerable atmospheric methane levels in the Surat basin with bubbling in the Condamine river.
- Volatile chemicals used and the gases released pose health risks to workers and people living nearby.
- Emissions of compounds have potential adverse health effects e.g. 44 hazardous air pollutants in one study.
- An infrared camera demonstrated substantial gas emissions from vents in Qld, contrary to industry claims.

The industry claims that more natural gas would enhance Australia's ability to meet increasing energy needs while at the same time reduce greenhouse gas emissions (2.1).

Fugitive emissions impact on climate change.

- Methane is a more powerful greenhouse gas than carbon dioxide – 86 times more powerful when considered over a 20-year timeframe and 34 times more over a 100-year timeframe.
- Emissions from unconventional gas have been severely underestimated in Australia – 2 to 17% of production rather than the 0.1% claimed.
- At more than 3% leakage, gas is actually more polluting than coal when used to generate electricity.

8. IMPACTS ON LAND *(15 references)*

Prime agricultural regions have been transformed into industrial areas through coal seam gas in Qld. In Queensland, 18,000 wells have been approved, and tens of thousands more are planned.

The impact on the land and the industrialisation unconventional gas production creates is neatly demonstrated in a series of 'Before and After' photos of various forest and agricultural areas in Queensland.

The background paper for the WA Inquiry claims that the footprint for unconventional gas will have a smaller footprint than coal seam gas. It is not appropriate to assume that. Australia's former and present Chief Scientists, Professor Chubb and Dr Finkel, have both admitted that Australia's unconventional shale gas industry will have a larger footprint and require considerably more water than CSG.

The large footprint of unconventional gas infrastructure represents a serious threat to biodiversity fragmentation through direct clearing of bushland, loss of native vegetation, fragmentation of important remnant vegetation, spread of invasive species and weeds, and increased fire risk.

Evidence arising in the past 18 months has demonstrated links between fracking and waste fluid reinjection with increased seismicity and earthquakes.

9. IMPACTS ON HUMAN AND ANIMAL HEALTH *(40 references)*

The industry claims that unconventional gas activities are safe.

There is a rapidly growing body of research that demonstrates this is far from the truth and that unconventional gas operations can have serious consequences for human and animal health.

Peer-reviewed scientific literature to 2016 involving more than **700** studies on the impacts of unconventional gas development show:
84% of public health studies indicate risks to public health
69% of water studies show actual or potential water contamination
87% of air quality studies indicate elevated air pollution.

A comprehensive review of **156** peer-reviewed publications found multiple potential hazards to human health from exposures to harmful air and water pollutants associated with unconventional gas mining.

The Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking, compiled by the Concerned Health Professionals of New York, contains over **900** papers with evidence on the risks and harms of fracking.

Public health problems associated with drilling and fracking, include:
- Increased rates of hospitalization, self-reported respiratory problems and rashes, trauma, drug abuse, and low birth weight among infants among residents living near drilling and fracking operations.
- Benzene has been detected in the urine of wellpad workers in Colorado and Wyoming.
- Air near gas wells in rural Ohio had levels of polycyclic aromatic hydrocarbons that surpassed those in downtown Chicago. They were also ten times higher than the levels found in rural areas without fracking operations, raising the lifetime risk of cancer for residents living near the well pads by 45 percent.
- Drilling and fracking activities can bring naturally occurring radioactive materials to the surface.

Some of the medical studies involving many thousands of individuals and patients in USA showed risks of:
- premature births and high-risk pregnancies.
- mild to severe asthma exacerbations.
- various combinations of migraine headaches, chronic rhinosinusitis and fatigue symptoms.
- cardiology and neurology effects.

A medical health survey in the Tara region of Queensland involving 113 people from 38 households showed:
- 58% of residents reported that their health was adversely affected by Coal Seam Gas.
- Symptoms included fatigue, headaches, clumsiness, increases in coughing, chest tightness, rashes, difficulty sleeping, joint pains, muscle pains and spasms, nausea, vomiting, nose bleeds, skin irritations and eye irritations.

Their reports of ill health have been trivialised and ignored by the Queensland Government.

The unconventional gas industry can harm mental health and individual and community wellbeing.

Twenty-four case studies have been compiled in USA of apparent harm to animals, mainly resulting from contamination of water wells, springs, ponds or creeks, some due to accidents or negligence, and others a consequence of normal operations. On seven cattle farms studied in the most detail, half the herd, on average, was affected by death or failure to breed.

Many public health and medical organisations in Australia are calling on governments to apply the Precautionary Principle, and refrain from allowing unconventional gas mining to occur in Australia until there is sufficient evident demonstrating that it is safe for people and the environment.

10. IMPACTS ON COMMUNITY (Social surrounds) *(20 references)*

The industry and Governments justify the development of unconventional gas because it will create local jobs, revive ailing rural communities, and provide tremendous economic benefits.

Few benefits are realised outside the gas industry, and there are serious social and economic effects on local communities and existing businesses.

Harmful impacts on the community include: intimidation, coercion and bullying by UG companies; intolerable noise and light pollution from flaring, traffic and UG infrastructure; contamination and depletion of water in farm bores; rivers bubbling with methane; bores running dry; stock losses associated with pipeline construction and water contamination; costly and time consuming interruptions to farming operations; huge trucks and heavy machinery on small local roads affecting lifestyle, safety and road infrastructure; dust impacts on pasture; increases in weed infestation; industry workers leaving mess from pipeline construction in farm paddocks; workers destroying fences and leaving gates open; properties not able to be sold; credit being denied; mental health impacts resulting from dealing with companies and the impacts of industry development; and physical health symptoms including respiratory ailments, headaches, rashes, nausea and vomiting, and nose, throat and eye irritations.

While the gas companies move on once the commercially viable gas has been extracted, the communities suffer long term. The unconventional gas mining leaves massive damage, and the community must foot the bill. Yet the community did not want it.

Many claims by gas companies about increased employment are mischievous.

- Claim of 100,000 jobs when only 9,000 were created
- Claim to create 2,900 jobs when only 30 were created.

Employment is actually reduced in other areas e.g. 1.8 agricultural jobs lost in Queensland for every 1 gas job created.

Farmers have been refused finance due to gas wells on their property.

The CSG industry is under-insured and landholders are likely to bear a substantial risk as a result. Landholders may be liable for impacts arising from unconventional gas activities if they lead to personal injury, property damage, or contamination. Yet farmers have been refused insurance cover for risks and contamination associated with unconventional gas extraction.

The impacts of unconventional gas on the water, air and land, and the consequent impacts on physical and mental health of those living in the area have broad impacts on the overall community. Experiences in dealing with these social impacts in Queensland are demonstrated in videos from a medical GP, a clinical psychologist and a Uniting Church Minister. Particular concerns include the negligent approach to risk management by gas companies, Governments promoting the interests of mining companies and neglecting their responsibility to protect the interest of the community, and farmers being treated with contempt by gas companies.

11. IMPACTS ON AGRICULTURE *(8 references)*

Fracking is an extremely water-intensive practice, taking valuable water from agricultural use. These activities have the potential to severely disrupt virtually every aspect of agricultural production and potentially even remove the land from production. Bores essential for the production have run dry, and contrary to legal obligations, gas companies have not made good to provide alternatives.

The presence of mining in the area reduces surrounding land values. Valuable agricultural and horticultural land is lost. Native forests and wild life are impacted. Experience elsewhere in Australia has shown that land owners have been refused bank finance due to uncertainty of the asset caused by the presence of wells on the property

Landholders will lose millions every year by hosting unconventional onshore gasfields. A 2016 CSIRO report found the alienation of productive farmland for CSG infrastructure in Queensland resulted in losses in gross economic returns of up to 10.9%. The total losses to gross revenues varied between $1.32m and $3.29m per property and averaged $2.17 million.

INFORMATION ON UNCONVENTIONAL GAS DEVELOPMENT FOR WA SCIENTIFIC INQUIRY

Prepared by Dr Bryan Whan for Lock The Gate Alliance

1. SCIENTIFIC STUDIES SHOWING IMPACTS OF UNCONVENTIONAL GAS

This paper reviews information on the impacts of unconventional gas development, citing over 240 references from the scientific literature, submissions to other inquiries on unconventional gas, reports from industry and Government agencies, personal case studies, videos, TV documentaries, and other press. In many cases the references are extensive reviews and literature databases, so the information indirectly refers to over 1,000 papers and scientific studies. While the reference list is quite extensive, there are many more similar studies that could be cited. To illustrate the authoritative nature of this review, the sources of the information include:

Organisations such as: *The Australian Council of Learned Academies, The Australia Institute, Melbourne Energy Institute, Doctors for the Environment Australia, Public Health Assoc of Aust, Aust Chief Scientist Office, Aust Council of Environmental Deans and Directors, Meat & Livestock Aust, Rural Industries Res & Development Corporation, Gas Industry Social & Environmental Research Alliance (GISERA), Office of Chief Economist, NSW Chief Scientist & Engineer, Qld Dept Natural Resources & Mines, National Toxics Network, Monash Univ, Univ of Qld, Qld Univ Technology, Southern Cross Univ, EPA NSW, Int Assoc of Hydrogeologists, National Academy of Sciences USA, Pennsylvania's Dept of Environmental Protection, NY State Dept of Environmental Conservation, NYS Department of Health Public Health, EPA United States, US Geological Survey, NY State Bar Association, USA Federal Court, Cornell State Univ, Univ of Colorado, Univ of Waterloo, Durham Univ, Stanford University, Duke Univ USA, Council of Canadian Academies, European Commission, Concerned Health Professionals of NY, Physicians for Social Responsibility USA, Johns Hopkins Bloomberg School of Public Health USA, U.S. Geological Survey,*

Papers published in (examples only): *Env Science & Technology, J of Env Science and Health, Env Science and Pollution Research, Env Health Perspectives, Env Science and Technology, Int J of Env Studies, J Env Psychology, Ecological Applications, Scientific American, Science, Oilfield review, Geofirma, The Tyee, J of Hydrology, Geophysical Research Letters, World Oil, Energies, Renewable Energy & Env Sustainability, Texas J of Oil, Gas & Energy Law, Seismological Research Letters, Scientific Literature, Env Geochemistry & Health, Epidemiology, J of Economic & Social Policy, Aust J Agric & Resource Economics, British Medical Journal, Psychiatry, Endocrinology, JAMA Internal Medicine, Medical J Aust, The Lancet, Compendium of Scientific Medical & Media Findings.*

There are extensive databases providing scientific evidence of the risks and harms *(1.7, 1.24)*.

ROGER: Repository for Oil and Gas Energy Research (PSE) – 1400 papers *(1.24)*

The Physicians Scientists and Engineers for Healthy Energy maintains a citation database on shale and tight gas development involving about **1400** citations *(1.24)* - abstracts and links to scientific papers and peer-reviewed journal articles. http://www.psehealthyenergy.org/site/view/1180

Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking – 900 papers *(1.7 http://www.psr.org/assets/pdfs/fracking-compendium-4.pdf)*

The New York based health organization, the *Concerned Health Professionals of New York,* has compiled the *Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking* - a fully-referenced compilation of the evidence for the risks and harms of fracking that brings together findings from the scientific and medical literature, government and industry reports, and journalistic investigation.

The latest edition of this compendium highlighted the following emerging trends:

- Growing evidence shows that regulations are simply not capable of preventing harm.
- Fracking threatens drinking water.
- Drilling and fracking emissions contribute to toxic air pollution and smog (ground-level ozone) at levels known to have health impacts.
- Public health problems associated with drilling and fracking, including reproductive impacts and occupational health and safety problems, are increasingly well documented.
- Natural gas is a bigger threat to the climate than previously believed.
- Earthquakes are a consequence of drilling and fracking-related activities in many locations.
- Fracking infrastructure poses serious potential exposure risks to those living near it.
- Drilling and fracking activities can bring naturally occurring radioactive materials to the surface.
- The economic instabilities of fracking further exacerbate public health risks.
- Fracking raises issues of environmental justice.
- Health care professionals are increasingly calling for bans or moratoria until the full range of potential health hazards from fracking are understood.

Many studies (numbers in brackets) are documented in the following categories:

- Air pollution (55)
- Water contamination (108)
- Inherent engineering problems that worsen with time (13)
- Radioactive releases (16)
- Occupational health and safety hazards (44)
- Public health effects, measured directly (23)
- Noise pollution, light pollution, and stress (12)
- Earthquakes and seismic activity (60)
- Abandoned and active oil and natural gas wells as pathways for gas and fluid migration (22)
- Flood risks (9)
- Threats to agriculture and soil quality (20)
- Threats to the climate system (56)
- Threats from fracking infrastructure (71)
- Inaccurate job claims, increased crime rates, threats to property value and mortgages, and local government burden (64)
- Inflated estimates of oil and gas reserves and profitability (23)
- Disclosure of serious risks to investors (Information from industry returns to Government)
- Medical and scientific calls for more study and more transparency (36)

Based on this scientific evidence, the Concerned Health Professionals of NY and Physicians for Social Responsibility concluded:

'Findings to date from scientific, medical, and journalistic investigations combine to demonstrate that fracking poses significant threats to air, water, health, public safety, climate stability, seismic stability, community cohesion, and long-term economic vitality. Emerging data from a rapidly expanding body of evidence continue to reveal a plethora of recurring problems and harms that cannot be averted or cannot be sufficiently averted through regulatory frameworks. There is no evidence that fracking can operate without threatening public health directly or without imperilling climate stability upon which public health depends. Industry swore that its cracking rock technology was safe and proven, but science now tells a different story. And in the words of a new commentary about fracking in the American Journal of Public Health: Mounting empirical evidence shows harm to the environment and to human health ... and we have no idea what the long-term effects might be.... Ignoring the body of evidence, to us, is not a viable option anymore.'

The industry claims that 'concerns about unconventional gas are prompted by false and exaggerated claims peddled by opponents of development, who have often declared they intend to stop all new oil and gas activity' *(2.1)*. In reality, opposition to unconventional gas comes from thousands of highly qualified scientific and medical experts world wide, as well as concerned, well informed citizens who have taken the trouble to research the topic extensively or have had personal experiences. They do not want to see the disasters of Queensland and the USA repeated in Western Australia.

2. SOME BASIC FACTS *(1.1, 1.2, 1.3, 1.4) 25 references*

- Unconventional gas production is highly invasive. While conventional gas production generally requires single wells, shale and tight gasfields involve the industrialisation of entire landscapes as hundreds or even thousands of closely spaced gas wells are required to extract commercially viable quantities of gas. Gasfields also require vast networks of access roads, gas pipelines, processing plants, compressor stations, and wastewater holding dams and treatment plants.
- Valuable agricultural and horticultural land is lost. Native forests and wild life are impacted.
- Modern fracking techniques used for unconventional gas extraction are vastly different to older fracking methods used in WA's conventional oil and gas industries. These newer, more damaging fracking processes have only been in use since the 1990's and require vast quantities of water and chemicals, much higher pressures, and riskier horizontal drilling techniques. Modern fracking technology has never been deployed on a commercial scale in Western Australia.
- Fracking is a water-intensive practice *(1.4)*. A single shale gas frack uses 11-34 million litres of water, and wells are often fracked on multiple occasions, sometimes up to ten times, multiplying overall water use.
- Some of this fluid returns to the surface as flowback, but up to 70% stays underground and is never recovered.
- Wastewater is brought to the surface during gas production. It may contain heavy metals, salts, radioactive materials and volatile organic compounds.

- WA could contain 280 trillion cubic feet of potential shale and tight gas resources *(1.12)*, with the Kimberley, Mid-West and South-West regions currently being targeted for exploration and pilot production.
- Fracking for unconventional gas is already underway in WA *(1.13)*, with around 12 exploration wells fracked in the past 11 years.
- Conservative estimates suggest that the Kimberley could see over 41,700 gas wells and the Perth Basin more than 14,500 *(1.14)*.
- A large swathe of Australia is covered in coal and gas leases & applications. Families and communities are suffering as a result. In parts of Queensland, the unconventional gas industry has impacted on the health of families living close to mines and gasfields. These impacts are only just beginning to be recognised, although people have been providing anecdotal evidence of the impacts for many years *(1.15, 1.16)*.
- In Queensland, the rate of change has seen prime agricultural regions transformed into industrial areas through coal seam gas *(1.3)*. 18,000 wells have been approved, and tens of thousands more are planned.
- Australia gets little benefit from coal and gas production because 83% of the mining industry is foreign-owned. Mining is one of the smallest employers in Australia, employing only 2% of the population which is less than the arts and recreation services industry. Most gas is shipped overseas. *(1.17, 1.18, 1.19)*

Successful actions to stop development of unconventional gas *(1.20, 1.21, 1.23)*

- The Government of Victoria has introduced legislation to ban fracking and unconventional gas exploration.
- Tasmania has instigated a moratorium on fracking, with a possible ban ahead.
- The Northern Territory has a temporary fracking ban in place while it holds its own fracking inquiry.
- The Queensland Parliament passed a bill to restore the rights of landholders and communities to object to major mining projects.
- Parts of NSW are protected from unconventional gas development following legislation that prohibits all unconventional gas activities within 2km of residential areas and the Upper Hunter equine and viticulture critical industry clusters *(1.23)*.
- The South Australian Liberal Party has promised to ban fracking in the state's South East for 10 years if it wins the state election in March 2018.
- Many local councils across Australia have passed motions opposing unconventional gas development and calling for a moratorium.

The growing evidence of actual harm, and the potential environmental and health risks from shale gas development, has now resulted in decisive action from governments across the globe to halt the expansion of this industry. Internationally, jurisdictions with some form of ban or moratorium in place include Scotland, Wales, Germany, Bulgaria, Romania, the Netherlands, Northern Ireland, Wales, the Czech Republic, Luxembourg and France as well as the US States of New York, Maryland, Florida and Vermont and the Canadian Provinces of New Brunswick, Newfoundland, Nova Scotia and Quebec *(1.6, 1.7, 1.20)*

The community does not want unconventional gas *(1.22)*

More than 450 Australian communities have declared themselves coal or gasfield free. Close to 20 WA communities have said they want to remain Gasfield Free. These communities include Brunswick, Stratham, Dandaragan, Greenough, Cervantes, North Boyanup, Moora, The Vines, Forest Grove, Stirling Estate, Quedjinup, Caversham East, Leeman, Greenhead, Exmouth, Irwin, Jurien, Carnamah and Chittering.

Gasfield Free communities follow an extensive survey of residents who are asked house by house, street by street, whether they want to declare their communities Gasfield Free. When a community declares itself Gasfield Free it is making a powerful statement to the gas industry that the industry does not have a social licence to operate in the community

Representing a large sector of the rural community, the Country Women's Association of WA passed a motion at its 2017 Annual Conference calling for an end to fracking and unconventional gasfields in WA. This follows a similar ban passed by the NSW branch of the CWA earlier in the year. *(1.10)*

3. INDUSTRY CREDIBILITY – PERSONAL CASE STUDIES *30 references*

The gas companies, the Australian Petroleum Production and Exploration Association (APPEA), and the WA Department of Mines, Industry Regulation and Safety claim that: *(2.1, 2.2, 2.2a, 2.3, 2.4)*

- Mining for unconventional gas is safe, and the risks are known and can be managed.
- The gas industry has a good track record of safe operations in SA, Qld, WA, NSW, and Victoria.
- Gas mining will provide jobs and investment to boost the economy.

- The industry claims it is transparent, consultative, and honest, and is committed to ensuring the equitable treatment of all stakeholders, building relationships based on trust, openness and mutual respect.
- It claims the established industries have not been disadvantaged by natural gas development.

This review provides abundant scientific evidence that refutes these claims. The following examples of personal stories also questions the industry's credibility of claiming a policy of consultation, honesty and public interest.

Landowners on the Darling Downs, Queensland *(1.3)*
- Families on the Darling Downs in Queensland have health problems through living close to the gas mining. They are no longer able to drink the water, with instances where gas was emitted from their water supplies. The presence of gas mining on their properties and the transformation of their prime agricultural land to an industrial zone which operates 24 hour a day has devastated their lives, and it has affected their mental as well as physical health. Their properties and livelihoods are ruined. The value of their properties has reduced drastically, preventing them from selling and moving on.
- Contrary to what the industry claims, 18 farmers and land owners in Queensland, NT and NSW featured in this video recounted experiences on how they were treated with contempt by the gas companies.

Megan Baker, Wilkie Creek Qld *(2.3)*
Megan's family suffered 5 years of negotiations and a legal battle with Arrow Energy, taking a huge toll on her family. The gas company dozed fences and introduced weeds, and vehicles would come and go all hours of the day and night. Stock were running everywhere because they could not be contained to one paddock due to the damage. They were forced out of production, so they eventually decided to sell the sheep flock.

Wayne Waker – Chinchilla, Queensland *(2.4)*
Wayne signed an access agreement for unconventional gas extraction by Origin Energy, but was given misleading information during negotiations. He was advised that coal seam gas would provide extra money and would have no impact. They cut boundary fences and went where they liked – all without consultation. He has pipelines running through his property, and 10 high vents pumping out methane gas. The company had no principles, morals or scruples, and treated the landowner with contempt. Wayne is worried about long term health, and his lifestyle and agricultural production have been ruined. His property is now not worth the original unimproved value.

Nood and Narelle Nothdurft – living in the heart of a gas field *(2.5)*
Their 860 acre farm was transformed into an industrialised gas field, with 4 processing plants and 7 gas wells. Within a 2.5km radius of their home there are 30 wells, 37 high point vents which vent methane 24/7/365, and hundreds of km of water and gas pipelines. There are 4 vents within 80m of their home with signs indicating the gas is flammable, explosive and dangerous. The gas company said it was only venting air, but FLIR camera images showed it was methane and VOCs. There is an unbearable noise generated from the gas infrastructure, with dust and methane emissions. Their children suffer from incredible health problems – severs headaches, vomiting, metal taste in their mouths, sore limbs, nasal problems.

Neil Stanley's story – Kogan Qld *(2.6)*
In late 2009, QGC drilled a gas well on an important cultural heritage site near Kogan in western Queensland. The site, a Bora Ring used in initiation ceremonies, was well documented and well known. QGC has never been made accountable for desecrating the site.

Greg and Joanne Vines' story – Wallumbilla, Qld *(2.7)*
for 2 years, the Vines battled gas giant Santos which wanted to lay a second pipeline through their property in south-west Queensland. The couple were worried about weeds being introduced as the machinery would have been in areas of parthenium infestation, a toxic plant that impacts heavily on pastoral production. Despite repeated requests, the company was unable to provide the Vines with adequate documentation to prove the machinery was weed free. The Vines locked their gates to keep the trencher off their land and protect their pasture business, but they were threatened with arrest on their own property and had their locked gates cut. Santos had a blatant disregard for people, and their fight has taken a heavy toll.

Voice from the Gaslands – George Bender's story *(2.17, 2.18)*
Arrow and Origin gas companies put 18 gas wells on George's two properties, under duress, resulting in him losing two precious underground water bores. These bores are among 85 in the area that are likely to run dry within 2-3 year, and a further 528 will be impacted in the longer term.

Negotiations with Kimberley traditional owners *(1.5 and 1.9)*
A traditional landowner, Mitch Torres, recounted her experience at a negotiation meeting with a gas company, where the company representatives misled the indigenous people by saying the chemicals used in fracking were

similar to those used in jelly beans. The indigenous participants had quite a different view about fracking when it was later explained correctly.

USA experience

There is extensive experience from USA of farmers living in areas subject to fracking. Farmers can't use the water, which catches on fire, and it is possible to have explosions in the house if it is not kept open. There are immense health issues, and children are most susceptible. Some farmers have been bought out by the gas companies, but they must sign confidentiality agreements. Agriculture and gas production cannot co-exist.

Misrepresenting tight gas as conventional

Gas companies have been known to misrepresent tight gas as 'conventional' in the past.

- Metgasco misrepresented the drilling planned at Bentley in NSW, obtaining an approval for conventional drilling, when it was in fact unconventional tight sands gas that is being sought.
- In South West WA, companies claim they are targetting conventional gas, when it is tight sandstone and limestone in the area. The company which originally applied for the gas licence over Capel, Boyanup and Dardanup was called 'Unconventional Resources Pty Ltd'. After community protest, they changed their name to Bunbury Energy.
- In the Mid-West, the Waitsia field is being heralded as the biggest conventional gas find in about 40 years. But the company has admitted they would start with 20 wells in 50 square kilometres. There is also tight Gas in exactly the same spot, so it is possible they will develop that eventually too. They will have the land access by then.

Industry credibility? Documentaries

A number of documentaries have been produced by reputable TV networks and production companies outlining the truth about unconventional gas production and its impacts.

- Lock The Gate: A fractured State *(1.5)*
- Australia's NOW Government – Fracking destroying our country *(2.8)*
- The Gas Rush: ABC's 4 Corners Feb 2010 *(2.9)*
- Undermined: Nine's 60 Minutes 14 May 2010 *(2.10)*
- Voices from Gasfields – it started with just one well *(2.11)*
- Food Security and Australia's Regional Way of Life: Coal Seam Gas: Alan Jones - National Press Club Address 19 October 2011 *(2.12)*
- Coal Seam Gas: Channel 10 'The Project' 21 Feb 2013 *(2.13)*
- Fracking an inconvenient truth 17 Aug 2013 *(2.14)*
- Exposing the real price of the US fracking industry *(2.15)*
- Water on fire – Marcellus shale reality *(2.16)*

4. CHEMICALS USED IN HYDRAULIC FRACKING *23 references*

Hydraulic fracture stimulation fluid is generally composed of around 90 per cent water, with 9.5% sand or ceramic beads, and 0.5% chemicals (1.25). Chemicals are added to improve the transportation of the proppant, prevent the growth of bacteria, reduce mineral clogging and prevent well corrosion over time. In Western Australia, all chemicals to be used need government approval.

The industry and supporters of fracking argue that only a small amount of chemicals is used in fracking (1.25, 4.17, 4.18, 4.19), and the chemicals used can be found in household products (4.21, 4.19, 4.18).

What the literature shows

4.1 Risks of chemicals *(4.3, 4.2, 4.1, 1.6)*

- While chemical additives make up less than 2% of the fracking fluid, this still translates to large quantities. A typical 15 million litre fracturing operation would use from 80 to 330 tons of chemicals *(4.20)*. A well may be 'fracked' a number of times. An estimated 18,500 kilograms were used in a coal seam gas fracking in Australia with up to 40% not recovered *(4.4)*.
- While some chemicals can be found in home products, they may not be safe for humans and the environment if they make their way into water supplies (3.8). While some chemicals may be harmless when used appropriately in the home at low concentrations, it does not follow that they are safe in the amount

and processes used in fracking, and in various untested combinations with numerous other chemicals. Even common salt can be harmful used in the wrong way.

Fracturing fluids can move through the environment and come into contact with humans in a number of ways, including surface leaks, spills, releases from holding tanks, poor well construction, leaks and accidents during transportation of fluids, flowback and produced water to and from the well pad, and run-off during blowouts, storms, and flooding events.

Hardly any of the chemicals used in fracking operations have been assessed by chemical safety regulator the National Industrial Chemicals Notification and Assessment Scheme (NICNAS). And little is known about the 'synergistic' effects of these chemicals – how they behave when mixed with other natural and introduced chemicals in a high pressure, high temperature environment *(4.5)*.

Benzene, Toluene, Ethylbenzene, Xylene or BTEX are volatile organic compounds (VOCs) found naturally in crude oil, coal and gas deposits and associated groundwater *(4.9)*. While they are prohibited from use in WA, they can be released from the coal seam via drill holes or fractures *(4.10)*. The short term health effects of BTEX include skin, eye / nose irritation, dizziness, headache, loss of coordination and impacts to respiratory system. Chronic exposure can result in damage to kidneys, liver and blood system. Benzene is strongly linked with leukemia *(4.11)* and diseases such non-Hodgkin's lymphoma (NHL).

Other VOCs can also be toxic. Some are known to cause cancer in animals (e.g. methylene chloride) or humans (e.g. formaldehyde), or are suspected human carcinogens (e.g. chloroform, bromodichloromethane). VOCs are also key ingredients in forming ozone (smog), which is linked to asthma attacks, and other serious health effects. VOC exposure may result in eye, nose, and throat irritation; headaches, visual disorders, memory impairment, loss of coordination, nausea, damage to liver, kidney, and central nervous system *(4.12)*. In one study, samples taken from the top of the well-head, a day after the well had been 'fracked', detected VOCs (bromodichloromethane, bromoform, chloroform and dibromochloromethane), as well as benzene and chromium, copper, nickel, zinc *(4.6)*.

Naturally occurring radioactive materials (NORMs) are found in coal seams and shale, e.g. uranium, thorium, radium-228 and radium-226 *(4.13)*. The radioactive material can be released through the drilling process in drill cuttings/muds and flowback water. Radium is a known carcinogen and exposure can result in increased incidence of bone, liver and breast cancer. Radon, a decay product of radium can cause lung cancer. The level of reported radioactivity varies significantly, depending on the radioactivity of the reservoir rock and the salinity of the water co-produced from the well. The higher the salinity the more NORM is likely to be mobilized. Since salinity often increase with the age of a well, old wells tend to exhibit higher NORM levels than younger ones *(4.14)*.

In Australia, BTEX chemicals have been found in 5 out of 14 monitoring wells at Arrow Energy's gas fields, near Dalby, Queensland. Benzene was detected at levels 6 and 15 times the Australian drinking water standard (0.001 milligram per litre /1ppb) *(4.15)*. Toluene and methane have been detected in a private drinking water bore in Queensland *(4.16)*.

For a typical shale gas well, daily produced water volumes range from 300 – 4,500 litres *(4.7)*. The amount of produced water from a coal seam gas well varies between 0.1 - 0.8 megalitres (ML) per day *(4.8)*.

4.2 National Toxics Network findings *(4.22)*

The National Toxics Network has found many volatile organic compounds that are carcinogenic, neurotoxic, or affect breathing around homes in the vicinity of gas fields *(4.22)*. It also tested drinking water tanks, and found heavy metals, chemicals like methylene chloride, caesium 137, and radioactivity. Emissions must be reported by industry, and one gas field, selected as an example, was reported to have produced 1,900 tons of oxides of nitrogen and 1,500 tons of carbon monoxide. Of great concern is the amount of particle matter that is produced. The Australian Chemical Regulatory system is quite inadequate at protecting the rights of the community.

5. WELL INTEGRITY AND FAILURE *14 references*

The industry claims there is no real risk of wells leaking, as well casings are thick and made of concrete and steel

What the literature shows *(1.3, 3.4, 3.5, 3.6, 3.7, 5.1, 5.2, 5.3, 5.4)*

5.1 Do modern gas wells leak?

- There is growing evidence to show that even strict regulations are simply not capable of preventing harm and that 'world's best practice' well construction just isn't enough to stop wells leaking.
- Studies consistently show that oil and gas wells routinely leak, allowing for the migration of natural gas and potentially other substances into groundwater and/or the atmosphere. Recent research suggests that the act of fracking itself may induce pathways for leaks.
- Some incidents (as well as breaches of approval processes and conditions) have come to light only because of whistle-blowers within government departments and gas companies.
- If Regulations only apply to the title holder during production, the rest of the community, who do not get any financial benefit, will have to bear the costs of maintaining the wells forever.

The International Association of Hydrogeologists in 2015 noted in its submission to the Hawke Inquiry *(5.6)*:
- Deterioration and failure of improperly decommissioned wells will, over time, result in long term release of oil and/or gas into the environment. Pathways in the annulus may develop that would allow oil, gas, and brine to move vertically across geologic formations and contaminate groundwater. Substances dissolved in the brine may include those that occur naturally in the shale formations and others injected during the hydraulic fracturing process.
- Upwardly migrating gas, known as stray gas, represents an explosion hazard if not properly vented away from buildings and drinking water wells.
- The risk that annular pathways will develop increases over time as chemical, mechanical, and thermal stresses causes deterioration of well structures and components.
- Failure modes of improperly abandoned wells include the formation of cracks in the cement casing or packers, corrosion of steel production casing, faulty valves, and leaking temporary plugs or surface caps.

5.2 Industry reports of risks

An industry paper in Oilfield Review 2003 *(5.5)*, published by Schlumberger, one of the world's largest companies specializing in fracking, admitted about 5 per cent of wells leak immediately, 50 per cent leak after 15 years, and 60 percent leak after 30 years.

The US Securities and Exchange Commission's website reviews annual forms filed by unconventional gas companies that identify the risks associated with their operations *(1.7)*. It is a requirement for companies to disclose 'the most significant factors that make the offering speculative or risky'.
- Oil and natural gas companies have routinely warned of drilling's serious risks. Such hazards and risks include leaks, spills, release of pollutants, flooding which could affect operations in low-lying areas, explosions, blowouts, environmental damage, property damage, injury, and death.
- Chesapeake Energy Corporation has stated that 'horizontal and deep drilling activities involve greater risk of mechanical problems than vertical and shallow drilling operations.'
- The companies also routinely warn of inadequate insurance to cover drilling harms.

The risks identified by these oil and gas companies are consistent with those identified in the exhaustive scientific studies undertaken.

5.3 Frequency of well failure

- Estimates of well failure rates vary although the more conservative well failure rates found in the literature are between 4.6% and 8.9%.
- Davies *et al.* (2014) *(5.7)* reviewed reliable databases of well integrity from around the world and found that failure rates were highly variable from 1.9 to 75 per cent, with the Marcellus Shale well failure rate at 6.3 per cent, for example. They found a greater proportion of failure in injection wells (such as those required for hydraulic stimulation) when compared to production only wells (such as in traditional oil/gas fields). They concluded it is not possible to have zero per cent well integrity failure. They also noted that the amount of information retained by oil and gas companies and regulators was not sufficient for an exhaustive study, and were not released even if available.
- A 2009 study from Alberta, Canada of more than 315,000 oil, gas and injection wells of various ages, showed that 'injection wells' into which liquids or gases are pumped are 2-3 times more likely to leak than conventional 'production wells'. The same study found that horizontal or inclined wells are observed to have significantly higher failure rates than vertical wells. It is universally acknowledged that problems with casing centralisation and cement slumping in horizontal or inclined wells may contribute to the increased incidence of leakage.
- Data from Pennsylvania's Department of Environmental Protection (DEP) for 2000-12 show over nine percent of shale gas wells drilled in the state's north eastern counties leak within the first five years.
- According to state inspections of all 6,000 wells drilled in Pennsylvania's Marcellus Shale before 2013, 6 to 10 per cent of them leaked natural gas, with the rate of leakage increasing over time. The rate was 6 per

cent in 2010 (97 well failures out of 1,609 wells drilled); 7.1 per cent in 2011 (140 well failures out of 1,972 wells drilled); and 8.9 percent in 2012 (120 well failures out of 1,346 wells drilled) *(5.13)*. Wells with horizontal underground arms were four times more likely to fail than vertical wells in the same area.

- A 2011 report from Pennsylvania, USA, showed about 75% of groundwater wells sampled within 1 kilometre of gas drilling in the Marcellus shale were contaminated with methane from the deep shale formations. Isotopic fingerprinting of the methane indicated that the deep shale was the source of contaminations, rather than biologically derived methane.
- In 2016, an interdisciplinary team led by University of Colorado researchers found methane in 42 water wells in the intensely drilled Denver-Julesburg Basin where high volume, horizontal fracking operations began in 2010. Of the 42 affected wells, 11 had already been identified by state regulators as suffering from 'barrier failures' *(5.8)*.
- In 2014, University of Waterloo researchers warned that natural gas seeping from 500,000 wellbores in Canada represented 'a threat to environment and public safety' due to groundwater contamination, greenhouse gas emissions, and explosion risks. Ten percent of all active and suspended gas wells in British Columbia now leak methane, and some hydraulically fractured shale gas wells in that province have become 'super methane emitters', spewing as much as 2,000 kilograms of methane a year *(5.9, 5.10)*.
- In 2014, the Council of Canadian Academies identified inherent problems with well integrity as one of its top concerns about unconventional drilling and fracking. According to one expert panel, 'the greatest threat to groundwater is gas leakage from wells from which even existing best practices cannot assure long-term prevention.' Cement may crack, shrink, or become deformed over time, thereby reducing the tightness of the seal around the well and allowing the fluids and gases to escape into the annulus between casing and rock and thus to the surface *(5.11)*.
- In 2015, the New York State Department of Environmental Conservation stated 'there is a risk that well integrity can fail, especially over time, and questions have arisen about whether high-volume hydraulic fracturing can cause seismic changes which could potentially result in fracturing fluid migration through abandoned wells or existing fissures and faults. Thus, high-volume hydraulic fracturing could result in significant adverse impacts to water resources from well construction and fracturing fluid migration' (5.12).
- Professor Anthony Ingraffea (Cornell State University, and previously a consultant and researcher in the oil and gas industry) showed leaking gas wells in a video *(5.4)*.

  An analysis of industry literature showed:
  - In 340,000 oil and gas well in Canada, 15-16% of conventional wells leak and 65% of modern deviated wells leak.
  - 35% of 1.8 million global wells leak – 5% in young wells and 35% in old wells.

  An analysis of public 75,000 inspection reports in Pennsylvania between 2000-2013 showed:
  - Leakage in old wells pre 2009 of 13% for unconventional wells and 20% for conventional wells.
  - Leakage in modern wells post 2009 were better, but still 12% in unconventional wells.

5.4 Incidents in Australia

- Peter Lindsay, a former CSG industry regulator in the Queensland Government (DERM) claimed that some of the infrastructure in Queensland is already failing *(1.3)*.
- An example of the effect of corrosive water on cementing and casing is provided by deep oil exploration wells drilled in the Perdika/Great Artesian Basin in NT in the 1960s. Now, some fifty years later, the steel casing has almost entirely corroded away, resulting in inter-aquifer contamination. This well required expensive rehabilitation works to stem artesian flow. This single bore cost the Northern Territory and Commonwealth Governments $500,000 to plug as the company responsible for the well was insolvent. This example highlights the issue of operator insolvency due to the boom and bust cycles of oil and gas development which complicate efforts to hold liable parties responsible and provide for timely environmental reclamation.
- A scalded area in NSW's Pilliga Forest has not recovered almost 10 years after a wastewater spill by Eastern Star Gas. Wastewater leaking from a pond in the Pilliga (on tenements that Santos bought from Eastern Star Gas) resulted in the contamination of groundwater with uranium and arsenic.
- There have been numerous reports of water contamination and health impacts by people living close to Australian CSG fields in Camden, NSW and on the Western Darling Downs in Queensland.
- In Western Australia a well in the Whicher Range, east of Margaret River was fracked in 2004 using diesel as the fracking fluid because other fluids caused the clay soils to swell. The experimental technique failed and more than half of the 1.2M litres of diesel remains trapped down the well.
- Hovea 8, a well in the northern Perth Basin, was shut in 2011 due to casing corrosion during production, only eight years into its operational life *(5.2, 5.14)*.
- In the Robe River oilfield of the Carnarvon Basin during the 1980's, some old wells were bleeding gas and saline water (*5.2*).

6. IMPACTS ON WATER - Ground water and Surface water *31 references*

The industry claims that the risk of groundwater and surface water contamination is very low.
(2.1, 2.2, 2.3, 2.4)

What the literature shows

6.1 Contamination of aquifers and surface water

There are numerous examples of peer-reviewed literature showing serious unconventional gas impacts on groundwater in the USA, regardless of the industry's insistence that there are no impacts. This should provide a warning to Western Australia that impacts do occur and are usually found by third parties *(5.2).*

The gas industry claims that because shale and tight gas extraction involves deeper rock layers, they are safer than gas extraction from shallow coal seams. But according to a European Commission Report *(6.1)* there is an overall high risk of ground and surface water contamination resulting from fracking.

Aquifers can be contaminated by fracking:

- through water seeping from leaking wells
- from faults induced by fracking
- from surface spills of produced water involved in the fracking process
- contaminated water from the gas source per se. *(1.6, 6.2, 6.3, 6.4).*

After fracking at each well, the large volumes of hazardous flow back fluid must be stored and disposed of. Surface water pollution can occur:

- when there are accidental spills of fluids or solids at the surface
- when well blow outs occur
- through discharge of waste water onto land surfaces or into waterways *(1.6, 6.2, 6.3, 6.4).*

Flowback fluids contain hazardous fracking chemicals as well as naturally occurring toxic substances released from target geological zones such as:

- methane
- BTEX (benzene, toluene, ethylbenzene, xylene)
- polycyclic aromatic hydrocarbons (PAHs)
- naturally occurring radioactive materials (NORMs)
- heavy metals and other volatile organic compounds (VOCs) *(6.5, 6.6, 6.7, 6.8).*

6.2 Contamination of ground water and drinking water in USA – Results of studies

- In the US state of Pennsylvania alone, more than 240 private drinking water wells have been contaminated or have dried up as the result of drilling and fracking operations over a seven-year period. There has been widespread drinking water contamination in 550 water samples throughout the heavily drilled Barnett Shale region in northern Texas *(6.9).*
- In March 2016 a USA federal jury awarded two Dimock, Pennsylvania couples $4.24 million after finding an oil and gas company responsible for contaminating their well water during drilling and fracking activities *(6.31).*
- Fracking-related solvents were found in private drinking water wells near drilling and fracking operations in Pennsylvania *(6.10).*
- Elevated levels of methane have been found in groundwater discharging into a stream near fracking operations in Pennsylvania along with high levels of methane in nearby private water wells due to a defective casing *(6.11).*
- Comparison of pre-drill and post-drill data on water quality found changes in water chemistry that coincided with the advent of drilling and fracking activities. Methane was also detected in most houses tested in this study *(6.12).*
- 56 of the 143 well owners surveyed in south-western Pensylvania in 2015 indicated changes in water quality or quantity. Chloride, sulphate, nitrate, sodium, calcium, magnesium, iron, manganese and strontium were commonly found, with 25 households exceeding the secondary maximum contaminate level for manganese. Methane was detected in 14 of the 18 houses tested. Since 2009, 65 horizontal wells were drilled within a 4 km radius of the community and each well was stimulated on average with 3.5 million gallons of fluids *(6.13).*

- A 2016 study by Stanford University scientists determined that fracking and related oil and gas operations have contaminated drinking water in the town of Pavillion, Wyoming, where residents have long complained about foul-tasting water *(6.14, 6.15)*.
- Analysis, in the journal *Environmental Science & Technology, 2017*, revealed 6,648 spills from the fracking industry from just four states - Colorado, New Mexico, North Dakota and Pennsylvania, in 10 years *(6.16)*. The researchers determined that up to 16 percent of fracked oil and gas wells spill hydrocarbons, chemically laden water, fracking fluids and other substances.
- Analysis of published data (Vengosh *et al.* 2014, *6.4*) showed evidence of stray gas contamination, surface water impacts in areas of intensive shale gas development, and the accumulation of radium isotopes and other contaminants in some disposal and spill sites.
- Recent research from the USA found higher levels of arsenic and other heavy metals, plus higher salinity, in water bores which were less than 3km from shale gas wells *(6.17)*. Other research has found increased methane concentrations in water bores closer to shale gas wells, creating an explosion hazard *(6.18)*.
- Studies from Duke University in the US have found high levels of radioactivity in a creek used for disposal of wastewater *(6.19)*.
- Using geochemical and isotopic tracers to identify the unique chemical fingerprint of Bakken region brines, a 2016 Duke University study found that accidental spills of fracking wastewater have contaminated surface water and soils throughout North Dakota where more than 9,700 wells have been drilled in the past decade. Contaminants included salts as well as lead, selenium, and vanadium. In the polluted streams, levels of contaminants often exceeded federal drinking water guidelines. Soils at spill sites showed elevated levels of radium *(6.20)*. Contaminants were observed in spill sites up to 4 years following the spill events, and it was concluded there is clear evidence of direct water contamination from fracking *(6.21)*.
- High levels of iodide, bromide, and ammonium were found in samples of wastewater from fracking operations in two US shale formations. The same chemicals were found when fracking wastewater was discharged into rivers and streams at three treatment sites in Pennsylvania and during an accidental spill in West Virginia *(6.22)*.

6.3 Experiences in Australia

- A review by Klohn Crippen Berger Free *(6.23)* for the Queensland Department of Natural Resources and Mines concluded that gas from CSG development can even occur in water bores that do not experience a water level decline from CSG development. These impacts have also been reported by numerous landholders who suffered bore impairment from excess gas.
- There have been numerous reports of water contamination and health impacts by people living close to Australian CSG fields in Camden, NSW and on the Western Darling Downs in Queensland. They are similar in nature to reports in the United States *(6.24)*.
- In Australia, Gavin Mudd from Monash University showed gas bubbling from the Condamine river. The industry claims this was not due to Coal Seam Gas! (1.3)
- Spills have also occurred in Australian CSG operations. A scalded area in NSW's Pilliga Forest has not recovered almost 10 years after a wastewater spill by Eastern Star Gas. Wastewater leaking from a pond in the Pilliga (on tenements that Santos bought from Eastern Star Gas) resulted in the contamination of groundwater with uranium and arsenic *(6.24)*.
- In May 2013 some 240,000 litres of oil were spilled at a conventional well in Santos's Zeus field west of Thargomindah. Despite clear evidence, the Queensland environment department chose not to prosecute Santos for this breach of conditions *(6.24)*.
- In the Northern Territory, Origin Energy used unlined pits for the storage of waste water, and then failed to responsibly remove all contaminants, leaving polluted water in areas that then flooded. Photos are available showing the state of a shale gas pad after gas fracking activities stopped in 2015 *(1.6)*.
- There have been a number of recorded contamination events in NSW during the exploration phase of coal seam gas development. Santos' CSG operations in the Forest region of NW NSW recorded at least 20 coal seam gas waste water spills and continuing leaks from evaporation ponds. Santos' records show spills and leaks from all parts of the operations, from evaporation ponds, pipelines, the wastewater treatment facilities and at well sites *(6.25)*.
- Eastern Star Gas was responsible for pollution offences in NSW. The EPA issued two penalty notices with fines of $1,500 each to Eastern Star Gas for discharging polluted water containing high levels of salt into Bohena Creek in March and November 2010 *(6.26)*.
- In 2014, Santos was found guilty of polluting an aquifer in the Pilliga Forest *(6.27)* with radioactive uranium 20 times safe levels as well as toxic heavy metals *(6.28)*.
- A spill in June 2011 in the Pilliga resulted in 10,000 litres of untreated toxic coal seam gas wastewater containing a mix of heavy metals (including arsenic, lead and chromium), salts and petrochemicals that

killed vegetation and wildlife. Santos was found guilty in the NSW Land and Environment Court and fined $52,000 *(6.29).*

7. IMPACTS ON AIR *25 references*

The industry states that the most common well integrity risk is slow leakage of methane around the external casing, but the consequences of such leaks, although negative from a climate change perspective, do not threaten health because natural gas is not toxic, the frequency of substantial leaks is low, and the leakage rates are low as well. (2.1)

What the literature shows

Unconventional gas mining and fracking will lead to large deliberate and fugitive emissions of methane, adding to climate change *(1.6).*

7.1 Gas emissions associated with fracking

- Damien Maher, a Senior Research Scientist with Southern Cross University, showed that methane levels surrounding gas mines were consistently higher – up to 3 times background values *(1.2).* It was previously shown that in the Condamine River area, considerable atmospheric methane levels and bubbling in the river, were associated with the CSG development in the Surat Basin area where fracking had occurred *(7.1).*
- It is increasingly being recognised that volatile chemicals used in the fracking process, and the gases released, pose health risks to workers and people living nearby. Volatile organic compounds and hydrocarbons (including the carcinogen benzene) are released during unconventional gas operations, from venting, holding tanks, ponds, compressors and other infrastructure. Some of these mix with nitrous oxides from diesel-fuelled machinery, creating ground level ozone – a significant respiratory irritant *(7.2).*
- Emissions measured near gas wells include the BTEX compounds - benzene, toluene, ethylbenzene, and xylene – of which benzene is a contributor to lifetime excess cancer risk *(7.3).* Emissions of formaldehyde, hydrogen sulphide, acrylonitrile, methylene chloride, sulphuric oxide, and volatile organic compounds (VOCs) are recorded near gas drilling, and all have potential adverse health effects. Trimethyl-benzenes, aliphatic hydrocarbons, and xylenes may cause neurological effects, and can irritate the respiratory system and mucous membranes *(7.4).*
- A 2012 study detected 44 hazardous air pollutants at unconventional gas well sites *(7.5),* whilst other recent USA studies *(7.6)* show that drilling and fracking emissions often contain strikingly high levels of benzene. The NYS Department of Health Public Health Review (the NYS Review) noted that 'studies provide evidence of uncontrolled methane leakage, emissions of other volatile organic chemicals, and particulate matter from well pads and natural-gas infrastructure as well as intermittently high dust and benzene concentrations'.
- Exposure to a range of harmful substances associated with unconventional gas operations constitutes a serious health hazard to those working or living near unconventional gas development *(7.7).* Emissions can contribute to community odour problems and respiratory health impacts such as asthma.
- The Bakken shale emits 250,000 tons of ethane per year *(7.8).* Emissions in this single region are 10 to 100 times larger than reported in inventories. Ethane is a gas that affects climate and decreases air quality.

7.2 Recorded Methane Venting in Australia (7.9, 7.10)

- An independent energy advisor, Tim Forcey, used an FLIR GF-320 infrared camera in the Queensland coal seam gasfields in 2017 to demonstrate substantial gas emissions from vents:
    - Continuous releases of methane from "high-point vents" on water-gathering pipelines
    - Intermittent releases of methane from other gas field equipment
    - Methane bubbling from the Condamine River and Wambo Creek.
- This report includes videos that amply demonstrate these emissions.
- Given the very large number of high point vents and other gas field equipment vents which are located throughout the Queensland CSG fields, if the scale of venting detected by the FLIR camera was replicated, it would represent a potentially vast, unmeasured contribution to global warming.

7.3 Concerns admitted by industry

Industry reports illustrate the level of industry concern:

- The industry publication GasTips, World Oil Oilfield Review, stated that between 7% and 19% of more than 1000 wells drilled from 2005 to 2007 in western Canada had gas migration along the casing annulus, and 9% to 28% of them had gas leakage through surface casing vents *(7.11).*

- Unintended natural gas migration along production wellbores, even for conventional gas, has been a chronic problem for the oil and gas industry as a result of poor primary cement jobs, particularly in gas wells *(7.12)*.
- Brufatto et al (2003) cite USA Mineral Management Service data from the Gulf of Mexico indicating, 'By the time a well is 15 years old, there is a 50% probability that it will have measurable gas build up in one or more of its casing annuli *(7.13)*.
- Schlumberger, one of the world's largest companies specialising in fracking, published in its magazine as long ago as 1994: 'Older fields will continue to benefit from the expertise of the corrosion engineer and the constant monitoring required to prevent disaster *(7.14)*.

7.4 Climate change:

The industry claims that more natural gas would enhance Australia's ability to meet increasing energy needs while at the same time reduce greenhouse gas emissions (2.1).

What the literature shows

Methane is a more powerful greenhouse gas than carbon dioxide – 86 times more powerful when considered over a 20-year timeframe and 34 times more over a 100-year timeframe. Large amounts of methane leak into the atmosphere throughout the lifecycle of gas development and production, so unconventional gas is likely to be as bad or worse for climate change than coal or oil *(7.24, 3.4)*.

As climate change is widely considered the major global health threat of this century, fugitive emissions produced from the gas industry are an unacceptable health risk *(7.15)*.

A recent review by the Melbourne Energy Institute on methane fugitive emissions from unconventional gasfields in the USA *(7.16)* concluded:

- Actual measurements above USA gasfields have recorded fugitive emissions of up to 17% of production. For comparison, the unconventional gas industry in Australia claims that its fugitive emissions amount to only 0.1% of production *(7.17)*.
- 'Top down' methods of measuring fugitive emissions, such as satellite imagery and aerial borne surveys, have revealed methane emissions that are many orders of magnitude greater than emissions recorded from 'bottom up' surveys using ground measurements'.
- It is widely recognized that at more than about 3% leakage, gas is actually more polluting than coal when used to generate electricity *(7.18)*.

The Australia Institute showed that emissions from unconventional gas have been severely underestimated in Australia *(7.19)*. The current methodology for measuring greenhouse gas emissions from unconventional gas extraction is based on assumed and outdated methane emissions factors, rather than direct measurement of wells, pipelines and other gasfield infrastructure. The estimate used by the Australian Government is 0.058 tonnes of methane leaked per kilotonne of methane produced, or 0.0058%. This estimate is based on a historic USA emissions factor designed for measuring conventional gas emissions and is no longer used in the USA. Actual measurements by 16 peer reviewed research projects, using improved technology to take direct measurements from gas fields in the US, have ranged from 2-17% of production *(7.20)*.

The impact of these unaccounted-for methane emissions is seen in recent research showing that USA methane emissions have risen 30% in the last decade. The study used evidence from atmospheric observations to trace the largest rise of these emissions to the central part of the USA, where oil and gas extraction has expanded dramatically over the same time period (7.21).

The Melbourne Energy Institute reported that methane gas migrating to the surface due to coal seam dewatering and depressurisation for coal seam gas production was a potentially significant source of greenhouse gas *(7.22, 7.25)*. It found that migration of methane along existing natural faults and fractures is possible and may increase with continued depressurization by unconventional gas mining. It noted that presence of free methane in water bores can be the direct consequence of depressurisation of the coal seams. The Melbourne Energy Institute also concluded that Australia may be dramatically under-estimating the fugitive methane emissions from unconventional gas.

Bista (2017) from Murdoch University *(7.23)* concluded that greenhouse gas emissions resulting from the development of Western Australia's five onshore gas basins would be equivalent to all other Australian emissions sources combined at 2014 levels each year for 20 years which is the general lifetime of a well. This paper concludes that onshore gas fracking without any control mechanism could not be considered as a transition fuel for climate change mitigation in Australia. Fracking emissions could be a highly significant source of greenhouse gas emissions nationally as well as globally.

8. IMPACTS ON LAND *17 references*

8.1 Transformation of productive land into industrial landscape

The biggest impact on land is the transformation of entire regions of beautiful productive land into an industrial landscape. **It could be argued that this alone is reason to not allow unconventional gas mining.** While the industry claims that the footprint is relatively small, a quick investigation shows this is not correct. The industry will claim that new technologies involving multiple lateral drillings will reduce this footprint, but this is yet to be determined.

The background paper for the WA Inquiry claims that the footprint for unconventional gas will have a smaller footprint than coal seam gas *(8.1)*. It is not appropriate to assume that yet. Australia's former and present Chief Scientists, Prof Chubb and Dr Finkel, have both admitted that Australia's unconventional shale gas industry will have a larger footprint, and require considerably more water, than CSG *(8.2, 8.3)*.

8.2 Well Density

Prime agricultural regions in Queensland have been transformed into industrial areas through coal seam gas *(1.3)*. 18,000 wells have been approved, and tens of thousands more are planned. The impact of the infrastructure on the landscape and water table is apparent when flying in this area *(8.16)*. The impact of the industrialisation is neatly demonstrated in a series of 'Before and After' photos of various forest and agricultural areas in Queensland. *A warning from Queensland:* *http://www.csgfreenorthwest.org.au/qlds_story* *(1.8)*

Although conventional oil and gas production can have many of the same types of water resource and environmental impacts (spills, well integrity failure etc.), the well density in an unconventional gas field, is hundreds to thousands of times higher than a conventional field *(5.2)*.

Early in the development of the tight gas industry, hydraulic stimulation was done on vertical wells so a higher well density was required. However, since the development and reduced cost of horizontal drilling techniques, lower well densities are more typical with multiple wells starting from the same drilling site or pad. Although this reduces pad and well density in the landscape, it potentially puts greater pressure on the sites in terms of likelihood of impact due to the increased failure potential in the vertical portion of the well hole. Regardless, there are large increases in well density when compared to conventional oil and gas *(5.2)*.

8.3 Rehabilitation

It may not be possible to fully restore sites in sensitive areas following well completion or abandonment, particularly in areas of high agricultural, natural or cultural value (European Commission report, *8.4, 1.6*). Over a wider area, with multiple installations, this could result in a significant loss or fragmentation of amenities or recreational facilities, valuable farmland or natural habitats.

Soils across the Darling Downs, some of the most productive agricultural land in Australia, could never be returned to prime agricultural land after development for unconventional gas *(8.17)*.

A recent USA study documents the failure of plant and soil systems disturbed by drilling and fracking activities to return to pre-drilling conditions following rehabilitation- even after 20 to 50 years *(8.5)*.

An interdisciplinary study published in *Science* 2015 demonstrated that the accumulating land degradation has resulted in continent-wide impacts of the unconventional gas industry in the United States, as measured by the reduced amount of carbon absorbed by plants and accumulated as biomass. This is a robust metric of essential ecosystem services, such as food production, biodiversity, and wildlife habitat, and its loss 'is likely long-lasting and potentially permanent'. The land area occupied by well pads, roads, and storage facilities built during this period is approximately three million hectares, roughly the land area of three Yellowstone National Parks *(8.6)*.

8.4 Fragmentation and Biosecurity

Experts in Australia have identified that the considerable surface footprint of CSG infrastructure represents a serious threat to biodiversity fragmentation through direct clearing of bushland, loss of native vegetation, fragmentation of important remnant vegetation, spread of invasive species and increased fire risk *(8.7)*.

The sheer scale of gas wells and associated infrastructure, presents genuine risks for unique natural landscapes. In Queensland, farmers have reported serious invasions of weeds following CSG development. One cattle farmer has initiated legal action against a CSG company after he had to destock his property at Dalby after a sudden infestation of the noxious African lovegrass weed following CSG activities *(8.8)*.

Lawyers in Queensland representing farmers dealing with the CSG industry consider that weeds may ultimately be one of the biggest legacies of the CSG industry *(8.9)*, and have highlighted the weaknesses of biosecurity measures.

8.5 Seismic Activity

Evidence arising in the past 18 months has demonstrated links between fracking and waste fluid reinjection with increased seismicity and earthquakes.

- International researchers in 2016 concluded that the underground injection of waste water from oil drilling had contributed to earthquakes in California in 2005 by changing pressures along an active fault *(8.10)*.
- An article in the Texas Journal of Oil, Gas, and Energy Law in 2016 exhaustively reviewed the literature on earthquake activity in areas of six states (Arkansas, Colorado, Kansas, Ohio, Oklahoma, and Texas) and concluded that courts should impose strict liability for earthquake damage caused either by fracking itself or by the underground injection of fracking fluids *(8.11)*.
- Emerging data summarised in Scientific American in 2016 suggested that pressure changes caused by fracking wastewater injection can migrate for years before encountering a geological fault and altering stresses in ways that allow for slippage *(8.12)*.
- A Canadian team of researchers determined in 2016 that hydraulic fracturing itself is linked to earthquake swarms in western Canada, in contrast to the central United States where disposal of fracking waste is the cause of most induced seismicity. Furthermore, lowering the volume of injected fluid may not be sufficient to prevent quakes *(8.13)*.

The evidence is strong enough that the Oklahoma Supreme Court ruled unanimously that homeowners can sue the oil and gas industry for injuries or property damage resulting from earthquakes. The number of earthquakes of magnitude 3.0 or higher has skyrocketed in Oklahoma since the advent of the fracking boom, with fewer than two per year before 2009 and more than 1,100 predicted to occur in 2015 *(8.14)*.

The Dutch government plans to compensate people whose homes and buildings were damaged in a 3.4 magnitude quake, blamed on extraction at Europe's biggest gas field. More than 900 homes and buildings were damaged, according to an association which collates reports from residents. Groningen, which houses the European Union's largest gas field, has been plagued by tremors which increased as gas production rose in the region through the 1990s. *(8.15)*

9. HEALTH IMPACTS *55 references*

The industry claims that unconventional gas activities are safe. To justify this, it quotes a report from Queensland Health which concluded no clear link could be drawn between the health complaints of some residents and the local CSG industry *(2.1)*. 'This report found that the nature of complaints meant there were multiple possible causes and explanations including faecal contamination in the water supply, the use of wood-fired heaters or open fires, and rainwater contaminated with bacteria, viruses or other organisms. These causes are not related to gas operations. The report noted the most prevalent reported symptoms are headache, transient (reversible) eye irritation, nosebleeds and skin rashes. These are common medical complaints.'

What the literature shows

There is a rapidly growing body of research that demonstrates that unconventional gas operations can have serious consequences for human and animal health.

Adgate, Goldstein and McKenzie (2014) *(9.1)* present a clear argument that unconventional gas mining poses risks to health, both directly and indirectly, and at the local, regional and global level. Thus, decisions on unconventional gas mining made by all Australian states and territories, and by other nations, affect us all.

There are numerous independent reviews involving many hundreds of peer-reviewed papers demonstrating the impacts of unconventional gas on human health.

9.1 Impacts shown from 700 peer-reviewed papers *(9.4, 9.4a, 9.2, 7.2, 9.3, 9.6)*

Scientific literature involving more than 700 studies on the impacts of unconventional gas development show:

- 84% of public health studies indicate risks to public health
- 69% of water studies show actual or potential water contamination

- 87% of air quality studies indicate elevated air pollution.

9.2 Saunders – 156 papers

A review of 156 publications (Saunders et al., 2016) (9.8) found multiple potential hazards to human health from exposures to harmful air and water pollutants associated with unconventional gas mining (9.7).

The major concerns identified were (9.9):

- There are direct local health concerns associated with living and working in close proximity to all steps of the unconventional gas mining process, not just the hydraulic fracturing ('fracking') component. These include potential exposures to air pollutants released during the whole process, including volatile organic compounds, fine silica, oxides of nitrogen, hydrogen sulphide, formaldehyde, ground level ozone and diesel fumes.
- Local communities may also face stress from an array of changes, including exposure to noise, lights, odours, and dust, as well as worries and fears about health, accidents, declining property values, increased traffic, industrialised landscapes, loss of community cohesion, post-construction job losses, local business loss, and changes to community character.
- Findings from various research studies have suggested associations between living close to unconventional gas operations and higher frequencies of negative health indicators, such as lower birth weights, more birth complications, more self-reported symptoms such as migraines, nasal and sinus problems and fatigue, and more hospitalisations due to heart, nerve and asthma conditions.
- At a local and regional level, unconventional gas activities near drinking water sources carry the potential for impacts on water quality.
- Dealing with wastewater from hydraulic fracturing safely remains a major challenge – each method and proposed new solution carries with it potential problems and complications.
- At a global level, there are grave concerns about the unconventional gas industry's contribution to climate change.

9.3 Review by Concerned Health Professionals of New York & Physicians for Social Responsibility.

Sources:

- *Concerned Health Professionals of New York & Physicians for Social Responsibility Compendium of scientific, medical, and media findings demonstrating risks and harms of fracking (unconventional gas and oil extraction). (2016, 2015) (1.7, 9.14).*
- *Chesapeake PSR (2016) The health effects of fracking. Fracking harms human health. Chesapeake PSR Physicians for social responsibility. Health and Energy Brief. (9.6)* Author – Gina Angiola, MD
- *Doctors for the Environment Australia: Submission to Inquiry into Hydraulic Fracturing in NT April 2017 (7.2)*

Some of the public health effects of unconventional gas development outlined in the Compendium of Fracking Risks compiled by the Concerned Health Professionals of New York *(1.7)*, include:

- increased rates of hospitalization for cardiological complaints, cancer, skin conditions, and urological problems;
- increase in frequency of health symptoms reported by residents as distance between households and gas wells decreased; with rashes and upper respiratory problems more prevalent among persons living less than one kilometre from drilling and fracking operations;
- increases in commercial vehicle accidents;
- a sharp rise in ambulance calls and emergency room visits for drug related cases and oilfield related injuries and accidents;
- increase in infant deaths to six times the normal rate over three years;
- congenital heart defects, and possibly neural tube defects in newborns, associated with the density and proximity of natural gas wells within a 10-mile radius of mothers' residences;
- elevated rates of low birthweight among infants born to mothers living near drilling and fracking operations during their pregnancies;
- reductions in average birthweight and length of pregnancy as well as increased risk for low birthweight and premature birth associated with proximity to fracking operations *(9.16).*

Health impacts have been identified from exposure due to proximity to active wells.

- In 2015, researchers at the Johns Hopkins Bloomberg School of Public Health analysed data from roughly 10,000 birth records in Pennsylvania and found a statistically significant association between proximity of the mother to active fracking operations and premature births and high-risk pregnancies *(9.10, 9.11).*
- In 2016, researchers at the Johns Hopkins Bloomberg School of Public Health analysed medical records of more than 35,000 asthma patients, ages 5 to 90 years old, and found a statistically significant association between proximity to active fracking operations and mild to severe asthma exacerbations *(9.12).*

- In 2016, researchers at the Johns Hopkins Bloomberg School of Public Health analysed responses to questionnaires received from more than 7,000 adult primary care patients in central and northern Pennsylvania, and found statistically significant associations between proximity to active fracking operations and various combinations of migraine headaches, chronic rhinosinusitis and fatigue symptoms *(9.39)*.
- In a further study from Pennsylvania, published in 2015, researchers examined health care use with fracking activity from over 95,000 inpatient hospital records. They found that hydraulic fracturing as determined by well number or density had a significant association with cardiology hospital inpatient rates, and well density had a significant association with neurology hospital inpatient rates *(9.13)*.

Exposures that may take years to become clinically apparent were identified.

- In 2015, researchers at the University of Pennsylvania and Columbia University reported an increase in cardiac and neurologic hospitalizations in two Pennsylvania counties with active fracking operations, compared with a neighbouring county where such operations had been banned *(9.34)*.
- In 2016, researchers working collaboratively with local residents near oil and gas operations in Wyoming reported combined results from environmental sampling and biomonitoring in one of the first studies of its kind. Toxicants and their metabolites, including BTEX6 chemicals known to damage multiple organ systems, were detected in air samples and in the urine of residents *(9.35)*.
- In 2016, researchers documented endocrine-disrupting chemicals in surface waters near fracking wastewater disposal sites in West Virginia. Such chemicals can have potent effects on human development at exceedingly low concentrations during critical developmental windows *(9.36)*. Researchers have also documented adverse effects on development and reproductive capacities of both male and female mice at concentrations that are relevant to real-life human environmental exposures *(9.37, 9.38)*.

Drilling and fracking emissions contribute to toxic air pollution and smog (ground-level ozone) at levels known to have health impacts *(9.14)*.

- The New York State Department of Environmental Conservation determined that fracking could increase ozone levels in downwind areas of the state, potentially impacting the ability to maintain air quality that meets ozone standards.
- Air near gas wells in rural Ohio had levels of polycyclic aromatic hydrocarbons that surpassed those in downtown Chicago. They were also ten times higher than the levels found in rural areas without fracking operations, raising the lifetime risk of cancer for residents living near the well pads by 45 percent.
- Increased air pollution and smog formation poses a serious risk to all those already suffering from respiratory issues, such as children with asthma.

Public health problems associated with drilling and fracking, including occupational health and safety problems, are increasingly well documented *(9.14)*.

- Health impacts among residents living near drilling and fracking operations include increased rates of hospitalization, self-reported respiratory problems and rashes, motor vehicle fatalities, trauma, drug abuse, and low birth weight among infants.
- Benzene has been detected in the urine of well pad workers in Colorado and Wyoming.
- The National Institute for Occupational Safety and Health identified oil and gas extraction industry workers among those at risk for silicosis, an incurable lung disease caused by exposure to silica dust from the silica sand that is used extensively in fracking operations.
- Fatality rates among workers in the oil and gas extraction sector in North Dakota were seven times the national fatality rates in this industry, which itself has more deaths from fires and explosions than any other private industry. An increase in workplace deaths has accompanied the fracking boom in West Virginia.

Drilling and fracking activities can bring naturally occurring radioactive materials to the surface *(9.14)*.

- Exposure to increased radiation levels from these materials is a risk both for workers and for residents.
- In Pennsylvania, radon levels in homes have been rising since the advent of the fracking boom, and buildings in heavily drilled areas have significantly higher radon readings than areas without well pads—a difference that did not exist before 2004.
- University of Iowa researchers documented a variety of radioactive substances including radium, thorium, and uranium in fracking wastewater, and showed their radioactivity increased over time; they warned that radioactive decay products can potentially contaminate recreational, agricultural, and residential areas.
- The New York State DEC's Findings Statement noted that naturally occurring radioactive materials (NORM) are brought to the surface in the cuttings, flowback water and production brine. The build-up of NORM in pipes and equipment has the potential to cause a significant adverse impact because it could expose workers handling pipes, for cleaning or maintenance, to increased radiation levels.

Unconventional gas development affects human health and well-being not only through direct exposures to toxic chemicals in air, water and soil, but also through many stressors introduced into communities. These include

excessive noise and light pollution, increases in traffic accidents and fatalities, increases in domestic violence, alcohol and drug use, crime and disruptions of family and community relationships.

The Physicians for Social Responsibility concluded that the science is increasingly clear. The health risks posed by fracking are real, significant and unacceptable. No regulatory framework has been shown to adequately protect public health or the environment *(9.6)*.

9.4 Medical health survey in the Tara region, Queensland *(9.15)*

This report documents an investigation during February and March 2013 by a concerned General Practitioner, in relation to health complaints by people living close to coal seam gas development in SW Queensland.

- Information was collected on 113 people from the 38 households in the Tara residential estates and the Kogan/Montrose region. Of these, 17 were children 5 years of age or less, 31 were children aged between 6 and 18, and 65 were adults aged between 19 and 82.
- 58% of residents surveyed reported that their health was definitely adversely affected by Coal Seam Gas, whilst a further 19% were uncertain. The pattern reported was outside the scope of what would be expected for a small rural community.
- In all age groups there were reported increases in cough, chest tightness, rashes, difficulty sleeping, joint pains, muscle pains and spasms, nausea and vomiting. Approximately one third of the people over 6 years of age were reported to have spontaneous nose bleeds, and almost three quarters were reported to have skin irritation. Over half of children were reported to have eye irritation.
- A range of symptoms were reported which can sometimes be related to neurotoxicity (damage to the nervous system), including severe fatigue, weakness, headaches, numbness and paraesthesia (abnormal sensations such as pins and needles, burning or tingling). Approximately one third of the all the 48 children to age 18 (15/48) were reported to experience paraesthesia. Almost all the 31 children aged 6-18 were reported to suffer from headaches and for over half of these the headaches were severe. Of people aged 6 years and over, severe fatigue and difficulty concentrating was reported for over half. Parents of a number of young children reported twitching or unusual movements, and clumsiness or unsteadiness.

No baseline air or water monitoring or baseline health studies were done prior to the Queensland Government permitting the widespread development of the CSG industry in close proximity to family homes. No ongoing health study or surveillance and no ongoing testing to monitor chronic exposure levels is in place. This is clearly unacceptable.

Since 2008, the people near Tara have informed successive Queensland Governments of their health problems, but their reports of ill health have been trivialised and ignored. A recent report released by the Queensland Government was inadequate and flawed. Only 15 people were examined clinically, with no medical staff actually visiting the site. The study undertook minimal non-systematic environmental sampling and relied mainly on inadequate industry commissioned data. Positive findings of volatile chemicals were dismissed, despite the fact they are potentially capable of causing health impacts, especially over long periods of time.

A 2018 paper by Dr McCarron *(9.32)* suggests a link between the escalating rise in hospital admissions for circulatory and respiratory conditions and a massive increase in air pollutants from the unconventional gas industry in south east Queensland. While recognising limitations on the data, partly due to anomalies in the data reported by industry and inadequate Government monitoring, it was concluded there was sufficient evidence to warrant full investigation.

9.5 Health Impacts Associated with Air and Water Pollution *(9.7)*

An array of chemicals capable of causing significant health impacts may be released during unconventional gas operations *(9.7, 9.17)* including:

- Volatile organic compounds, including BTEX (Benzene, Toluene, Ethylene and Xylene), that occur naturally in the shale, and evaporate from the flowback wastewater after fracking and from flaring excess gas
- Polyaromatic hydrocarbons (PAHs), heavy metals, naturally-occurring radioactive materials (NORMs)
- Endocrine-disrupting chemicals
- Nitrogen oxides
- Hydrogen sulphide from gas processing
- Formaldehyde (from the breakdown of escaping methane)
- Diesel fumes from extensive truck movements
- Ground level ozone, that forms from mixtures of pollutants and which is known to travel large distances.

Workers, and possibly people living very close to hydraulic fracturing operations, may also be exposed to unsafe levels of fine silica due to the large volumes of sand used, increasing the risk of silicosis *(9.7)*.

The following are some health studies that have emphasized the health risks posed by potential exposure to chemicals that may be released during unconventional gas operations via water and air.

- USA experience has indicated that health risks associated with air pollution are at least as serious to the health of people living nearby as the risks mediated through water contamination *(9.7, 9.42, 9.43).*
- While significant concern has been raised about the large number and potential toxicity of the chemicals used in hydraulic fracturing and drilling muds, many researchers emphasise that the highly saline flowback waters containing naturally occurring chemicals are of substantially greater concern from an environmental and public health aspect *(9.44, 9.45, 9.46).* The combination of chemicals and their resulting by-products can accumulate and persistent indefinitely in the environment or be taken up by plants and animals and may enter the food chain *(9.7).*
- A study by Elliott *et al. (9.45)* examined the carcinogenicity data on 1177 chemicals in fracking fluids and wastewater and 143 chemicals identified in scientific papers reporting air pollutants published before 2016. Over 80% of these chemicals were not evaluated for carcinogenicity. Among 119 chemicals that were evaluated, 49 water and 20 air pollutants were possible or known carcinogens and 20 were associated with leukemia/lymphoma, including benzene, butadiene, cadmium, diesel exhaust and PAHs *(9.7).*
- A second study by Elliott et al. *(9.47)* examined the reproductive and developmental toxicity of 1021 chemicals identified in fracturing fluid and waste-water, and found that toxicity information was lacking for 781 (76%). Among the 240 that had been evaluated, 103 were known to have the potential for reproductive toxicity and 95 for developmental toxicity *(9.7).*
- Toxins of greatest concern linked to gas extraction include volatile organic compounds (like benzene), poly-aromatic hydrocarbons, heavy metals and radioactive materials. These can affect the respiratory, endocrine, nervous and cardiovascular systems and some, notably benzene, can cause cancer *(9.7, 9.44, 9.48).*
- Diesel engines emit particulate matter, nitrogen oxides and volatile organic compounds, and was recently classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC 2014) *(9.7).*
- Silica, handled in very large quantities in the drilling and hydraulic fracturing processes, has the potential to pose serious risks to the respiratory health of exposed workers, causing silicosis decades later. There is also evidence of potent endocrine disrupting chemicals associated with the industry *(4.23).* Ground level ozone, that forms from mixtures of pollutants emitted during unconventional gas mining is also of significant concern, and can travel large distances, acting at a regional level *(9.7).*
- Anecdotal reports and findings of a community study found significantly higher reports of respiratory (39% vs 18%) and skin (19% vs 3%) conditions among people living within 1 km compared to those living more than 2 km from shale gas wells in Pennsylvania *(9.7, 9.49).*
- People living near unconventional gas wells throughout the world, including near coal seam gas wells in Tara, Queensland, have anecdotally reported similar distressing symptoms, as well as headaches, nosebleeds, numbness and tingling sensations *(9.7, 9.15, 9.50).*
- A study conducted by Macey et al (2014) identified levels of air-borne toxins above Federal guidelines in four USA States where substantial oil and gas production activities had occurred.
- Negative health outcomes have been found to occur more often in groups of residents with greater exposure to shale gas mining, compared with groups with lower exposure *(9.7):*
  - Developmental problems during pregnancy and infancy – lower birth weight, small for gestational age, higher frequency of serious birth complications, specific birth defects *(9.51, 9.52, 9.52)*.
  - Hospitalisations – for cardiovascular and neurological disorders and for those with existing asthma conditions *(9.54, 9.55).*
  - Symptoms – migraine headaches, chronic nasal and sinus irritation, fatigue, nausea, skin rashes, eye irritation, nosebleeds, and asthma worsening requiring medication changes *(9.15, 9.49, 9.54).*
- Petroleum-based hydrocarbons can break down underground in ways that promote the leaching of naturally occurring arsenic, a known human carcinogen, into groundwater *(9.19).*
- Elevated levels of toxic BTEX (Benzene, Toluene, Ethylene, Glycene) chemicals in flowback water from fracked wells were detected at AGL's Waukivory CSG Project at Gloucester, NSW *(9.20).* It is likely the chemicals were mobilized due to the fracking process. This well is now abandoned.
- In a 2013 study, surface and groundwater near unconventional gas activity in Colorado contained endocrine-disrupting chemicals in concentrations high enough to interfere with the response of human cells to male sex hormones and estrogen. Exposure to endocrine-disrupting chemicals can increase the risk of reproductive, metabolic, neurological, and other diseases *(9.33).*

9.6 Impacts on mental health, psychosocial wellbeing and community cohesion

There are many avenues through which the unconventional gas industry can harm mental health and individual and community wellbeing *(9.9).*

- The initial phase impacts include distress and anxiety due to disagreements that split the community into those who support the industry and those who oppose it.

- In the 'boom' phase tight-knit communities can feel inundated with strangers coming in, swamping unprepared health and mental health services. Crime may also increase. Such impacts are detrimental to the social cohesion and for some, the moral character, of the community.
- In the post-construction phase, jobs decline dramatically and housing demand drops. Production ramps up with drilling and fracking, with its 24-hour lights, noise, odours, tree clearing and truck movements - causing some people to feel a loss of control, loss of peace and a feeling of being trapped and unable to escape.
- These phases present risks of depression, anxiety and increased use of alcohol and other drugs for coping.

Doctors for the Environment Australia note that 'water and air pollution, water shortages, permanent degradation of productive agricultural land and loss of livelihood and landscape all have mental health consequences for communities living in a gas field *(9.21)*.

A 2013 study involving 12 workshops established that CSG operations in south west Queensland placed rural communities 'under sustained stress' *(9.22)*. Study participants reported that mining and CSG operations 'significantly impacted or exacerbated issues such as the health, social fabric and economy of the community', and the authors noted that local health services faced 'unsustainable pressure'.

A 2014 article in the Medical Journal of Australia noted that 'gas developments can have numerous and considerable social and psychological effects, which may exacerbate more direct health risks' *(9.23)*.

A 2014 CSIRO study *(9.24)* noted that local farmers perceived the nature of CSG development in South West Queensland as an 'invasion' or 'occupation', whilst a previous study in Chinchilla found residents describing a 'tsunami of change' *(9.25)*.

Interacting and engaging with CSG companies also have a significant negative impact on farmer's wellbeing *(9.26)*, resulting in issues of stress, conflict and disconnection.

A survey of 378 Australian farmers, predominantly from Queensland and NSW, published in Journal of Environmental Psychology *(9.27)* in 2016, found that farmers concerned about the impacts of coal seam gas on their health, community and the environment, were more likely to report symptoms of depression and decreased levels of wellbeing.

Schlumberger Oilfield Australia Pty Ltd was fined $162,500 after a worker at a Queensland drilling site was burned when exposed to unsafe levels of radiation *(9.41)*.

9.7 Livestock health risks (9.28, 9.6)

Twenty-four case studies in USA have been compiled of apparent harm to animals, mainly resulting from contamination of water wells, springs, ponds or creeks, some due to accidents or negligence, and others a consequence of normal operations. On seven cattle farms studied in the most detail, half the herd, on average, was affected by death or failure to breed.

In one case, of 60 cattle with access to a creek contaminated with fracking wastewater, 21 died and 16 failed to reproduce, while 36 cattle without access to the tainted water remained healthy *(9.40)*.

In another case, of 140 cattle exposed to fracking waste, about half died and many others bore stunted or stillborn calves, while 60 others in another pasture had no problems.

The Concerned Health Professionals of NY compiled several other cases of affected livestock. In Pennsylvania, one farmer whose cows were exposed to drilling wastewater in 2010 lost 8 out of 11 newborn calves.

A 2012 case study in the USA also found serious evidence of harm to domestic stock from shale gas drilling waste contamination, including cattle deaths, stillbirths and reproductive problems (9.29).

9.8 Involvement of health experts (9.7)

Far too frequently, public health, psychological/mental health and medical expertise are 'missing from the table' in assessing the impacts of unconventional gas on health (Goldstein et al., 2012). Experts in engineering, safety science, environmental management and toxicology, while extremely important, should not be assumed to also have a comprehensive, in depth understanding of the impacts of unconventional gas on the health and wellbeing on people's lives. Direct public and psychological health expertise is required.

9.9 Precautionary principle

Many people assume that the precautionary principle is being applied by government *(9.7)*, i.e. that,

- preventive action would be taken in the face of uncertainty
- the proponents of a proposed activity would be required to demonstrate its safety, not the community

- governments would explore a wide range of alternatives to possibly harmful actions
- government would encourage public participation in decision making.

In submissions to the NSW Chief Scientist and Engineer's examination of the public health and safety of coal seam gas mining in 2013, many public health organisations and the Australian Medical Association, called for application of the Precautionary Principle. The Australian Medical Association stated simply, 'If in doubt, turn CSG off' *(9.30).*

The British Medical Journal recently published a joint letter with similar sentiments signed by 18 leading medical scientists, stating: 'The arguments against fracking on public health and ecological grounds are overwhelming. There are clear grounds for adopting the precautionary principle and prohibiting fracking' *(9.31).*

Many public health and medical organisations in Australia are calling on governments to apply the Precautionary Principle in this situation, and refrain from allowing unconventional gas mining to occur in Australia until there is sufficient evident demonstrating that it is safe for people and the environment. Among these organisations are:

- Doctors for the Environment Australia
- Public Health Association of Australia
- Australian Medical Association
- National Toxics Network
- Climate and Health Alliance, which includes 28 professional health bodies, e.g. Australian Psychological Association, Australian Council for Social Services, Australian College of Nursing, Australian Research Alliance of Children and Youth.

10. COMMUNITY *23 references*

The industry and Governments justify the development of unconventional gas because it will create local jobs, revive ailing rural communities, and provide tremendous economic benefits.

What the literature and experience show

10.1 Impacts on the community

In the course of its work supporting landholders and communities facing the impacts of unconventional gas developments, Lock the Gate Alliance hears firsthand about the impact unconventional gas development is having on the livelihoods, health and well-being of Australian farming families living adjacent to and surrounded by gas activities. These harmful impacts include: intimidation, coercion and bullying by UG companies; intolerable noise and light pollution from flaring, traffic and UG infrastructure; contamination and depletion of water in farm bores; rivers bubbling with methane; bores running dry; stock losses associated with pipeline construction and water contamination; costly and time consuming interruptions to farming operations; huge trucks and heavy machinery on small local roads affecting lifestyle, safety and road infrastructure; dust impacts on pasture; increases in weed infestation; industry workers leaving mess from pipeline construction in farm paddocks; workers destroying fences and leaving gates open; properties not able to be sold; credit being denied; mental health impacts resulting from dealing with companies and the impacts of industry development; and physical health symptoms including respiratory ailments, headaches, rashes, nausea and vomiting, and nose, throat and eye irritations.

For many affected landholders, these impacts affect all facets of life and are making their living situation untenable. Personal testimonies of a number of affected landholders can be viewed in a series of short films compiled by the Lock the Gate Alliance talking about the impacts on them *(10.1).*

While the gas companies move on once the commercially viable gas has been extracted, the communities suffer long term *(1.3).* The unconventional gas mining leaves massive damage, and the community must foot the bill. Yet the community did not want it.

Queensland's experience shows that reality does not match the unconventional gas industry's claims. Few benefits are realised outside the gas industry, and there are serious social and economic effects on local communities and existing businesses *(10.2).*

10.2 Unconventional gas led to a degradation of public resources in QLD

A study in the Darling Downs of Queensland between 2008 and 2013 by the industry-funded Sustainable Minerals Institute at the University of Queensland surveyed stakeholders from different sectors in the local community including the local business community, agriculture, local government, advocacy groups and

environmental consultants, as well as the mining and unconventional gas industries *(10.3)*. Far from mining and unconventional gas providing economic benefits, local businesses felt that it had reduced financial capital, human capital, infrastructure, social capital and natural capital. Local businesses had to compete with inflated gas industry wages to recruit and retain staff, and they experience increased rent and competition for services. There were disruptions to farmers from the rollout of access roads, pipelines, water treatment plants and other infrastructure.

10.3 Community cohesion and wellbeing:

The Queensland and NSW experience has shown that when an unconventional gas industry is forced upon communities against their wishes, there is potential for significant conflict and social upheaval and disruption as a result *(1.6)*. Lock the Gate members and local community groups report a range of impacts on their mental and emotional wellbeing, including:

- A sense of injustice that they do not have the right to refuse access to companies for UG activities and that this industry is being forced on an unwilling population.
- Fear and anxiety about the impacts of the unconventional gas industry on their family's health and the quality of the air and water they rely upon.
- Concern about the impact of unconventional gas development on the economic viability of their farms and property values.
- A sense of anger and betrayal that governments are supporting industry rather than communities in the development of the unconventional industry.
- A sense of anger that the industry is being pushed ahead rapidly without proper consideration of the impacts and before proper scientific studies have been done and baseline data collected.

Doctors for the Environment Australia note that the lack of a veto right for landholders in relation to unconventional gas development, the stress involved in dealing with companies (often against their will), the lack of full information and disclosure on the realities of unconventional gas development, and the often underhanded tactics employed by companies contributes to a sense of powerlessness, betrayal and frustration amongst landholders and affected communities. The injustice and powerlessness contribute to distress and poorer mental health outcomes. Unconventional gas development can 'divide previously close-knit rural communities, increasing tension and disharmony'.

According to DEA, in eastern Australia, the stress and disruption caused to farmers has already been shown to force some of them to leave a CSG drilling area, allowing once productive lands to lapse into disuse. In the USA long-time residents are moving, unable to bear the changes the gas industry has wrought on their landscape and community.

A study on landholders in Queensland found that unconventional gas operations placed rural communities under sustained stress, with study participants describing significant impacts on the health, social fabric and economy of local communities (10.4).

10.4 Boom Bust impact

The scale of the 'bust' after the short unconventional gas construction period ends is severe, and long-term job opportunities are extremely limited. Queensland Treasury figures reveal that more than 10,000 fly-in-fly-out jobs have been lost in the Surat Basin since the CSG construction boom peaked in 2014. In June 2014 there were 14,490 non-resident jobs in the region, and by June 2016 that had reduced to just 3,820 jobs (10.5), similar to pre-CSG levels.

The gas industry frequently makes claims about delivering substantial flow-on jobs in regional communities, particularly in the services industry, and job multipliers are frequently used to derive large job estimates. However, research undertaken by CSIRO's Gas Industry Social and Environmental Research Alliance found that job spill-overs into non-mining employment in the Surat Basin were negligible (10.6).

10.5 Employment impacts (*The Australia Institute, 2017 7.19*)

- While gas companies continually spruik the promise of more jobs for local communities as a justification for unconventional gas development, the simple fact is that it is a relatively small employer in the long term.
- The majority of gas industry jobs are required for the short construction phase only, they are not ongoing, as modern gas fields are highly mechanized and need very few people to operate them. Local employment opportunities are minimal with the majority of skilled workers being brought in from elsewhere with fly-in-fly-out workforces.
- The industry has made some incredible claims about its capacity to employ. In 2012 it claimed it created 100,000 jobs whereas the Australian Bureau of Statistics showed there were only 9,372 additional jobs. A

2011 report prepared for Santos by Allen Consulting Group found that a potential coal seam gas development in Northwest NSW would increase employment opportunities in NSW by 'around 2,900 ongoing full time positions', even though the project would only create about 30 gas industry jobs. Over 500 jobs would apparently be created in the public sector, at taxpayer expense *(10.7)*.

- Far from creating many additional jobs, the coal seam gas industry has been found to reduce employment in certain sectors. The Office of the Chief Economist's 2015 Review into the Socioeconomic Impacts of Coal Seam Gas in Queensland reported that 1.8 agricultural jobs are lost for every CSG job created *(10.8)*. Similarly, a study of Queensland's unconventional gas expansion by CSIRO's Gas Industry Social and Environmental Research Alliance found that for every 10 additional people employed in coal seam gas, 18 agricultural jobs were lost *(10.9, 10.10)*.
- The Chair of the NT Fracking Inquiry claimed there could be 32,000 jobs created by fracking in the NT, yet the Australia Institute states from the Inquiry's own research, there is a very high probability that no long term jobs will be created in the Northern Territory. Even the best case would be for only 500, but this was a very low probability. The Research Director of the Australia Institute criticised the inquiry chair, saying its own commissioned research had been ignored. The Chair later admitted she had quoted the wrong figure. *(10.19,10.20)*. Interestingly, the APPEA claimed that up to 6,300 new long-term jobs could be created *(2.1)*.

10.6 Property values and credit Availability

Rabobank, the world's leading specialist in food and agribusiness banking, stated risks from unconventional gas mining included reductions in farm productivity, efficiency, land values and credit availability. It also indicated that concurrent CSG mining and agricultural activities on agricultural land could result in problem loans or defaults (10.11).

In 2016 it was revealed that a Queensland family was unable to obtain a bridging loan using their property for equity, because the property had four coal seam gas wells on it. The Commonwealth bank stated that coal seam gas wells on the land make the security unacceptable for residential lending purposes *(10.12, 10.13)*.

10.7 Insurance

Insurance companies have refused to insure against risks associated with unconventional gas extraction, both in Australia and in the USA. In the USA, homeowners can be confronted with uninsurable property damage for activities that they cannot control *(10.14)*.

In the north west of NSW, farmers have been refused insurance cover for risks and contamination associated with unconventional gas extraction *(10.15)*.

Landholders are concerned they may be liable for any negative impacts caused by hydraulic fracturing. In 2014, the NSW Chief Scientist released a report, which concluded that the CSG industry was markedly under-insured and that landholders were likely to bear a substantial risk as a result *(10.16)*.

Meat and Livestock Australia has advised there is a genuine risk that landholders may ultimately be responsible for liabilities arising from unconventional gas activities if they lead to personal injury, property damage, or contamination *(10.17)*.

The Rural Industries Research and Development Corporation cite a case study in Queensland where a landowner was advised by their supply chain partners that they would be liable for any contamination caused by coal seam gas activities. Neither the CSG company nor the insurer would agree to indemnify the landholder against that risk *(10.18)*. Legal advice indicated:

- Gas companies are refusing to include provisions in access agreements to accept liability for any contamination that may occur.
- Gas companies in Australia are under-insured and do not have adequate insurance to cover the types of risks that CSG activities bring.
- Some graziers have reported that insurers have examined the risk to them of unconventional gas contamination and found it too high to offer insurance.

One must ask the obvious question: **Why don't the companies cover the liabilities if the process is so safe and free of risks?**

10.8 USA experience

The impacts on the community in Australia are a repeat of the experience in USA. Sixty-four studies showed industry claims of job creation and economic benefits were exaggerated, and economic analyses found that property values, tax revenues and tourism diminished *(1.7)*.

10.9 Experiences in dealing with social impacts in Queensland *(10.21,10.22, 10.23)*

Dr Wayne Somerville, a clinical psychologist in northern NSW, has dealt with mental health impacts arising from unconventional gas industrialisation in NSW and Queensland *(10.21)*. Turning rural areas into gas fields creates social, psychological and environment stresses that undermine mental health. The impacts from unconventional gas industrialisation arise not only from its adverse impacts on the environment and human health, but also from the negligent approach to risk management from gas companies, regulators and political supporters. Governments promote interests of mining companies over individuals, small businesses and farming communities. The inability to control access to property, loss of property values, and damage to land, destroys farmers livelihood and the legacy for their children.

The gas industry and its political supporters appear to believe the industry is entitled to an assumption of innocence i.e. that unconventional gas is safe unless the community can prove otherwise *(10.21)*. This is the reverse to other industries, such as the pharmaceutical industry, where the industry must prove a new product is safe before it is approved. There is community concern that it appears the regulatory authorities do not have the interests of the community at heart.

Rev Graham Slaughter *(10.22)* witnessed how the rapid expansion of the unconventional gas industry marched over people's lives and communities with very little long-term benefit, compared to the pain, suffering and disruption that has occurred. It is clear co-existence is not possible. There was a strong distrust of the Government, as queries were ignored and there was a reluctance to properly investigate health problems. The lure for wealth took precedence over community well-being, as mining companies had greater access to water and farmers' land could be taken over.

Dr Geralyn McCarron, a Brisbane GP, outlined studies to indicate the Queensland Government has failed in its duty of care to people in the gas fields *(10.23)*. Despite warnings from the AMA, appropriate research and regulations were not initiated. Data collected by the gas industry showed that emissions of air toxins known to cause human health escalated. Particulate matter known to cause cardiovascular and respiratory diseases were up 6,000% to 1,926t. Oxides of nitrogen, which affect the eyes, throat and lungs, were up 500% to 10,000t. Formaldehyde, an irritant to eyes, nose and throat, and can cause cancer, increased from 12kg to 160t. Problems raised with the Government have been ignored and treated with contempt. High levels of volatile organic compounds around homes, radioactivity, toxic fumes from flares, acid rain, and cancer concerns were reported without any action. The gas industry claimed that steel particles coated by sulphur and chlorine were sugar deposits left by insects!

11. IMPACTS ON AGRICULTURE

11.1 Threat to agriculture in WA

Across Western Australia large areas of highly productive farmland are under threat from Unconventional Gas mining. Unconventional gas production is highly invasive, with the industrialisation of entire landscapes from the closely spaced wells, networks of roads and gas pipelines, and the infrastructure to extract, process and store the gas and waste. Fracking is an extremely water-intensive practice, taking valuable water from agricultural use. These activities have the potential to severely disrupt virtually every aspect of agricultural production and potentially even remove the land from production.

The presence of mining in the area reduces surrounding land values. Valuable agricultural and horticultural land is lost. Native forests and wild life are impacted. Experience elsewhere in Australia has shown that land owners have been refused bank finance due to uncertainty of the asset caused by the presence of wells on the property *(10.11, 10.12, 10.13)*.

11.2 Landholders will lose millions every year by hosting unconventional onshore gasfields

A 2016 CSIRO report found the alienation of productive farmland for CSG infrastructure in Queensland resulted in losses in gross economic returns of up to 10.9% *(11.1)*. The total losses to gross revenues varied between $1.32m and $3.29m per property and averaged $2.17 million.

The Lock the Gate Alliance notes that the methodology was estimating economic losses based solely on reduction in land area and did not attempt to quantify losses resulting from disruption to operations, dust generation, spills and leaks of wastewater or the spread of weeds. Therefore, total losses to landholders will undoubtedly be far higher.

11.3 Threats to agriculture and soil quality *(1.7)*

The compendium of scientific, medical, and media findings *(1.7)* cited 20 studies and concluded:

- Drilling and fracking take agricultural land out of production and pose risks to the agricultural sector.
- In California, fracking wastewater illegally injected into aquifers has threatened crucial irrigation supplies to farmers in a time of severe drought.
- The reuse of fracking wastewater for irrigation in California's San Joaquin Valley raises questions about contamination of food crops via bio-absorption through roots.
- Studies and case reports from across the country have highlighted instances of deaths, neurological disorders, aborted pregnancies, and stillbirths in farm animals that have come into contact with wastewater.
- Potential water and air contamination put soil quality as well as livestock health at risk.
- Farmers have expressed concern that nearby fracking operations can hurt the perception of agricultural quality and nullify value-added organic certification.
- Fracking chemicals in agricultural soils can interact with each other in ways that slow down their biodegradation.

12. LAND ACCESS

12.1 Land owners have no rights to prevent access by the mining company.

Landowners have no rights to veto gas development on their land. Petroleum leases are issued by the Department of Mines and Petroleum with no consultation or rights to object. The affected landowners, businesses or the community do not have to be notified, as has been the case with the current leases. If a landowner initially refuses access, the matter will be referred to a Magistrates court after three months to decide on appropriate compensation.

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Further information

www.dontfrackwa.com.au

www.frackfreewa.org.au

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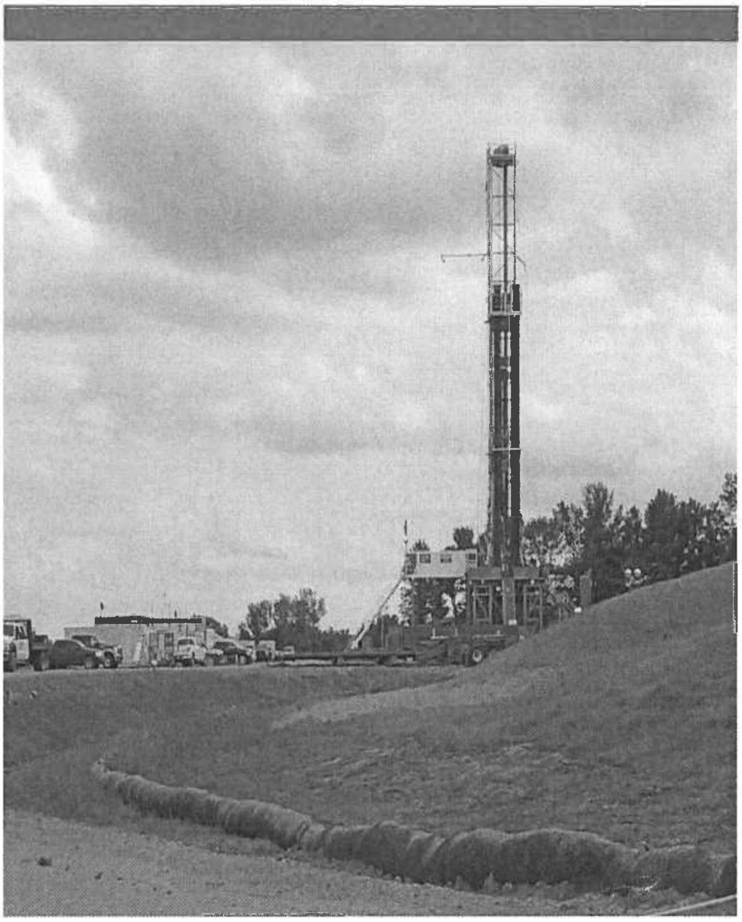

Health concerns associated with unconventional gas mining in Western Australia: A critical review

Part 1. What are the potential health concerns associated with the development of shale gas mining in Western Australia?

Part 2. Are these health concerns adequately addressed by two Western Australian governmental reports that contributed to policy decisions on the topic?

"The Reports" reviewed in Part 2

"Hydraulic fracturing for shale and tight gas in Western Australian drinking water supply areas: Human health risk" WA Health Department, June 2015
(referred to as **The WA Health Report)**

and

"Implications for Western Australia of hydraulic fracturing for natural gas" Western Australian Standing Committee of Environment and Public Health Affairs, Report 42, 2015
(referred to as **The WA Parliamentary Report)**

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Health concerns associated with unconventional gas mining in WA

Executive Summary

This paper examines the evidence available from peer-reviewed journal publications regarding the broad array of health concerns associated with unconventional gas mining and whether two Western Australian governmental reports used to contribute to policy decisions on unconventional gas, adequately and accurately address these health concerns.

Part 1. Based on international experience, what are the health concerns associated with the development of shale gas mining in Western Australia?

Providing a comprehensive, up-to-date and accurate answer to this question requires continuous attention to rapidly emerging evidence reported in the peer-reviewed literature. The number of papers on the topic of unconventional gas has risen rapidly from very few in 2012 to over 900 today as the pace and breadth of research has expanded dramatically across the United States. While gaps remain, most of the evidence from these studies has heightened, rather than reduced, concerns about potential negative impacts of unconventional gas mining on health and wellbeing.

In December 2016, a comprehensive systematic review of 156 peer-reviewed publications was published, examining the evidence of human exposures to harmful air and water pollutants, health impacts, seismic activity and climate impacts of unconventional gas mining. This review found multiple potential hazards to human health associated with mining and substantial gaps in understanding that prevented confirmation of the safety of the industry, and recommended no new developments in the United Kingdom until research demonstrated its safety. The major concerns identified by this systematic review and other research publications are described below.

There are **direct local health concerns** associated with living and working in close proximity to all steps of the unconventional gas mining process, not just the hydraulic fracturing ('fracking') component. Thus, any sincere examination of the implications requires us to broaden the scope of inquiry to all steps.

These **local concerns** include potential exposures to **air pollutants** released during the whole process, including volatile organic compounds, fine silica, oxides of nitrogen, hydrogen sulphide, formaldehyde, ground level ozone and diesel fumes. Local communities may also face **stress** from an array of changes,

including exposure to noise, lights, odours, and dust, as well as worries and fears about health, accidents, declining property values, increased traffic, industrialised landscapes, loss of community cohesion, post-construction job losses, local business loss, and changes to community character.

Findings from various research studies have suggested associations between living close to unconventional gas operations and higher frequencies of negative health indicators, such as lower birth weights, more birth complications, more self-reported symptoms such as migraines, nasal and sinus problems and fatigue, and more hospitalisations due to heart, nerve and asthma conditions. These findings are concerning, and more research is needed to better understand these links.

At a **local and regional level**, unconventional gas activities near drinking water sources carry the potential for **impacts on water quality**. Dealing with wastewater from hydraulic fracturing safely remains a major challenge – each method and proposed new solution carries with it potential problems and complications.

At a **global level**, we are gravely concerned about the unconventional gas industry's **contribution to climate change**. Hopes that fracking methods would allow gas to become a 'safe and clean bridging fuel'—significantly lowering greenhouse gas emissions while we move from coal to renewable energies—are not supported by current knowledge. Current indications are that unconventional gas leads to higher than expected fugitive emissions of methane across all steps of the extraction and delivery process. This, with a more rapid than expected climate change progression, makes immediate steps to reduce emissions of potent greenhouse gases, like methane, a top priority.

Part 2. Are health concerns accurately and adequately addressed by The Reports that contributed to policy decisions on unconventional gas?

The Reports do not appear to have fully and accurately assessed the potential risks and benefits of the industry to the health and wellbeing of Western Australians, based on current knowledge.

There are four major concerns, identified as follows:

Concern 1. The Reports did not accurately and sufficiently acknowledge the recommendations from many professional public health and medical groups, both in Australia and abroad, to apply the Precautionary Principle to unconventional gas mining.

- These groups assert that, given the high degree of uncertainty regarding significant health risks and the extent to which these health risks can be managed, the industry should not be allowed to proceed until long-term safety is demonstrated. This assertion is based on evidence from the peer-reviewed literature and should not be overlooked or dismissed.

- Furthermore, the information contained in the submissions to the Inquiry from a number of health organisations, including the Department of Health's own submission, do not appear to be adequately understood or considered in the Parliamentary Report. Of particular concern is the lack of legislative power of the Department of Health to guarantee that health considerations are given equal weight to other considerations in the decision-making regarding approvals, regulation, location and management of hydraulic fracturing operations. The submission also highlights the need for the Department of Health to be engaged from the start and granted sufficient power to proactively assess and participate in risk management and risk communication with sufficient information to provide transparent and accurate information to the community.

Concern 2. The terms of reference and/or scope of the review was not sufficient to capture the health and wellbeing risks associated with the unconventional gas industry. These risks arise from much more than just the hydraulic fracturing aspect of shale and tight gas mining.

- Some examples of insufficiently examined, but important, risks are exposure to chemicals in air and wastewater, including endocrine-disrupting chemicals, and mental health risks from psychosocial stress due to exposure to noise and loss of place and community cohesion.

- The Department of Health identified a number of other significant concerns associated with the unconventional gas industry, including air and soil pollution that needed to be fully addressed after the primary concern regarding the protection of water supplies was fully secured.

Concern 3. The Reports do not reflect current understandings from recent research evidence, which support, rather than refute, risks from unconventional gas activity. Other publications highlight the inadequacy of regulation in the protection of human and environmental health.

- Important examples include two systematic reviews, as well as a paper on asthma exacerbations *(Journal of the American Medical Association).* Another recent source provided evidence of impacts on drinking water resources, particularly the US EPA's seminal final report entitled, "*Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources,*" December 2016. Many instances of proven contamination of water supplies as a result of various stages of the unconventional gas mining processes are described. The conclusion of this report was that contamination of water supplies can and has occurred. Furthermore the report highlights that, due to a lack of documentation and comprehensive data available, the extent to which drinking water resources have been impacted by hydraulic fracturing remains unquantified. Hence despite the extensive experience in the United States, the actual, as opposed to the predicted, safety of the operation to drinking water resources remains unknown.

- In its Parliamentary submission, the Department of Health clearly states a position that hydraulic fracturing should not be allowed to occur in priority areas of public drinking water sources or within two kilometres of private drinking water wells, 100 year flood plains and lands with 'sensitive use'.

Concern 4. Issues of potential bias in the interpretation and communication of knowledge- versus-opinion that favour industry over the communities that will have to bear the risks that industry brings.

In order to address this concern, we urge the government of Western Australia to conduct an independent and rigorous update of the evidence of potential health benefits or risks associated with the entire lifecycle of the industry. This would assist the State in making the best decision on the industry's future.

This investigation should:

- Engage the Department of Health as well as additional independent public health experts in defining the scope and terms of reference for the review, ensuring that it is sufficiently wide to include all significant health concerns and risks and the latest international and local evidence.

- acknowledge that many professional public health and medical groups in Australia, the United Kingdom, the United States and elsewhere, are calling for the Precautionary Principle to be

applied to unconventional gas development because of existing scientific evidence and continuing uncertainties regarding the multiple potential risks to people and the environment.

- refrain from insinuating that the debate is simple and involves only myths and facts and communicate the correct definition of the precautionary principle in the proceedings.

- accept that appropriate and accurate understanding of the implications of unconventional gas mining for Western Australia requires analysis of evidence from peer-reviewed literature, acknowledging that unproven regulations and untested solutions to challenging issues can place human health at risk. It also requires respectful listening to individuals and families whose lives have been disturbed by anticipated, perceived and actual impacts of gas developments near or within their farms, residences and communities.

- fully reveal to the community the current evidence of risks and impacts across the entire life cycle of this industry on health and wellbeing of people and their environment. The risks, and their impacts should they occur, need to be clearly recognised as community-borne costs worthy of compensation and consideration in economic, social and health cost-benefit analyses.

- equally scrutinize and make public the realistic short-, medium- and long-term economic benefits of the unconventional gas industry to enable accurate comparisons between its full likely costs and benefits. This should also be used to compare the cost-benefit ratios of unconventional gas mining with other potential state developments that may carry greater benefits with fewer potential health and environmental losses.

Part 1.

Based on international experience, what are the health concerns associated with the development of shale gas mining in Western Australia?

1. Purpose of this critical review

This review aims to increase recognition and understanding of current knowledge from peer-reviewed publications regarding the direct and indirect risks and concerns relevant to shale gas mining operations to the health and wellbeing of potentially affected residents. The paper is aided by a comprehensive systematic review of 156 peer-reviewed papers and reviews of public health impacts of unconventional natural gas development conducted by Saunders, McCoy, Goldstein and Saunders. This work was published in the peer-reviewed journal *Environmental Geochemistry and Health* in December 2016.

This information is then used to examine two important Western Australian documents that appear to be guiding policy and decision making about the future of the shale gas industry in the state. We compare these documents with some of the submissions to the Inquiry from health organisations. We ask the question, do these documents fully and accurately assess the risks and benefits of the industry to the health and wellbeing of Western Australians? Is there certainty that the recommendations made in the reports are sufficient to protect the health and wellbeing of affected communities? We also consider how a green light on shale gas mining in WA may contribute to health challenges of future generations and people beyond the state.

2. Introduction

Until recently, methane (natural) gas used in households and industries around the world has mainly come from areas with large, concentrated deposits of gas that is released relatively easily (i.e., without fracking). As global reserves of these 'conventional' sources of gas from accessible locations are dwindling, remaining deposits, such as those located in deep offshore waters, are increasingly complex and expensive to recover. The gas industry is now focused on obtaining gas from 'unconventional sources', including gas within deep shale deposits in the Perth and Canning Basins of Western Australia. The government has expressed significant interest in promoting shale gas mining in these locations. As in other states and territories, this has been met with significant community opposition.

Because gas is spread out in low concentrations within shale beds, 'unconventional gas' mining requires many more wells and well-heads, and deep, horizontal drilling and fracking to release the gas. Because of the investment needed for these expensive operations, the capacity to link into a large international export market is often required in order for the venture to be commercially viable.

To date, there are few Australian examples of the industry for WA to learn from. Queensland has the most advanced unconventional gas industry, harvesting gas from coal seams that are much shallower than the shale beds in WA. The industry began gaining momentum in 2005, resulting in approximately 4402 wells in production by 2015[1], and continuing. The industry extends across Queensland, in the form of pipelines and compressor stations, and major industrial development expansions for processing, liquefying and shipping gas overseas. The export business raises, rather than lowers, gas prices for Australian consumers—an impact that has already been felt by Queenslanders.

Australian experience with unconventional gas is recent and, therefore, limited. The United States' experience is now extensive. The US Energy Information Administration estimates that there are currently 300,000 unconventional gas wells in production. It was estimated in 2013 that 15.3 million Americans[2] were living within a mile of at least one unconventional gas or oil well that had been hydraulically fractured at least once since 2000. These extensive operations began despite very few peer-reviewed research publications on possible environmental and health impacts. Now there is a rapidly growing body of literature. In 2015, a count of peer-reviewed publications[3] on environmental and public health concerns relevant to shale and tight gas mining found 685 publications, with over 80% published after 2013.

3. Two important definitions and some background concepts

Two terms need to be defined for the purposes of this paper. **First,** it is critically important to be aware that the word 'fracking' is often used in two different ways.

For the industry and in an engineering sense, 'fracking' is most often defined narrowly, meaning only 'hydraulic fracturing' – which is just one part of a very complex and multi-step process that finds, extracts, processes and delivers gas from unconventional sources for export or gas for domestic use. In sharp contrast to the engineering definition, communities tend to use the word 'fracking' to refer to the entire process that is used to produce unconventional gas, from start to finish.

The scope of this paper is aligned with the community definition of 'fracking', also referred to as 'shale gas mining' or 'unconventional gas mining'.

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[1] https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0020/238124/petroleum.pdf
[2] https://www.wsj.com/articles/SB10001424052702303672404579149432365326304
[3] http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0154164

Secondly, it is important to remember in investigations such as this, that the definition of 'health' that is consistent with the Australian Institute of Health and Welfare (AIHW), refers not just to getting a disease as a result of exposure to chemicals used in hydraulic fracturing. The AIHW glossary defines health as follows:

> *Term relating to whether the body (which includes the mind) is in a good or bad state. With good health the state of the body and mind are such that a person feels and functions well and can continue to do so for as long as possible.*

It defines public health as follows:

> *Term variously referring to the level of health in the population, to actions that improve that level or to related study. Activities aimed at benefitting a population tend to emphasise prevention, protection and health promotion as distinct from treatment tailored to individuals with symptoms. Examples include provision of a clean water supply and good sewerage, conduct of anti-smoking education campaigns, and screening for diseases such as cancer of the breast and cervix.*

These definitions are consistent with Aboriginal definitions of health, which also emphasize the connection between an individual's health and their contribution to the wellbeing of the whole community:

> *"Health is not just the physical well-being of the individual, but the social, emotional, and cultural well-being of the whole community. This is a whole-of-life view and it also includes the cyclical concept of life–death–life"* (NAHS Working Party 1989:x).

Importantly, Aboriginal definitions of health consider not just present, but also future life and wellbeing. This is extremely relevant, for decisions made today may affect the health, wellbeing and quality of life of future generations. Indeed, Australians generally also care deeply about the health and wellbeing of current and future children.

The impacts of environmental damage may not be evident immediately and also may add to risks associated with other environmental changes. We must, therefore, consider possible future outcomes to make sure we protect the health of today's children into their adulthoods and beyond. This means that uncertainties regarding any long-term impact should not be ignored or discounted as less important as short-term impacts.

4. What are the main concerns in terms of fracking's effect on health?

The need for shale gas mining to extend across large areas, often brings wells and other parts of the operation close, and sometimes very close, to where people live. Many communities are conscious of the wide array of changes in their physical and social environment brought with unconventional gas mining. Key concerns, for which evidence is growing, are described below.

4.1 Hazards and Potential Risk Pathways

4.1.1. Risks from air pollution

An array of chemicals capable of causing significant health impacts may be released during unconventional gas operations. These include:

1) volatile organic compounds, including BTEX (Benzene, Toluene, Ethylene and Xylene), that occur naturally in the shale, and evaporate from the flowback wastewater after fracking and from flaring excess gas;

2) endocrine-disrupting chemicals;

3) nitrogen oxides;

4) hydrogen sulphide from gas processing;

5) formaldehyde (from the breakdown of escaping methane);

6) diesel fumes from extensive truck movements and

7) ground level ozone, that forms from mixtures of pollutants and which is known to travel large distances.

Workers, and possibly people living very close to hydraulic fracturing operations, may also be exposed to unsafe levels of fine silica due to the large volumes of sand used, increasing the risk of silicosis.

4.1.2. Risks to water quality and water security

Many of the chemicals and chemical types mentioned above, plus additional chemicals such as polyaromatic hydrocarbons (PAHs), heavy metals, naturally-occurring radioactive materials (NORMs) and a wide array of known and unknown chemicals used in drilling and hydraulic fracturing fluid, have the potential to damage the health of people who are exposed. Workers and community residents may become exposed through contact with water that has been contaminated through the handling of the large quantities of chemicals and wastewater involved. Water security could be affected by the large amounts of water used in each hydraulic fracturing event (many times per well, many wells),

contamination of aquifers rendering them unusable for human consumption, and in some places damage to the ecosystem that may reduce the quality of drinking water sources. These concerns would be particularly acute during times of water scarcity and could cause competition with agriculture uses.

A news release on the seminal US EPA report[4], *"Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources"*, released in December 2016, follows:

"EPA identified cases of impacts on drinking water at each stage in the hydraulic fracturing water cycle. Impacts cited in the report generally occurred near hydraulically fractured oil and gas production wells and ranged in severity, from temporary changes in water quality, to contamination that made private drinking water wells unusable.

As part of the report, EPA identified certain conditions under which impacts from hydraulic fracturing activities can be more frequent or severe, including:

- *Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources;*
- *Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources;*
- *Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources;*
- *Injection of hydraulic fracturing fluids directly into groundwater resources;*
- *Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources; and*
- *Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater resources.*

The report provides valuable information about potential vulnerabilities to drinking water resources, but was not designed to be a list of documented impacts.

Data gaps and uncertainties limited EPA's ability to fully assess the potential impacts on drinking water resources both locally and nationally. Generally, comprehensive information on the location of activities in the hydraulic fracturing water cycle is lacking, either because it is not collected, not publicly available, or prohibitively difficult to aggregate. In places where we know activities in the hydraulic fracturing

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[4] https://www.epa.gov/hfstudy

water cycle have occurred, data that could be used to characterize hydraulic fracturing-related chemicals in the environment before, during, and after hydraulic fracturing were scarce.

[Author's note: A most important point in this extract is this final sentence:] *Because of these data gaps and uncertainties, as well as others described in the assessment, it was not possible to fully characterize the severity of impacts, nor was it possible to calculate or estimate the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle."*

This conclusion makes it clear that, despite some 300,000 unconventional gas wells being drilled, hydraulically fractured and operating in the United States, the safety of the operation to drinking water resources is not demonstrated.

Further unknowns and uncertainties regarding water

At times, various 'solutions' to problems can actually cause further problems and may not be subject to research before implementation. For example, the siting of multiple wellheads on the same pad, and drilling multi-directionally may both reduce surface footprint. However, the wellheads may not be placed in optimal positions for the location of the 'sweet spots' of gas in each direction. This may mean longer distance drilling, and larger water requirements and greater pressures for hydraulic fracturing.

Furthermore, the reuse of flowback water after fracking for additional fracking (recycling) may result in increasingly high concentrations of hazardous chemicals, elevating risks in handling and ultimate disposal. According to Webb et al. (2014), recycling wastewater is not often used because of the increased concentrations of hazardous chemicals. An analysis by Parker et al. (2014) revealed multiple challenges of wastewater of fracking-affected water, which is also very expensive.

Any such proposed 'adaptive management' changes should be accepted only after extensive consideration of the potential complications and risks they may pose. Additionally, contamination risks to water in agricultural areas should also be seen as potential food safety concerns, as livestock and produce may be affected. Very little research has been done to investigate this possible concern.

4.1.3. Loss of mental health, psychosocial wellbeing and community cohesion

There are many avenues through which the unconventional gas industry can harm mental health and individual and community wellbeing. The **initial** phase impacts include distress and anxiety due to disagreements that split the community into those who support the industry and those who oppose it. In the 'boom' phase tight-knit communities can feel inundated with strangers coming in, swamping

unprepared health and mental health services. Crime may also increase. Such impacts are detrimental to the social cohesion and for some, the moral character, of the community. In the **post-construction** phase, jobs decline dramatically and housing demand drops. Production ramps up with drilling and fracking, with its 24-hour lights, noise, odours, tree clearing and truck movements - causing some people to feel a deep sense of loss of control, loss of place and loss of peace and a feeling of being trapped and unable to escape. All of these phases present risks of depression, anxiety and increased use of alcohol and other drugs for coping.

There are particularly important concerns when considering the potential psychosocial and spiritual impacts of unconventional gas mining on Aboriginal people and communities. While there are no research publications to date, many Aboriginal and Torres Strait Islander people are leading efforts to protect the environment and health in the face of challenges from mining and climate change.

4.1.4 Risks for children

Since 2013, there has been an increasing focus on the likely vulnerability of developing fetuses and children to environmental hazards as compared to adults. The complex developmental processes that occur during gestation are exquisitely sensitive to chemicals and signals in the uterine environment. There is a growing understanding of the negative impacts of various exposures to the mother during pregnancy on birth outcomes, for example air pollution (PM2.5) and tobacco smoking on birth weight and preterm births, as well as alcohol and other drugs on brain development. Many of the chemicals involved in unconventional gas mining have reproductive and developmental toxicity.

Infants and children continue to face higher risks from toxic exposures due to their higher metabolic and respiration rates, their smaller body size and smaller and immature organs, including the liver, lungs and kidneys that deal with or store many toxins that enter the body. Children also experience greater exposure to toxins in the environment through outdoor play activities, compared to adults.

It is also very important to recognise that infant and child well-being is highly sensitive to psychosocial and community stressors, including noise, negative emotions expressed by others and witnessing aggression and conflict.

Despite this, only a small body of literature specifically examines potentially harmful exposures to air- and water-borne pollutants associated with unconventional gas mining for children. Two reviews by Webb et al. (2014, 2016) identify significant concerns:

- Webb, E., Bushkin-Bedient, S., Cheng, A., Kassotis, C.D., Balise, V., Nagel, S.C. Developmental and reproductive effects of chemicals associated with unconventional oil and natural gas operations (2014) Reviews on Environmental Health, 29 (4), pp. 307-318.

- Webb, E., Hays, J., Dyrszka, L., Rodriguez, B., Cox, C., Huffling, K., Bushkin-Bedient, S. Potential hazards of air pollutant emissions from unconventional oil and natural gas operations on the respiratory health of children and infants (2016) Reviews on Environmental Health, 31 (2), pp. 225-243.

4.1.5 Greenhouse gas emissions and climate impacts

Unfortunately, early claims that the use of unconventional gas for energy will have positive impacts on greenhouse gas emissions in comparison to coal are no longer justified. The idea that gas makes a good 'bridging fuel' to assist the transition from coal to renewable energy sources is not validated. It is now clear that the impacts of gas emissions were underestimated for a number of reasons:

- Compared to what was initially expected, higher proportions of the extracted gas escapes as fugitive emissions. This occurs for reasons of well-casing failures, or leaky pipes and infrastructure or, possibly, fracking-induced channels for gas flow from underground to surface.

- The recognition that methane's long-term impact on warming is 86 times more potent than carbon dioxide over 20 years.

- The enormous impact of accidents involving well blowouts and leakage from methane storage sites, as exemplified by the 2016 Aliso Canyon disaster, but potentially occurring at many similar sites in future.

4.1.6 Insufficiency of regulation to prevent these risks

Regulations on paper are neither sufficient, nor appropriately implemented to prevent damage from the industry – due to human failure, for example. Instances of failure in the United States are presented in the fourth edition of the "*Compendium of scientific, medical and media findings demonstrating risks and harms of fracking*" (unconventional gas and oil extraction).

4.2 Evidence from studies measuring health Impacts

As stated previously, studies attempting to measure health impacts of the industry remain relatively few but are increasing, and are mostly limited to physical health consequences. Negative health outcomes that have been found to occur more often in groups of residents with greater exposure to shale gas mining, compared with groups with lower exposure, include:

- Developmental problems during pregnancy and infancy – lower birth weight, small for gestational age, higher frequency of serious birth complications, specific birth defects.

- Hospitalisations – for cardiovascular and neurological disorders and for those with existing asthma conditions (emergency department visits and inpatient stays).

- Symptoms – migraine headaches, chronic nasal and sinus irritation, fatigue, nausea, skin rashes, eye irritation, nosebleeds, and asthma worsening requiring medication changes.

While these findings are **associated** with unconventional gas activity geographically, they do not provide 'proof' of cause and effect. This is to be expected because we lack specific measures of exposure to the chemicals and stressors involved. Research necessary to provide direct causal evidence of effects, such as randomized controlled trials, are unethical and unfeasible in this context. However, an increasing number of studies provide support for a **causative** relationship between the industry and elevations in these health concerns by demonstrating:

- Plausibility – there are logical links between the health problems being experienced and the kinds of chemicals and distressing experiences associated with living near industry operations.
- Dose-dependence – finding a higher frequency of problems with higher exposure (closer distance to wells, higher densities of wells, more intense gas production).
- Time relationship – showing that the increases in health problems began only after commencement of industry activities in the areas.
- Association still evident after allowing for other causes – for example, controlling for the potential contribution of smoking, socioeconomic status, community age profiles, legacies of other industrial activities in the area, etc.

4.3 Principles regarding public health

Good health is highly cherished. Australian citizens generally believe that their state and national governments make responsible decisions that protect their health above other considerations, even where there is uncertainty. Thus many people assume that the **precautionary principle** is being applied by government, i.e., that preventive action would be taken in the face of uncertainty; that the proponents of a proposed activity would be required to demonstrate its safety, not the community; that governments would explore a wide range of alternatives to possibly harmful actions; and that government would encourage public participation in decision making[5].

It should be noted that many public health and medical organisations are calling on governments to apply the Precautionary Principle in this situation, and refrain from allowing unconventional gas mining to occur in Australia until there is sufficient evident demonstrating that it is safe for people and the environment. Among these organisations are:

- Doctors for the Environment Australia
- Public Health Association of Australia
- Australian Medical Association
- National Toxics Network
- Climate and Health Alliance, which includes 28 professional health bodies including the Australian Psychological Association, the Australian Council for Social Services, Australian College of Nursing and the Australian Research Alliance of Children and Youth.

[5] (Kriebel D, Tickner J, Epstein P, et al. The precautionary principle in environmental science. Environmental Health Perspectives. 2001;109(9):871-876).

Part 2.

Critique: Are these health concerns adequately addressed by The Reports that contributed to policy decisions on the topic?

The Reports examined in this critique are the Standing Committee of Environment and Public Health Affairs report 42 entitled, "*Implications for Western Australia of hydraulic fracturing for natural gas,*" (the WA Health Report) and the WA Health Department's report entitled, "*Hydraulic fracturing for shale and tight gas in Western Australian drinking water supply areas: Human health risk*" (the WA Parliamentary Report). Further submissions into the Inquiry by the Department of Health and other public health and environmental health organisations were also reviewed.

Contemporary evidence (summarized in Part 1) was used to assess the adequacy and accuracy of two Western Australian government reports that have thus far contributed to government policy and decision making on unconventional gas in the state. This analysis concludes that The Reports could not fully and accurately assess the potential risks and benefits of the industry in regard to the health and wellbeing of Western Australians, in the light of knowledge now available in 2017.

It is also important to note that clear evidence was provided in submissions to the Inquiry from a range of health organisations including the Department of Health, about potential health risks that are not brought forward in the WA Parliamentary Report. Furthermore, the significant uncertainties regarding the safety of the industry to human health from air pollution, noise, soil contamination, threats to livelihoods and psychosocial stressors and as a result of contamination of drinking water sources and risks to food security.

Justification for this statement of inadequacy and for recommendations going forward includes:

Concern 1. The reports did not accurately and sufficiently acknowledge the recommendation from many professional public health and medical groups, both in Australia and abroad, that the Precautionary Principle should be applied to unconventional gas mining.

Applying the Principle would mean that the industry would not be allowed to proceed until there is sufficient evidence that ensures the safety of people and the environment. This is advisable due to the large number of potentially significant hazards involved in the unconventional gas industry, the emerging evidence of health impacts, and the large number of persisting uncertainties, particularly of potential cumulative (long-term) impacts.

We emphasise, this assessment has been conducted with knowledge available to 2017, which was not available to the Committee and Health Department. Nevertheless, by 2014, public health and medical opinion in the United States, Australia and other countries was increasingly raising serious questions about the uncertainties surrounding the safety of the industry, and many negative incidents had already been reported in the United States in easily accessible locations. Many medical and public health groups, including the Australian Medical Association, Doctors for the Environment Australia, Climate and Health Alliance, Public Health Association of Australia and the National Toxics Network called for a moratorium and/or application of the Precautionary Principle in unconventional gas mining until the large number of uncertainties were resolved.

While there was substantial input and quotations from the industry and engineering associations, notably ACOLA, regarding industry safety to the environment, there was no corresponding voice from public health and medicine reported in the inquiry that appeared to raise and explain the array of human health risks and concerns arising from the industry. Although a range of health concerns were mentioned in the WA Health Report, they were not examined in depth or considered in the WA context.

The most extensive systematic literature review on the public health impacts of unconventional gas mining to date (Saunders et al., 2016) reported the following definition of the Precautionary Principle, updated from its original publication in 2001:

> *The Wingspread Declaration on the Precautionary Principle counsels that 'When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not established scientifically. In this context the proponent of the activity, rather than the public, should bear the burden of proof' (Science and Environmental Health Network 2016).*

In concluding their review of 156 peer-reviewed publications on exposure pathways [air, water], seismicity, and health, economic and social and climate change impacts associated with unconventional gas mining, the authors [Saunders et al. (2016)] state:

> *As the available evidence does not enable a definitive public health judgment, a position shared by the US Centers for Disease Control (Centers for Disease Control and Prevention), we have a duty to pursue and assess that evidence while ensuring that, in the meantime, communities are not exposed to unacceptable risks. Several countries and North American states have banned, or imposed moratoria on, hydraulic fracturing including France, Bulgaria, Germany, Scotland, Wales, New York, Nova Scotia, Newfoundland, Quebec and New Brunswick (Finkel et al. 2015) ... Considering the uncertainties surrounding the health, environmental, social, global warming potential and economic*

implications of unconventional gas within this internationally recognised framework, it would seem prudent to incentivize further research across all the domains of UNGD related impact, and delay any proposed developments until the products of this investment have been peer-reviewed and assessed.

The Western Australian Department of Health, Doctors for the Environment Australia, the Public Health Association of Australia, Environmental Health Australia and individual medical and health professionals, among others, submitted information to the WA Inquiry that raised many concerns about the impact of the industry on human health. Much of this informed knowledge and the consensus regarding uncertain risks and concerns raised do not appear to have been adequately investigated in the WA Parliamentary report.

While the WA Health Report does raise a number of uncertainties, there is an implied acceptance that health risks can be managed. As the first sentence of the Foreword states, "The Western Australian Health Department continues to be a strong advocate for adoption of a risk management approach for all proposals for new industries, developments or technologies where people live or work close to public water resources, to ensure protection of health".

It is recognised, however, that the WA Health Report is only one component of a number of submissions and contributions of the Department of Health to the Parliamentary Inquiry. Three of these are publically available, namely:

- Written submission into the Inquiry, October 2013;
- Transcript of the evidence provided by the Executive Director of Public Health and the Principal Toxicologist of the Western Australian Department of Health on February 17, 2014;
- Written submission of additional evidence provided by the Executive Director describing the management of radioactive material in Western Australia.

These documents demonstrate that the following concerns were made known to the Inquiry, including:

- That limitations of the Health Act 1911 do not enable the Department of Health to "act proactively and on a risk management basis". This situation leaves the Department of Health without legislative power to ensure the protection of health within resource proposals and can, and has, according to the Legislative Assembly (2007, p. 93), led to "a recurring theme of '***...a failure to place Public Health considerations on the same basis of other considerations".***

The submission argued that it is imperative that this be corrected and that the Department of Health be consulted and engaged from the start and in decision-making processes. The Department also emphasizes that the absence of legislative power prevents a requirement for its involvement in proactively assessing and preventing risks to water supplies and contamination.

- That "good risk communications with transparent and accountable disclosure of risks" balanced 'as much as possible' with Commercial in Confidence needs of the industry is required.

- That P1 and P2 Priority source protection areas for Public Drinking Water Source Areas be identified and off limits to hydraulic fracturing, and that hydraulic fracturing not occur within the EPA separation distance of 2km from private drinking water wells, 100 year flood plains and 'sensitive land uses'.

- That proposals for the re-use of recycled wastewater be required to comply with existing national guidelines for water recycling and reuse for the protection of the environment and health.

The Department of Health submission also includes a full and accurate definition of the Precautionary Principle, and identifies its relevance to considerations regarding approvals for unconventional gas developments.

It is critical to also consider that risk management approaches are sufficient only where the technical capacity to alleviate all risks exists and is clearly and sufficiently demonstrated. Relying on risk management approaches also requires certainty that a sufficient level of regulation, monitoring, early detection, correction and preventative actions can be operationalised, paid for by appropriate bodies, and sustained over time. Experience documented in the US EPA Final Report regarding impacts of hydraulic fracturing in the United States shows that such a level of assessment, monitoring, detection and correction has not occurred, making it impossible to able to estimate on a wide scale how much contamination of water supplies has resulted from the industry. This raises serious questions about the extent to which people have been exposed to undetected contaminants in water they have consumed, and particularly to endocrine-disrupting chemicals that have the potential to affect human development and reproduction at very low concentrations.

Furthermore, the Physicians for Social Responsibility and Concerned Health Professionals of New York have compiled four extensive editions of "*Compendium of scientific, medical and media findings demonstrating risks and harms of fracking*" (Unconventional oil and gas extraction) in the United States.

The authors argued that, based on this extensive experience, "regulations have not prevented significant harms; and that some harms are not preventable through regulatory opportunities".

Even if risk management were theoretically possible, all governments should be asking whether their regulatory agencies have – and will continue to have - the capacity to adequately monitor and respond to the many potentially hazardous chemical, social, mental and physical health risks posed by large numbers of producing and depleted wells. The future security of these regulations will depend on the commitment of future government leadership to place the protection of human and environmental health above that of industry demands, where conflicts exist.

It therefore appears that these evidence-based arguments may have been included in the discussion of 'exaggerations' described in the WA Parliamentary Report, rather than as evidence regarding uncertainties that require serious examination. With further evidence accumulating, this is a serious oversight.

Concern 2. The terms of reference and/or scope of the review were not sufficient to capture the health and wellbeing risks associated with the unconventional gas industry. These risks arise from much more than just the hydraulic fracturing aspect of shale and tight gas mining.

Item 1.8 identifies that "The Committee is satisfied that the four issues emphasized in its terms of reference: land impact, chemical use, water quality and the legacy of hydraulic fracturing reflect recurring concerns identified in submissions received". It also indicates that the Committee did its own research. It is not clear why the Committee did not recognize the many additional concerns raised in the literature and in the submissions of many professional health bodies and scientists. These include climate change, chemical exposure, air pollution and psychosocial and community distress presenting risks to mental health.

The need for shale gas mining to sprawl across large areas, often bringing wells and other parts of the operation close and sometimes very close to the places where people live, work, go to school and play is a major and immediate concern. While many other developments introduce a number of community impact concerns, the particularly extensive industrial aspects of the unconventional gas industry and the health concerns that accompany them, are likely a driver of unusually high levels of community opposition. Without clearly articulating and addressing these concerns with residents, who have a diversity of perspectives, and serious attention to the alleviation of psychosocial and physical risks, it is unlikely that a 'social licence' will be obtained.

It should be noted that the Department of Health identified a number of significant concerns associated with the unconventional gas industry, including air and soil pollution that needed to be fully addressed after the primary concern regarding the protection of water supplies was fully secured.

Concern 3. **The Reports do not reflect current understandings from recent research evidence which support, rather than refute, risks from unconventional gas activity. Other publications highlight the inadequacy of regulation in the protection of human and environmental health.**

Most of the Health Risk Assessment work within the WA Health Report was done in 2014 and based on government reports rather than peer-reviewed publications, which were sparse at the time. Since 2015, many key publications have helped to advance our understanding, and simultaneously increased confidence in the real possibilities of these risks. The WA Health Report raises many questions that have guided the surge in new research and commentary since 2014, when this research was in its infancy.

Two new publications of particular importance to assessing health risks associated with chemicals in hydraulic fracturing fluid and wastewater are summarized below:

- Elliot, E.G., Trinh, P., Ma, X., Leaderer, B.P., Ward, M.h., Dezeiel, N.C. Unconventional oil and gas development and risk of childhood leukemia: Assessing the evidence (2017). Science of the Total Environment, 578: 138-147.

This study examined the carcinogenicity data on a total of 1177 chemicals in fracking fluids and wastewater (US EPA) and 143 chemicals identified in scientific papers reporting air pollutants that were published before 2016.. The researchers found that over 80% of these chemicals were not evaluated for carcinogenicity. Among the 119 chemicals that were evaluated, 49 water and 20 air pollutants were possible, probable or known carcinogens and 20 were associated with leukemia/lymphoma, including benzene, 1,3 butadiene, cadmium, diesel exhaust and PAHs.

- Elliot, E.G., Ettinger, A.S., Leaderer, B.P., Bracken, M.B., Deziel, N.C. A systematic evaluation of chemicals in hydraulic fracturing fluids and wastewater for reproductive and developmental toxicity (2017). Journal of Exposure Science and Environmental Epidemiology 27:90-99.

Summary: This study examined the reproductive and developmental toxicity of 1021 chemicals identified in fracturing fluid, wastewater or both. The researchers found that toxicity information was lacking for 781 (76%). Among the 240 that had been evaluated, 103 were known to have the potential for reproductive toxicity and 95 for developmental toxicity.

The previously mentioned comprehensive systematic literature review by Saunders et al. (2016) highlighted a major gap in our understanding of the interactions between the many chemicals in wastewater produced after hydraulic fracturing. Interactions are not considered in the WA Health Report – not surprisingly because there is still little to no understanding of this complex area, as reported by Saunders et al (2016).

Furthermore, the Health Report states on page 6 that chemical by-products or chemicals within flowback water do not need to be identified, referencing the Department of Mines and Petroleum (2013). Given that many of the air-borne pollutants, notably BTEX chemicals, as well as heavy metals, naturally occurring radioactive materials and polyaromatic hydrocarbons exist in the flowback water, it is unclear how these potentially toxic chemicals will be assessed.

Finally, the WA Health Report does not examine the growing body of concern regarding endocrine-disrupting chemicals involved in unconventional gas mining. Evidence of endocrine-disrupting activity in surface and groundwater in areas with unconventional gas mining raises concerns. These chemicals can interfere with endocrine function at very low concentrations without any signs or symptoms.

Balise et al. (2016) published a systematic review of 45 peer-reviewed publications examining the association between conventional gas extraction processes and the presence and potential impacts of endocrine-disrupting activity. The review concluded that there is moderate evidence for an increased risk of preterm birth, miscarriage, birth defects, decreased semen quality, and prostate cancer that could result from disruption of the estrogen, androgen, and progesterone receptors by chemicals associated with oil and gas production. The authors postulated that unconventional gas mining was likely to pose more risks to reproductive health than conventional gas operations given the many endocrine-disrupting chemicals involved in the hydraulic fracturing process. Key papers include:

- Davies, PJ, Gore, DB, Khan, SJ. Managing produced water from coal seam gas projects: implications for an emerging industry in Australia (2015). Environmental Science and Pollution Research 22: 10981-11000.

- Kassotis CD, Tillitt, DE, Lin C, McElroy JA, Nagel SC. Endocrine-disrupting chemicals and oil and natural gas operations: potential environmental contamination and recommendations to assess complex environmental mixtures (2016). Environmental Health Perspectives 124(3):256-264.

- Balise VD, Meng C-X, Cornelius-Green JN, Kassotis CD, Kennedy R, Nagel SC. Systematic review of the association between oil and natural gas extraction processes and human reproduction (2016). Fertility and Sterility 106(4): 795-819.

Other peer-reviewed publications not available at the time of The Reports:

Other examples of systematic literature reviews of particular relevance for human exposures, [direct] human health risks, socio-economic impacts and climate change include the following:

- Saunders, PJ, McCoy, D, Goldstein, R, Saunders, AT. A review of the public health impacts of unconventional gas development (2016). Environmental Geochemistry and Health, DOI 10.1007/s10653-9898-x.

- Werner, AK, Vink, S, Watt, K, & Jagals, P. Environmental health impacts of unconventional natural gas development: A review of the current strength of evidence (2015). Science of The Total Environment, 505, 1127-1141.

Other important examples of recent papers addressing health impacts of unconventional gas developments include:

- Hays J, Shonkoff SBC. Toward an understanding of the environmental and public health impacts of unconventional natural gas development: A categorical assessment of the peer-reviewed scientific literature, 2009-2015. *PLoS ONE* 2016; **11:** e0154164. Available: **http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0154164**

- Casey JA, Savitz DA, Rasmussen SG, Ogburn EL, Pollak J, Mercer DG, et al. Unconventional natural gas development and birth outcomes in Pennsylvania, USA (2016). Epidemiology 27: 163-172.

- Rasmussen SG, Ogburn EL, McCormack M, Casey JA, Bandeen-roche K, Mercer DG, et al. Association between unconventional natural gas development in the Marcellus Shale and asthma exacerbations (2016). Journal of the American Medical Association Internal Medicine 176(9): 1334-1343.

- Voiland A. *Methane Matters. Scientists work to quantify the effects of a potent greenhouse gas.* NASA Earth Observatory, 2016. Available: **http://earthobservatory.nasa.gov/Features/MethaneMatters/**

The following publication provides the first quantitative evidence of the extent to which farmers' anxieties about unconventional gas mining (CSG) contribute to the burden of stress and mental health

problems among farmers and so adds to the large literature on the psychosocial impacts of coal and gas mining communities:

- Morgan MI, Hine DW, Bhullar N, Dunstan DA, Bartik W. Fracked: Coal seam gas extraction and farmers' mental health (2016). Journal of Environmental Psychology 47: 22-32.

Recent publications on potential impacts on drinking water resources

The likelihood and severity of impacts on drinking water supplies were identified as leading considerations for Western Australia's policy development on unconventional gas mining. There is now a much larger body of research examining this in the peer-reviewed published literature than there was in 2014. Most notable is a seminal report released in its final version by the US EPA in December 2016. The EPA has found scientific evidence that activities in the hydraulic fracturing water cycle can and has impacted on drinking water resources at many steps of the process, including both surface and ground water sources. The report does little to support the suggestion that the risks to drinking water supplies is negligible or manageable with regulatory regimes.

Further, the EPA report highlighted the lack of data available:

Because of ..... data gaps and uncertainties, as well as others described in the assessment, it was not possible to fully characterize the severity of impacts, nor was it possible to calculate or estimate the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle.

This conclusion makes it very clear that, despite some 300,000 unconventional gas wells being drilled, hydraulically fractured and operating in the United States, the experienced safety of the operation to drinking water resources cannot be properly quantified.

Recognising, even in October 2013, prior to many recent studies, the Department of Health's submission to the Parliamentary Inquiry clearly states a position that hydraulic fracturing should not be allowed to occur in priority areas of public drinking water sources or within two kilometres of private drinking water wells, 100 year flood plains and lands with 'sensitive use'.

This advice does not appear to be adequately noted or addressed in the WA Parliamentary Report.

Concern 4. Issues of potential bias in the interpretation and communication of knowledge- versus-opinion that favour industry over the communities that will have to bear the risks that industry brings.

The WA Parliamentary Report carries a perhaps-unintended tone that can be interpreted as disrespectful and lacking in transparency in the discussion about 'facts' and 'myths'. The reality is — as now described in the US EPA's final report and in the extensive systematic literature review by Saunders et al. (2016) identified above — that there are many uncertainties and unknowns that cannot be ignored. These uncertainties are not myths — they are highly significant to considering the current and future impact of the unconventional gas industry. Examples include: long-term well integrity, how actual gas yields over time influence the rate of well proliferation for commercial viability, GHG emissions and climate impact, behaviour of the mixtures of chemicals involved in water and air-borne emissions as opposed to toxicities of individual chemicals, etc.

It is disappointing that in the four mentions of the 'Precautionary Principle' in the WA Parliamentary Report, no definition of the principle is provided. One such mention (Chapter 4, section 4.1.08; page 65) quoted from the Department of Health submission follows:

- *All decisions relating to hydraulic fracturing should be transparent with all decision-making being properly supported with scientific evidence and in accordance with the Precautionary Principle.*

With the exception of the above statement, each time the Precautionary Principle is mentioned, it is followed by a statement about an expectation of the total elimination and/or exaggeration of risks by precautionary proponents. The Precautionary Principle does not insist that all risks be eliminated and it should not be insinuated that the multiple public health and medical organisations, and the many jurisdictions that have decided not to go ahead at present, are either exaggerating or requiring complete elimination of risks.

The Department of Health submission to the Parliamentary Inquiry, along with those submitted to the Inquiry by other public health and medical organisations, provided the Inquiry with the accurate definition of the Precautionary Principle and simultaneously with reasons why its application is needed in decisions regarding hydraulic fracturing approvals.

Conclusion and Recommendations

The work undertaken towards the WA Parliamentary and Health reports were completed in 2014 and 2015. Since that time, there has been a surge in peer-reviewed publications. The majority of these publications, including two seminal systematic literature reviews and a US EPA report presenting extensively analysed experimental evidence on impacts on drinking water supplies, have only added weight and urgency to our concerns regarding the potential for significant health impacts to be borne by the WA community.

The new evidence includes studies showing associations between the industry and increased presence and concentration of air and water contaminants and psychosocial stressors which may impair health. Children have been identified as potentially at greater risk. In parallel, studies report increased frequency of health impacts, such as frequencies of asthma exacerbations, cardiovascular and neurological conditions requiring hospitalisation, lower birth weights and other birth complications, nasal and sinus symptoms, migraine headaches and increased mental health burden are all associated with living close to industry operations and are gravely concerning.

In order to address this concern, we urge the government of Western Australia to conduct an independent and rigorous update of the evidence of potential health benefits or risks associated with the entire lifecycle of the industry. This would assist the State in making the best decision on the industry's future. This investigation should:

- Engage the Department of Health as well as additional independent public health experts in defining the scope and terms of reference for the review, ensuring that it is sufficiently wide to include all significant health concerns and risks and the latest international and local evidence.

- Acknowledge that many professional public health and medical groups in Australia, the United Kingdom, the United States and elsewhere, are calling for the Precautionary Principle to be applied to unconventional gas development because of existing scientific evidence and continuing uncertainties regarding the multiple risks to people and the environment.

- Refrain from insinuating that the debate is simple and involves only myths and facts and communicate the correct definition of the precautionary principle in the proceedings.

- Accept that appropriate and accurate understanding of the implications of unconventional gas mining for Western Australia requires analysis of evidence from peer-reviewed literature, acknowledging that unproven regulations and untested solutions to challenging issues can place

human health at risk. It also requires respectful listening to individuals and families whose lives have been disturbed by anticipated, perceived and actual impacts of gas developments near or within their farms, residences and communities.

- Fully reveal to the community the current evidence of risks and impacts across the entire life cycle of this industry on health and wellbeing of people and their environment. The risks, and their impacts should they occur, need to be clearly recognised as community-borne costs worthy of compensation and consideration in economic, social and health cost-benefit analyses.

- Equally scrutinize and make public the realistic short-, medium- and long-term economic benefits of the unconventional gas industry to enable accurate comparisons between its full likely costs and benefits. This should also be used to compare the cost-benefit ratios of unconventional gas mining with other potential state developments that may carry greater benefits with fewer potential health and environmental losses.

Any health (and socioeconomic, international security, environmental) assessments of the implications of further developments to extract unconventional gas (itself a highly potent greenhouse gas) cannot be complete without consideration of the state of the climate. Concentrations of carbon dioxide in the atmosphere are now permanently above 400 parts per million according to the US National Oceanic and Atmospheric Administration[6] with previously unseen impacts on global stability in temperature, sea level rise, droughts, floods and heat waves. These lead to well-documented direct and indirect health impacts and contribute to the urgency of our response to move to clean, renewable energies. There are large net improvements that would be achieved in reducing greenhouse gas emissions as well as all of the health impacts described in this report by shifting from unconventional gas to existing renewable energies. These improvements dwarf those that might achieved in transitions from coal or 'clean coal' to unconventional gas, and arguably at lower cost.

The sooner our decision makers commit and follow through on the actions we need in rejecting continuation of coal, oil and gas production and welcome proven cleaner energies such as wind and solar, the more health benefits will accrue to the people of Western Australia and globally.

We urge the new Western Australian government to conduct an updated and fully comprehensive review of the potential direct and indirect impacts of proceeding with an unconventional gas industry on human health and wellbeing, both now and in future.

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[6] https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html

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Western Australia's Tight Gas Industry

A review of groundwater and environmental risks

Dr. Ryan Vogwill

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Executive Summary

Cook *et al.* (2013) stated in the Australian context that "Shale gas production is no different from any other development of the landscape and like most other land uses, it poses some risks to the condition of the water, soil, vegetation and biodiversity, and has the potential to impact on the capacity of natural resources to supply human, as well as ecological needs into the future." The current study reinforces that premise.

We are working towards a sufficient level of understanding of the geology, hydrogeology, groundwater dependent ecosystems and their links to social values to manage the existing groundwater use in the northern Perth Basin. The increase in water required for a tight gas industry amplifies this issue. There is also the risk of local to regional scale impacts to water quality. The Canning Basin, in particular, is only just starting to be understood in this context.

There is uncertainty around the magnitude of environmental impacts of the tight gas industry. Comprehensive studies are lacking, but this should not be interpreted as tight gas extraction having no potential for impacts. Rather, the tight gas industry does not apply enough resources to the assessment of risk to groundwater and the environment.

There are a number of examples of peer-reviewed literature showing serious unconventional gas impacts on groundwater in the US, regardless of the industry's insistence that there are no impacts. This should provide a warning to other jurisdictions (such as Western Australia) that impacts do occur and are usually found by third parties. In particular, the typical lack of baseline data collected prior to any unconventional hydrocarbon industrial activity occurring makes impacts difficult to conclusively identify.

Areas where tight gas exploration or production occurs are at risk of impact, the level of risk depending on local factors which are currently difficult to assess due to a lack of data. Hence a precautionary approach should be applied as hydraulic stimulation is irreversible. If there is no significant impact potential, this should be provable. Exploration alone has capacity to impact groundwater resources and the environment, albeit on a local scale near sites that are hydraulically stimulated, including areas hydraulically connected to those sites through faults and other potential conduits. The development of a full production scale tight gas industry in Western Australia has the potential for similar regional-scale impacts to water resources as have been observed in other jurisdictions.

There is no proof that impacts which have occurred elsewhere cannot or will not happen in Western Australia, particularly in areas such as the Canning Basin in the Kimberley and the North Perth Basin in the Mid-West that we are only just starting to understand hydrogeologically. There are exploration leases which cover many parts of the Canning and Northern Perth basins, but also in many other parts of Western Australia including the South West. In areas set aside for conservation or public drinking water source protection, it is advisable to exclude all tight gas activities. Even if economically viable deposits are found in those areas, extracting them would pose an unacceptable risk based on the issues explored herein. There are current exploration leases over Gnangara Mound, Perth's most important groundwater resource, for example. Public drinking water source protection areas in rural Western Australia are also covered by exploration leases, as are many areas of groundwater supported agriculture.

The Whicher Range in the southern Perth Basin is a poignant Western Australian example of the lack of certainty in methods used by unconventional gas proponents to investigate the risks to aquifers. The Whicher Range seismic data interpretations from 2004 and 2012 draw quite different interpretations of the same data. The 2004 interpretation shows relatively little connectivity between faults and relatively little propagation of faults to the surface, hence the industry's appraisal of hydraulic stimulation as low risk at this site. The 2012 analysis of the same data shows significantly more fault connectivity at depth in the target zone and fault propagation to nearer the surface. The 2012 interpretation of subsurface structure (faulting) presents a much greater risk that the 600,000 litres of unrecovered diesel injected into the hydraulic stimulation target zone may reach aquifers near the surface.

There is anecdotal evidence that leaks in conventional oil wells have happened already in Western Australia but detailed studies do not exist. Unconventional wells are likely to leak more frequently due to the additional pressure they are subjected to over long production timeframes. There are no detailed monitoring networks set up around the more than a dozen wells hydraulically stimulated thus far in Western Australia. The existing regulatory framework is not giving certainty that impacts are not occurring in the existing conventional and unconventional wells. Hence how can the regulatory framework give the public certainty that the impacts observed in other jurisdictions will not occur here?

The recommendations of this report are as follows:

1. Require that industry proponents fund the investigations necessary to present a robust and defensible understanding of the impact risk (incorporating geology, hydrogeology, environment and Aboriginal cultural heritage, including their linkages) in Western Australia, prior to undertaking tight gas exploration or production activities. This needs to account for project-specific impacts as well as cumulative impacts of a fully-developed tight gas industry.
2. Require that groundwater take be licensed and impact assessed, particularly given the risk of impact from water supply and tight gas wells in the proclaimed Groundwater Areas of the northern Perth and Canning basins. The Department of Mines and Petroleum (DMP) (2015) states that it only *may* require licensing.
3. Modify the Western Australian regulatory environment to incorporate the issues explored herein, in particular the issues around drilling, monitoring, project approvals and cumulative impacts. The Department of Water (DoW) allocation planning process is an example of a regulatory framework managing cumulative impacts. Given the risk of water and environment related impacts, DoW should have a more significant role in the approval process for the unconventional hydrocarbon industry, not just its water supply.
4. Upgrade groundwater allocation plans for the relevant areas to intensive plans as soon as possible and prior to any additional tight gas exploration or production activities.
5. Augment good oilfield practice (in terms of drilling practice and regulation) with hydrogeological best practice, particularly in the context of unconventional gas wells that pose risks to confined aquifers.
6. Require post well abandonment monitoring across relevant aquifers. Further, in consideration of the long time frames for some impacts to be revealed, a trust fund approach would ensure that resources are available for post abandonment monitoring and well failure remediation.

7. All costs for impact assessment and baseline monitoring should be borne by unconventional hydrocarbon (UCH) proponents, not the tax payer, in line with the recommendations by Cook *et al.* (2013). The example of Palat *et al.* (2015), where government bore the costs of a project assessment, is unacceptable.
8. Audit all existing oil and gas wells in Western Australia, in terms of well leakage and well integrity. This will provide an understanding of the impact of existing activities as well as invaluable data on long-term well integrity in a State context.
9. Choose a number of representative existing conventional oil and gas wells, and unconventional wells that will be drilled and stimulated, for detailed hydrogeological investigations. This should include faults and other potential flow conduits, and these sites should be monitored for long term water quantity and quality impacts. The investigations would require the installation of nested piezometers (monitoring wells installed in different depths) across all aquifers (both potable and non-potable) across the full vertical extent of the tight gas wells. Monitoring networks (both local and regional) should be in place for at least 12 months prior to any hydraulic stimulation activity to ensure appropriate baselines are collected.
10. The recommendations in Cook *et al.* (2013) are comprehensive across all areas of UCH projects in Australia and the reader is suggested to review them also. They recommend that baseline studies are completed before exploration activities are undertaken and that a precautionary approach is applied due to the serious nature of potential impacts.
11. Declare a permanent moratorium on drilling and related exploration or production activities in conservation estate and public drinking water source areas. The risks associated with surface activities alone in the hydraulic stimulation process justify this, let alone the risks of hydraulic stimulation and well failure, which are difficult to currently quantify.
12. Make the Environmental Assessment and Regulatory System (EARS) and EARS2 publically available. The community has the right to know the environmental impact assessment under which tight gas exploration projects are being approved.

A moratorium on further exploration or production experiments is a regulatory option which will ensure protection of the environment and groundwater resources until such time as baseline studies are completed so the impact of all activities (including both exploration and production) can be rigorously assessed. However, a permanent moratorium is recommended over conservation estate and public drinking water source areas, given the considerable risk that even surface activities hold in the context of the biodiversity values or long term water supply security that these areas are created to protect.

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Introduction

Unconventional hydrocarbon (UCH) production, particularly projects involving hydraulic stimulation (or "fracking"), is widely recognised as a highly controversial issue. Over recent years, there has been considerable separation between proponents and opponents of utilising UCH resources. The debate continues, in assessing what the actual and potential impacts are and what they will be.

Substantial UCH deposits, consisting of unconventional oil and unconventional gas, occur in many areas around the world. These provide a considerable increase in available hydrocarbon reserves, important in the context of dwindling hydrocarbon resources and worldwide energy supply (Boyer *et al.* 2011; International Energy Agency (IEA) 2013). Worldwide occurrence of established and potential unconventional gas deposits are shown in Figure 1. Note that the areas with unknown potential were not included due to scarcity of exploration data or the lack of abundant reserves in conventional natural gas reservoirs. It is likely that UCH deposits do occur in some of these areas (Boyer *et al.* 2011).

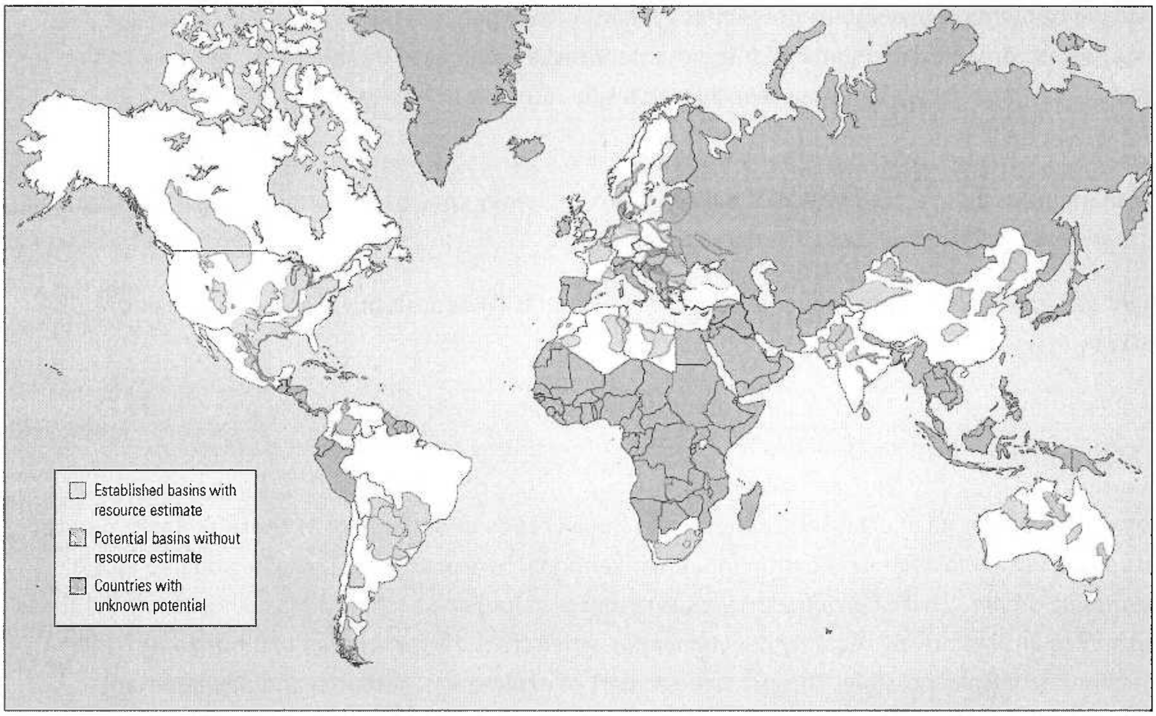

Figure 1 - Global shale gas resources (Boyer *et al.* 2011).

Aim

The aim of this report is to summarise the potential for impacts to groundwater resources and dependent ecosystems in Western Australia from the extraction of tight and shale gas, an UCH resource. This report represents a review of the main references relevant to this scope, as opposed to an exhaustive review of all literature, which is available elsewhere[1].

[1] For example, US EPA (2016) reviewed over 1200 sources of information for their report into the impacts of hydraulic fracturing for oil and gas.

This report makes recommendations for managing the process of extracting UCH resources with minimum risk to aquifers and ecosystems due to water contamination, in a Western Australian context. Note that air quality issues have not been included, nor have issues relating to infrastructure construction and operation, all of which can create additional impacts.

Unconventional Hydrocarbons: What are they and how do we extract them?

Like unconventional oil, unconventional gas terminology is not rigorously and unanimously defined. The terminology used varies by reference and jurisdiction, but herein unconventional gas is defined as gas which is found in unusual types of reservoirs. These fall into four categories: tight gas; shale gas; coal bed methane; and methane hydrates.

Tight gas is natural gas trapped in extremely low-permeability, typically low-porosity rock, often shale but can also be sandstone or limestone. Tight gas may also contain condensates, a low-density mixture of hydrocarbon liquids present as gaseous components in raw natural gas. Shale gas is natural gas contained in organic-rich sedimentary rocks dominated by shale and, because of the types of reservoir, it is sometimes considered a sub-category of tight gas (IEA 2013).

Coal-bed methane (CBM) is methane trapped within coal seams. Methane hydrates are made up of methane trapped in a solid lattice of water molecules under specific conditions of temperature and pressure typically in deep ocean sediments.

Tight gas and shale gas are the most common forms of UCH deposit but not in all jurisdictions (IEA 2013).

Shale gas and tight gas often occur in areas of conventional hydrocarbon resources (Figure 2), typically deep in the geological profile of sedimentary basins below the point of thermal hydrocarbon maturity (Huc and Vially 2012). The presence of UCH deposits has been identified for some time by the oil and gas industry and was initially seen as a nuisance as these deposits created issues during exploration and extraction of conventional hydrocarbons. There has been a lack of economic drivers (cost of production versus resource value) and technical feasibility to extract these resources until relatively recently (25 years ago), when fracture stimulation and horizontal drilling became technically possible. This occurred as part of exploration, research and development programs in the United States, focussed on the Barnett Shale in Texas (Boyer *et al.* 2011). Finding and exploring the economic potential of these deposits has since become a global pursuit for many hydrocarbon exploration companies.

The United States has been producing from tight gas deposits (including shale gas) for more than 35 years. Tight and shale gas have become a significant (>50 per cent) and increasing proportion of gas production since the early 2000's. By 2040, it is predicted than the United States will produce two-thirds of its natural gas from unconventional sources (US Energy Information Administration 2013).

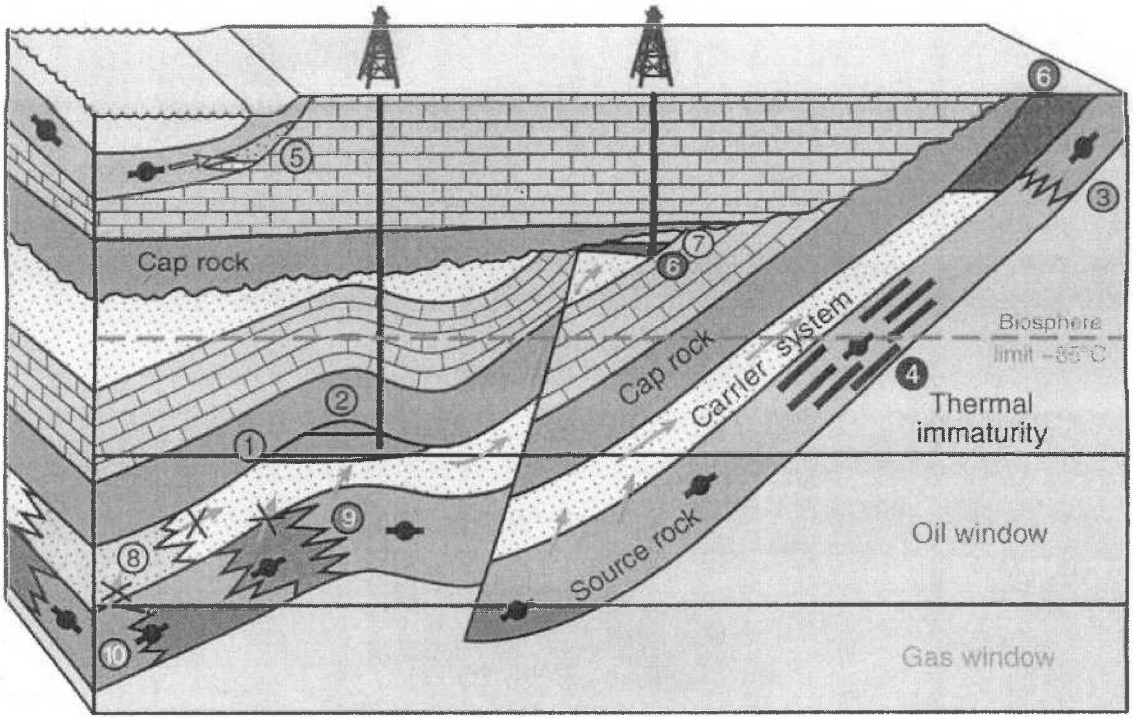

Figure 2 - Extended petroleum system: (1) conventional oil, (2) conventional thermogenic gas, (3) oil shale (immature source rock), (4) coal seams and coal bed methane, (5) primary biogenic gas and methane hydrates, (6) heavy/extra heavy oils, bitumen (7) secondary biogenic gas, (8) tight gas (typically tight sands), (9) tight oil/oil from source rocks and (10) shale gas. Modified after Huc and Vially R. (2012).

Operational Issues in the Tight Gas Industry

Exploration and Production

As the United States has pioneered the tight/shale gas industry, most issues associated with the industry are best explained using their experiences and examples (although every UCH deposit will be different). Since the early work done on the Barnett Shale there has been a rapid expansion of tight gas exploration and production in the United States. Figure 3 shows the location of these deposits (or plays). According to Boyer *et al.* (2011), the Marcellus Shale has the largest documented reserves followed by the New Albany Shale while the Barnett and Haynesville-Bossier Shales were the greatest gas producers in 2011. From 2000 to 2010 annual production of shale gas in the United States increased from 0.25 to 4.87 billion m^3 of dry gas, and is continuing to increase (U S Energy Information Administration, 2016).

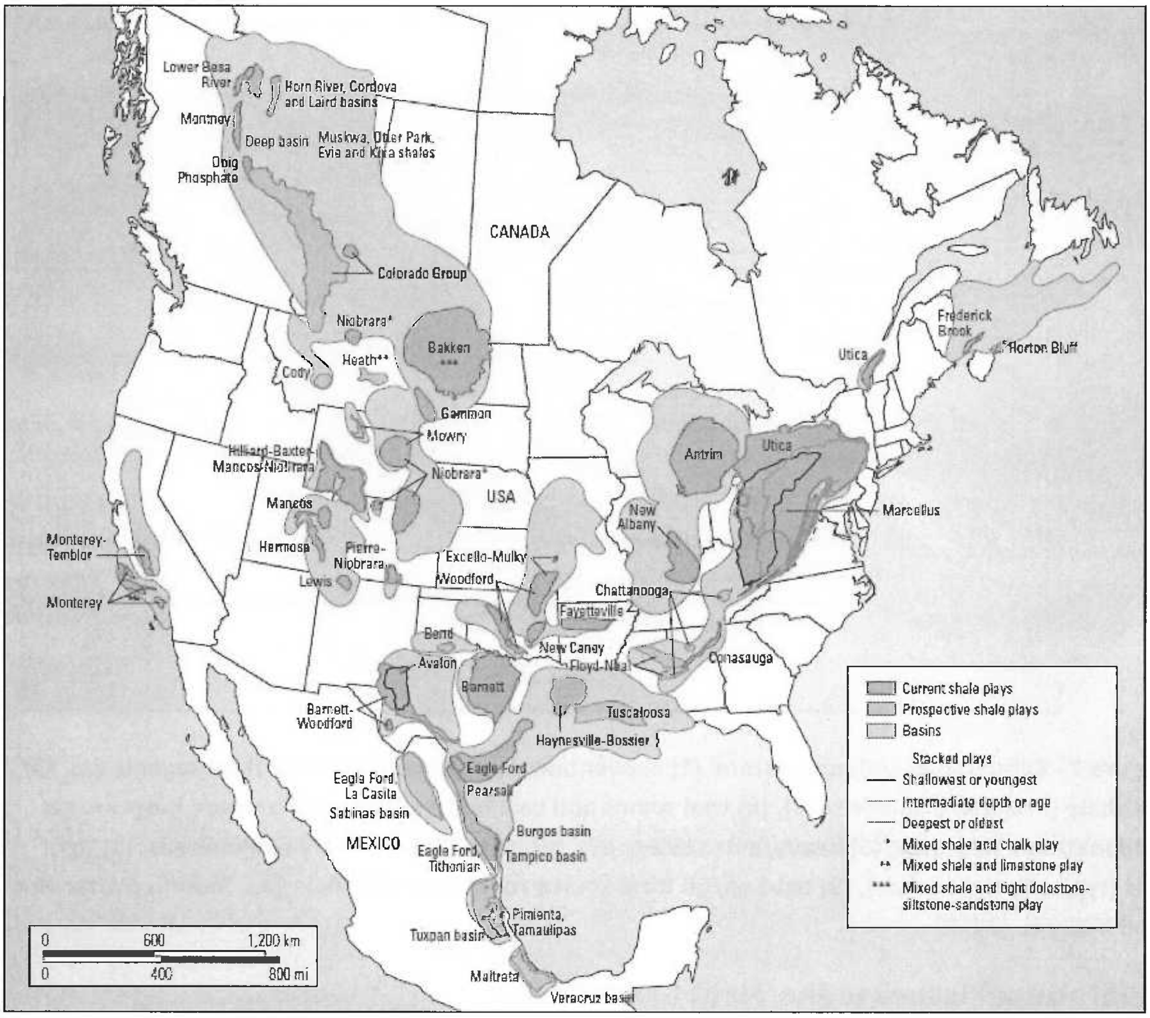

Figure 3 - Shale gas deposits in Northern America (Boyer *et al.* 2011).

There are documented impacts to the environment and water resources which can be attributed to tight gas projects (Vengosh *et al.* 2014; US EPA 2016). However, prior to describing impacts, it is important to briefly review the hydraulic stimulation process (see Figure 4), as environmental impacts can occur at any stage of this process and the natural resources and receptors impacted vary depending on which stage of the process said impacts occur. According to the United States Environmental Protection Agency (US EPA 2016), there are five stages to a hydraulic stimulation project and the potential areas of impact at each stage are highlighted:

1. water acquisition - the withdrawal of groundwater or surface water to make hydraulic fracturing fluids. Groundwater and surface water resources that provide water for hydraulic fracturing fluids can also provide drinking water for public or non-public water supplies used for agriculture and may also support groundwater dependent ecosystems. This is a key issue in arid areas and areas of limited water resources;
2. chemical mixing - the mixing of a base fluid (typically water), proppant (typically sand to hold open fractures), and additives (which vary company to company) at the well site to create hydraulic fracturing fluids. Spills of additives and hydraulic fracturing fluids can result in large

volumes or high concentrations of chemicals reaching groundwater, impacting groundwater and surface water with the potential to also impact dependent ecosystems;

3. well injection - the injection and movement of hydraulic fracturing fluids through the oil and gas production well and in the targeted rock formation. Belowground pathways, including the production well itself if there is an integrity breach, natural fractures (faults etc.) and newly-created fractures can allow hydraulic fracturing fluids, other fluids and gases to reach underground drinking water resources. Given groundwater can also support surface water resources (Winter *et al.* 1998), this can potentially impact on surface and groundwater resources and dependent ecosystems (Entrekin *et al.* 2015);
4. produced water handling - the onsite collection and handling of water that returns to the surface after hydraulic fracturing and the transportation of that water for disposal or reuse. Spills of produced water can impact groundwater and surface water; and
5. wastewater disposal and/or reuse - the disposal and reuse of hydraulic fracturing wastewater. Disposal practices (such as in unlined or poorly lined pits) can release inadequately treated or untreated hydraulic fracturing wastewater to groundwater and surface water resources, impact agricultural water quality and subsequently the wider environment. In some cases, hydraulic fracturing fluids are disposed of directly into groundwater systems.

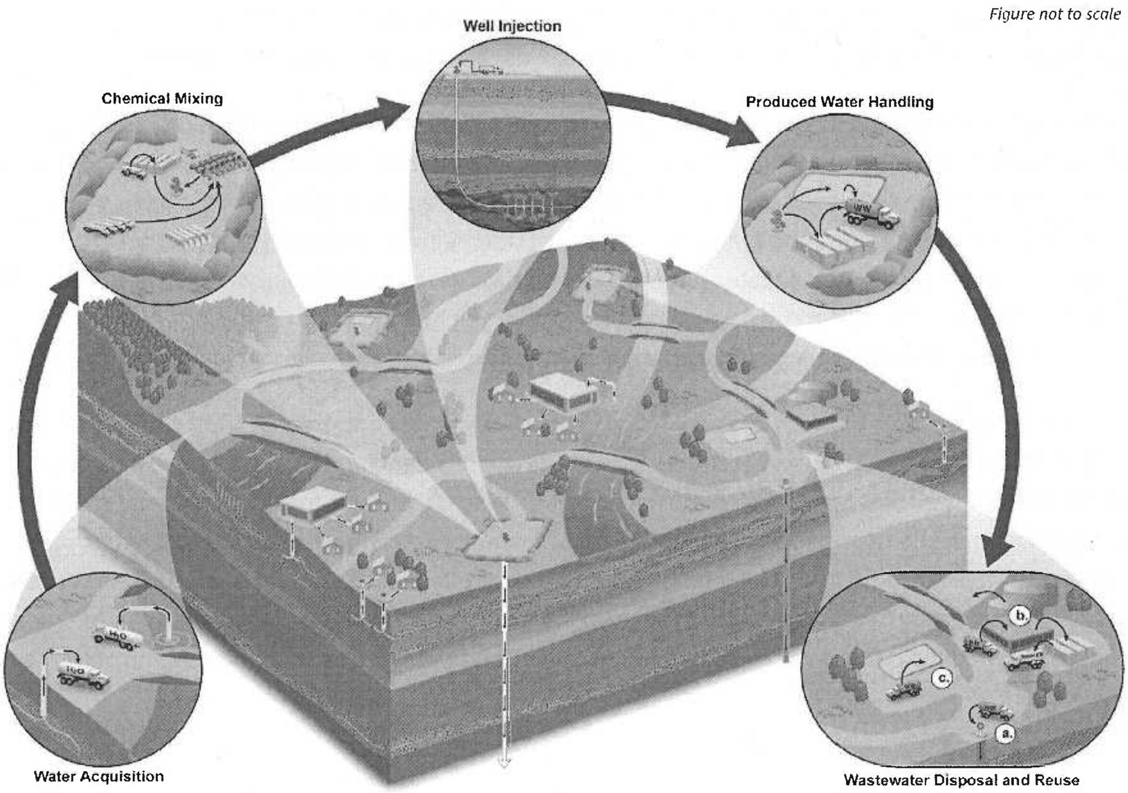

Figure 4 - Diagrammatic representation of the stages of the hydraulic stimulation process (US EPA 2016).

It is also important to note that hydraulic stimulation of an individual well may occur multiple times over long time periods. Wells may be hydraulically stimulated multiple times to induce continued gas production, or increased gas output. In most cases the lifetime of an individual well is decades (US EPA 2016). A typical timeline of activities is shown in Figure 5 below.

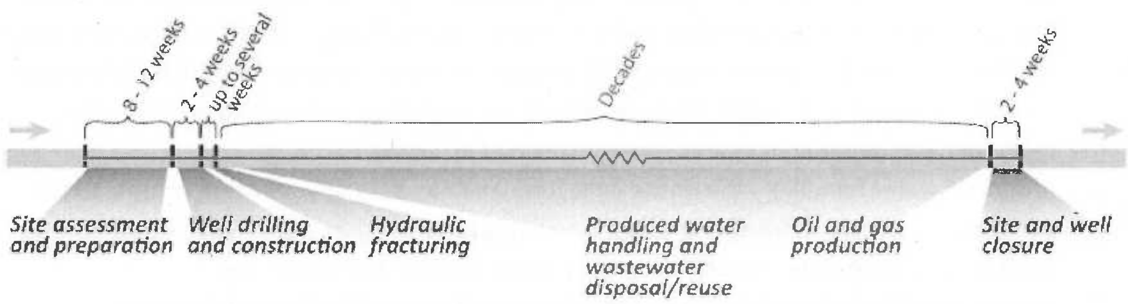

Figure 5 - Timeline and summary of activities at a hydraulic stimulation well (US EPA 2016).

Well Density and Well Integrity

It is important to note that although conventional oil and gas production can have many of the same types of water resource and environmental impacts (spills, well integrity failure etc.), the well density in a unconventional oil/gas field, when compared to a conventional oil/gas field, is hundreds to thousands of times higher (Figures 6 and 7) depending on when and which commercial operator is developing the particular project, the drilling design and the level of hydraulic stimulation required.

Early in the development of the tight gas industry, hydraulic stimulation was done on vertical wells so a higher well density was required (Figure 6). However, since the development and reduced cost of horizontal drilling techniques, lower well densities are more typical with multiple wells starting from the same drilling site or pad (Figure 7). Although this reduces pad and well density in the landscape, it potentially puts greater pressure on the sites in terms of likelihood of impact due to the increased failure potential in the vertical portion of the well hole. Regardless, there are large increases in well density when compared to conventional oil and gas.

This increased well density increases the risk of impact as greater numbers of wells are present to potentially fail and require increased industrial activity (vehicle movement, spills, pipelines etc.) during construction and operation of these dense well fields. This increases the potential spatial scale and magnitude of impact when compared to conventional oil/gas wells. There are also major issues with the legacy that this well density can leave in the landscape, as even properly constructed wells may lose integrity through time. Well integrity failure rates are difficult to quantify, due to lack of baseline monitoring, and to compare, due to scant during and post stimulation monitoring (Davies *et al.* 2014).

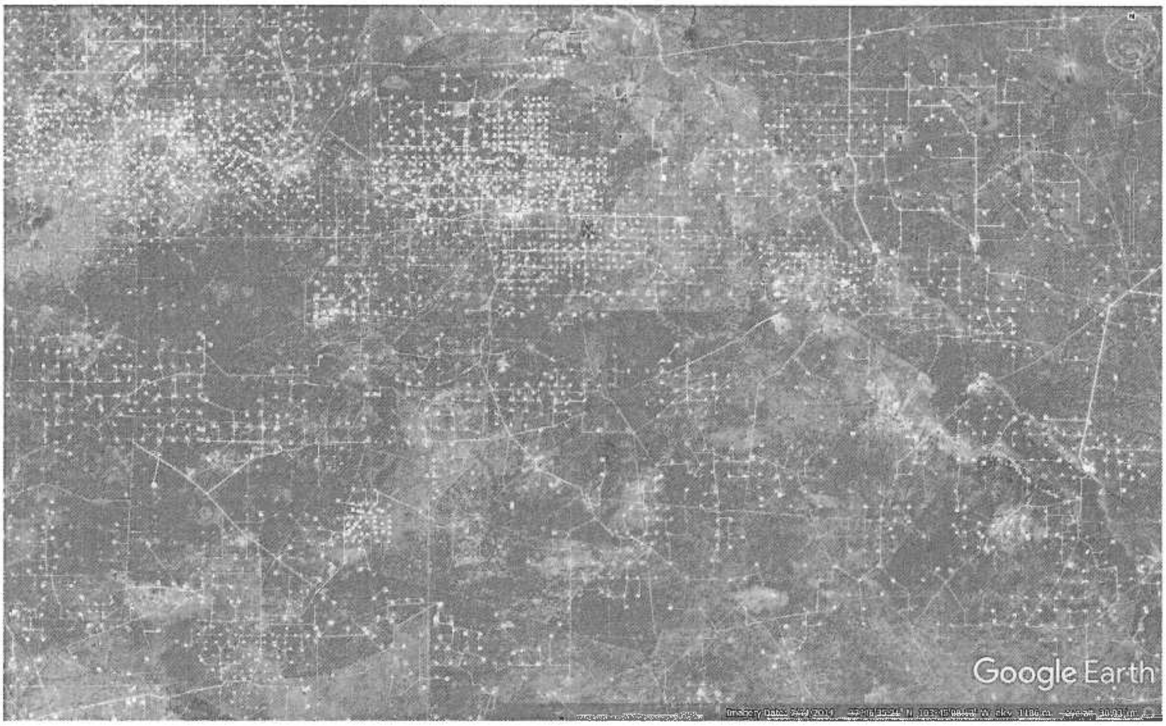

Figure 6 - 31.5 km (east-west) typical aerial view of the Wasson Oil Field in Texas, some areas have well density as high as 9 wells per square kilometre with a well spacing of 500m (Source Google Earth accessed 04/01/2017).

Figure 7 - 32 km field (east-west) typical aerial view of the Maverick Basin Oil Field in Texas, note the reduced but still high well density when compared to Figure 6 above (Source Google Earth accessed 04/01/2017).

Well Integrity Failure Rates

Davies *et al.* (2014) reviewed only reliable databases of well integrity from around the world and found that failure rates were highly variable from 1.9 to 75 per cent, with the Marcellus Shale well failure rate at 6.3 per cent, for example. They found a greater proportion of failure in injection wells (such as those required for hydraulic stimulation) when compared to production only wells (such as in traditional oil/gas fields). They concluded it is not possible to have zero per cent well integrity failure. They also noted that the amount of information retained by oil and gas companies and regulators was not sufficient for an exhaustive study, hence better records and more post production/abandonment integrity auditing is required to assess the well integrity and impacts of unconventional hydrocarbon projects - but typically much of these data are not released (if they even exist) by the project proponents (Brantley 2015).

Potential groundwater contamination pathways (white arrows in Figure 8) due to failure in well integrity can include: (1) a casing and tubing leak into the surrounding rock, (2) the uncemented space behind the casing (called the annulus), (3) the small space behind the casing (microannulus) between the casing and cement, (4) gaps in cement due to poor cement quality or poor installation, and (5) microannuli between the cement and the surrounding rock (US EPA 2016).

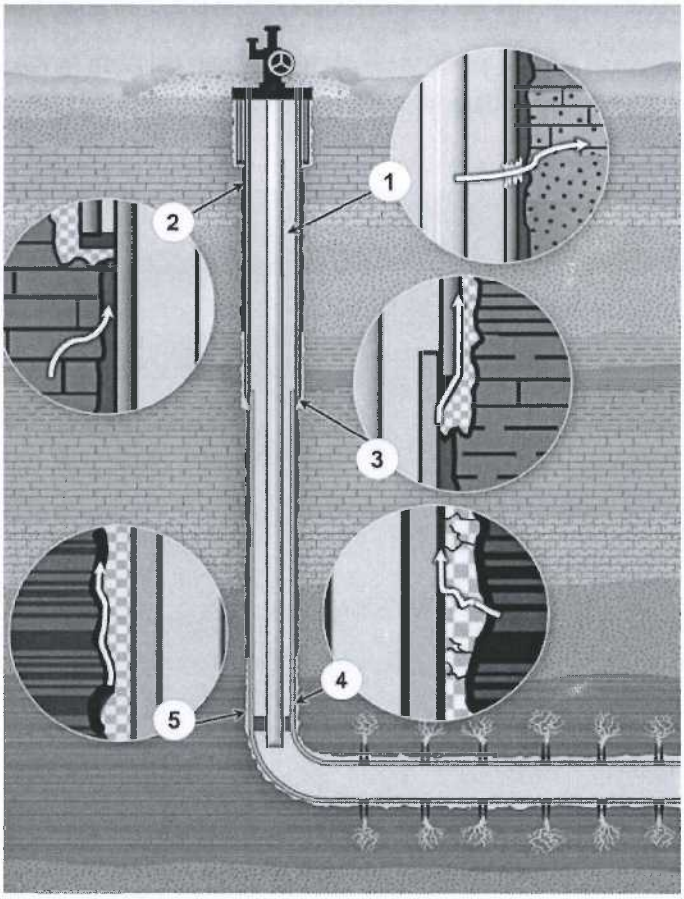

Figure 8 - Potential groundwater contamination pathways (white arrows) due to failure in well integrity (US EPA 2016). Note that this figure is not to scale.

The short and long-term effects of repeated hydraulic fracturing on well componer and casing are not well understood (US EPA 2011; Cohen *et al.* 2012) but are likely integrity (Davies *et al.* 2014). Therefore, increased and ongoing monitoring of well the lifetime of projects (and post abandonment) may help understand and subseq risk of well failure (Cook *et al.* 2013) as well as allow us to better understand well failure rates generally.

Well Abandonment

Once the operations at an oil/gas well (including both conventional and unconventional projects) used for either exploration or production ceases, this well is "abandoned". Well abandonment involves cementing and capping to ensure the well poses as little threat to water and environmental systems as possible or to prevent providing a pathway for gas emissions. As previously noted, it is not possible to have a zero per cent well failure rate during production let alone post abandonment (Davies *et al.* 2014).

This issue was also highlighted in a 2012 review completed in the United Kingdom (The Royal Society and the Royal Academy of Engineering 2012), which noted that abandonment requirements and an abandonment plan should be considered in the original well design, hence subject to regulation. No subsequent monitoring is required in that jurisdiction. The Royal Society and the Royal Academy of Engineering (2012) also recommended that on-going aquifer monitoring should occur post abandonment. In the United Kingdom, operators maintain responsibility for abandoned wells, with liability to remediate ineffective abandonment. However, without post abandonment monitoring (coupled with effective baseline monitoring) this would be near impossible to pursue in most cases. In the United States, post abandonment monitoring appears rarely, if ever, to be required or undertaken. Much of the information on well integrity and abandonment is held by industry, hence not in the public domain (Lennon and Evans 2016).

Long-Term Well Integrity

The very long-term integrity of a cemented and plugged abandoned well (beyond 50 years) is a topic where more information is needed, but it is unlikely that wells will maintain integrity over the long term. The subsurface environment is highly diverse and aggressive in terms of water chemistry (pH and high salinity, for example). Hence, materials used in well construction such as cement, fibreglass and steel are typically not stable in the subsurface for extended periods, particularly in the context of hydraulic stimulation which exposes these materials to pulses of intense pressures over long time frames (Davies *et al.* 2014; Cook *et al.* 2013).

In unconventional hydrocarbon well fields there will be a legacy of abandoned wells, which will need to retain integrity if we seek to avoid connections across the subsurface often over thousands of metres. These wells often intersect aquifers used for current and/or future water supply, subsequently well integrity is critical in protecting these vital resources which also support groundwater dependent ecosystems. The hydraulic integrity of strata containing waters from re-injection of flowback and other wastewaters (one common waste disposal method) from the hydraulic stimulation process will also be compromised if well integrity is not maintained (Cook *et al.* 2013). This is a critical point and is currently broadly not well addressed by the industry or regulators, which will be responsible for monitoring well integrity and remediating wells which have

lost integrity 20-30 years after a hydraulic stimulation project has completed. These issues are also relevant to conventional hydrocarbon wells, however, the increased number and greater spatial extent of wells in an unconventional project increases these risks exponentially.

There is also an issue relating to the effect of hydraulic stimulation on nearby abandoned conventional hydrocarbon wells (US EPA 2016). In most cases, well communication (pressure interaction) during fracturing results in a pressure surge accompanied by a drop in gas production at the hydraulically stimulated well and additional flow of produced water or hydraulic fracturing fluid at a nearby conventional well. However, if the offset well is not capable of withstanding the high pressures of fracturing, more significant damage can occur and subsequently compromise well integrity in the conventional well. An example of this issue occurred in January 2012, when hydraulic stimulation at a horizontal well near Innisfail in Alberta, Canada, caused a surface discharge of fracturing and formation fluids at a nearby operating vertical oil well (Energy Resource Conservation Board (ERCB) 2012).

Environmental Impacts

One of the most controversial topics surrounding UCH revolves around environmental impacts. There have been a number of highly publicised documentaries produced examining both sides of this debate. However, this report is concerned with peer reviewed, documented scientific evidence, not popular media. There are numerous studies assessing the environmental impacts of hydraulic stimulation: for example 1200 cited sources were used as part of the US EPA (2016) report which identified a risk of impact to both groundwater and surface water systems and their dependent ecosystems from a variety of aspects of the UCH industry. It is outside the scope of this report to review all of these sources but some of the key studies will now be examined.

A critical review (Vengosh *et al.* 2014) identified four potential risk areas for water resources (and dependent ecosystems):

(1) the contamination of shallow aquifers with stray gas due to well integrity failure, which can also potentially lead to the contamination of shallow groundwater with saline water, hydraulic stimulation fluids etc.;

(2) the contamination of surface water and shallow groundwater from spills, leaks, and/or the disposal of inadequately treated wastewater;

(3) the accumulation of toxic and radioactive elements in soil or stream sediments near disposal or spill sites; and

(4) the over extraction of water resources for high-volume hydraulic fracturing that could induce water shortages or conflicts with other water users, particularly in water-scarce areas.

Analysis of published data (Vengosh *et al.* 2014) showed evidence of stray gas contamination, surface water impacts in areas of intensive shale gas development, and the accumulation of radium isotopes and other contaminants in some disposal and spill sites. Another recent and significant study (Alawattegama *et al.* 2015) assessed water quality concerns in an area of hydraulic fracturing in south-western Pennsylvania that started late 2009. Well water samples were collected, analysed and where available pre-drill and post-drill water quality results and legacy operations (e.g. gas and oil wells, coal mining) were incorporated.

In Alawattegama *et al.* (2015), 56 of the 143 well owners surveyed indicated changes in water quality or quantity while 63 respondents reported no issues. Colour change (brown, black or orange) was the most common (27 households). Chloride, sulfate, nitrate, sodium, calcium, magnesium, iron, manganese and strontium were commonly found, with 25 households exceeding the secondary maximum contaminate level (SMCL) for manganese. Methane was detected in 14 of the 18 houses tested. The 26 wells tested for total coliforms (2 positives) and E. coli (1 positive) indicated that septic contamination was not a factor in the majority of wells. Repeated sampling of two wells revealed temporal variability in contaminants. Since 2009, 65 horizontal wells were drilled within a 4 km (2.5 mile) radius of the community and each well was stimulated on average with 3.5 million gallons of fluids. This study underscores the need for baseline studies of water quality, thorough analyses of data, documentation of legacy activity, pre-drill testing and long term monitoring post hydraulic stimulation.

The Pavilion unconventional gas field in Wyoming is another example of a site in the US where there have been impacts to shallow aquifer water quality due to hydraulic stimulation related activities. In their study, DiGiulio and Jackson (2016) detected organic compounds present in hydraulic stimulation fluids in shallow groundwater in wells installed by the US EPA. Other dissolved water constituents such as salt etc. were also detected. This study took over 10 years to complete, was not funded by industry and suggested that the entire groundwater resource for this area was contaminated with chemicals present in hydraulic stimulation fluids as well as target formation water. DiGiulio and Jackson (2016) suggested that this contamination had primarily come from leakage from surface ponds, however, given the lack of detailed investigation at this site there may be potential for shallow deep connectivity to also be contributing.

The direct contamination of shallow groundwater from hydraulic fracturing fluids in deep formations is an area of intense research interest and debate, which has not been conclusively answered either way. It is likely that the severity of this risk will vary on a site specific basis, but could occur via fluid movement through either induced or natural permeable structural features. Permeable pathways could include wellbores, faults, joints, induced fractures or some combination thereof (Engelder *et al.* 2009). The debate about the existence and impact of permeable pathways continues (US EPA 2012; Vidic *et al.* 2013; Lange *et al.* 2013; Gassiat *et al.* 2013; Ingraffea *et al.* 2014; Birdsell *et al.* 2015; Flewelling and Sharma 2015; Lefebvre *et al.* 2015; US EPA 2016).

In a recent review of the transport of hydraulic fracturing fluids in the subsurface, Birdsell *et al.* (2015) identified four drivers for upward migration of hydraulic fracturing and formation fluids: (1) topographically driven flow in a regional groundwater discharge zone, (2) overpressure in a shale gas reservoir, (3) the increase in pressure due to hydraulic fracturing fluid injection, and (4) buoyancy of hydraulic fracturing fluid. They also identified that some of these mechanisms are persistent while others are short lived. Some result directly from hydraulic fracturing while others are pre-existing mechanisms that may be active in conjunction with hydraulic fracturing. Birdsell *et al.* (2015) concluded that, in the absence of permeable pathways, the travel time for hydraulic fracturing and formation fluids to the surface will be in the order of thousands of years, contradicting and questioning the veracity of the widely criticised Myers (2012) paper which predicted impact in much shorter timeframes. The time for impacts to potentially occur will vary from location to location and will require complex assessments to determine.

Birdsell *et al.* (2015) also cited a number of examples where this migration has apparently occurred due to the presence of permeable pathways in short (operational) time frames. Llewellyn *et al.* (2015) concluded in their study of Marcellus Shale gas wells in Pennsylvania that the most likely explanation of the presence of natural gas and organic compounds in initially potable groundwater was stray natural gas and drilling or hydraulic fracturing compounds. These contaminants were driven approximately 1-3 km from the target formation for hydraulic stimulation along shallow to intermediate depth fractures to the aquifer used as a potable water source. Other authors (Warner *et al.* 2012) identified, through the use of geochemical tracers, the presence of natural and permeable pathways between deep hydraulic stimulation target formations and shallow aquifers in this locality.

With regards to shallow groundwater or environmental impact from deep target formation and shallow aquifer connectivity, Reagan *et al.* (2015) identified five plausible failure scenarios which are shown diagrammatically in Figure 9:

(1) Extensive vertical fracturing of the formations bounding the reservoir because of inadequate design or implementation of the hydraulic stimulation operation, with the resulting fractures reaching shallow aquifers or even permeable formations connected to these formations;

(2) Sealed/dormant fractures and faults that can be reactivated by the hydraulic stimulation, creating pathways for upward migration of gas, hydrocarbons and other contaminants;

(3) Induced fractures/faults that reach groundwater resources after intercepting conventional hydrocarbon reservoirs, which may create an additional source (not shown in Figure 9 as there are too many variables in this scenario);

(4) Hydraulic stimulation creating fractures that intercept older, abandoned unplugged wells (or wells with integrity failure) or their vicinity. This can be caused by lack of information about the location and installation specifics of the abandoned wells, or because of inadequate design or implementation of the stimulation operation resulting in excessively long fractures. These aging wells can intersect and communicate with freshwater aquifers, and inadequate or failing completions/cement can create pathways for contaminants to reach the potable groundwater resources; and

(5) Failure of the well completion during stimulation because of inadequate/inappropriate design, installation and/or weak cement. In this case, the well itself is the weak link, and it either includes open voids, or is fractured during the stimulation process, or both. Thus, improper cementing and well completion can result in continuous, high-permeability pathways connecting the reservoir with the shallow aquifer, through which contaminants can be discharged towards the surface. Note that the overlying formations may or may not be fractured in this case.

The likelihood of these impact scenarios manifesting will vary on a site by site and case by case basis, but Reagan *et al.* (2015) concluded they are all possible.

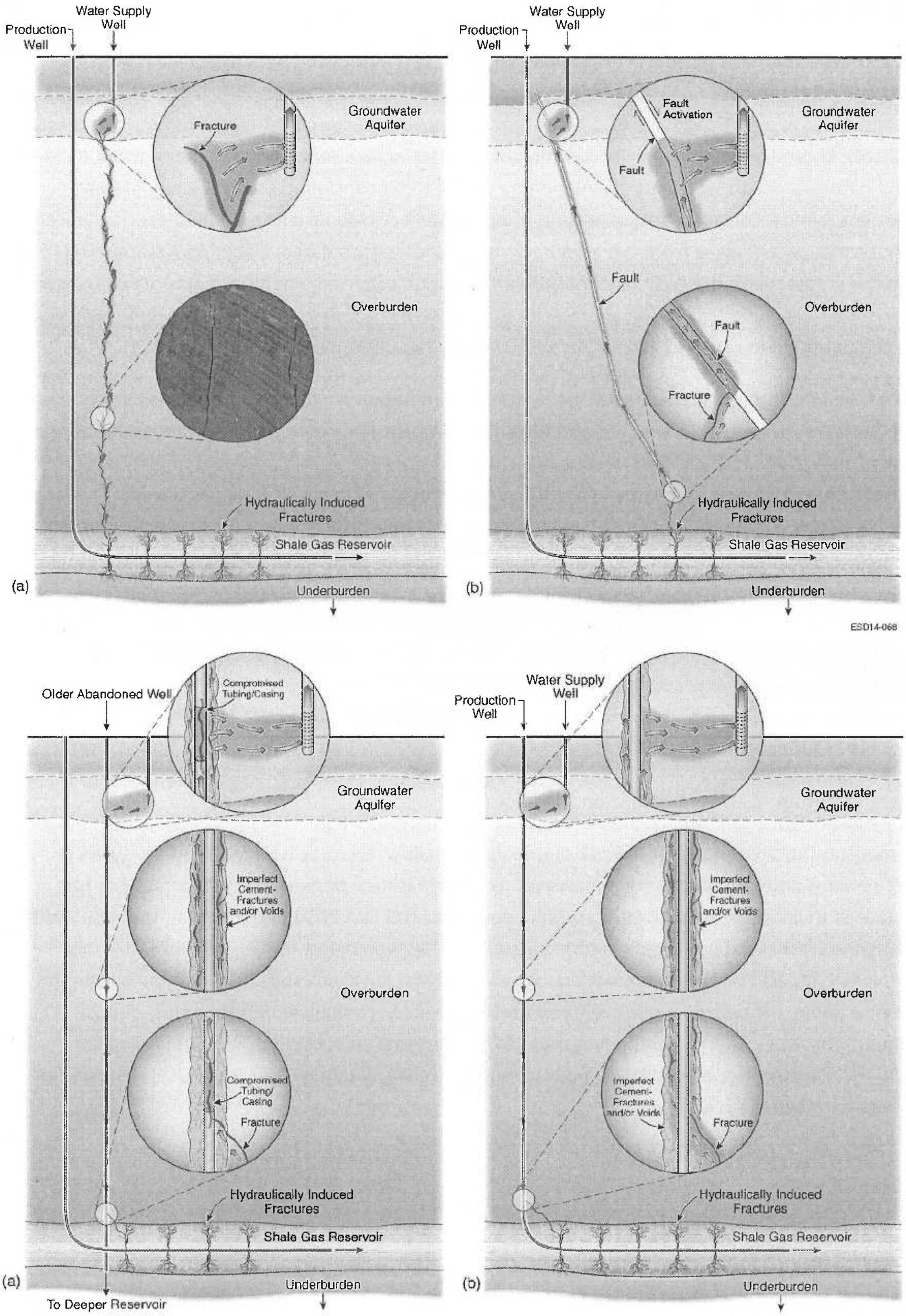

Figure 9 - Shallow - deep connectivity scenarios. Upper (a) extensive vertical fracturing. Upper (b) sealed/dormant fracture reactivation. Lower (a) older, abandoned wells. Lower (b) well failure (Reagan *et al.* 2015).

Induced Earthquakes

The occurrence of microseismic events (small earthquakes) associated with hydraulic fracturing during and after the hydraulic stimulation process is well documented (US EPA 2016). There has also been increases in seismic activity associated with wastewater disposal through aquifer injection (US EPA 2016). This microseismic activity has the potential to increase the permeability of conduits and extend naturally occurring fractures. Vulgamore *et al.* (2007) concluded the possibility of fault movement (almost certain to increase conduit permeability) in some settings could extend laterally for thousands of feet away from the area being hydraulically stimulated. Fisher and Warpinski (2012) found the greatest induced hydraulic fracture propagation occurred when the fractures intersected pre-existing faults. It is also important to note that these earthquakes, regardless of their magnitude, have the potential to cause or accelerate well integrity failure as well (Davies *et al.* 2014).

Most of the earthquakes produced by the hydraulic stimulation and wastewater disposal process are small (between magnitude 2 and 3.6) and too small to cause significant damage. However, there are concerns that some of the largest earthquakes in the United States midcontinent in 2011 and 2012 may have been triggered by nearby hydraulic stimulation fluid wastewater disposal wells. The largest (as at 2013) was a magnitude 5.6 event which damaged hundreds of homes, destroyed 14 homes and injured two people. The mechanism responsible for causing this earthquake appears to be weakening of a pre-existing fault by elevating the fluid pressure causing fault reactivation and slippage (Ellsworth 2013). In September 2016, a 5.8 magnitude earthquake hit the same area and there is now a class action lawsuit against a number of the companies undertaking hydraulic stimulation and waste water disposal by injection in that area (http://www.usatoday.com/story/news/2016/11/07/oklahoma-earthquake-fracking-well/93447830/ accessed 10/1/2017).

Target Formation - Surface Separation Distance

It is important to point out that the risk of impact to shallow, typically potable aquifers, surface water systems and the environment increases as the separation between target formations for hydraulic stimulation and freshwater aquifers decreases (US EPA 2016). For context, the depth of the main hydraulic stimulation targets in the United States is given below in Table 1. Note that the examples of impact reviewed above (Vengosh *et al.* 2014; Llewellyn *et al.* 2015) are both from the Marcellus Shale, considered a relatively representative, neither shallow nor deep UCH deposit. This statement must be qualified by the fact that all UCH deposits will occur in different geological conditions. Further, these conditions might vary significantly within an individual UCH deposit, not just between them (Table 1).

Table 1 - Review of depth of target formation - aquifer separation in the United States (US EPA 2016).

Basin/play/ formation[a]	Approx. depth (ft [m] below surface)	Approx. net thickness (ft [m])	Distance between top of production zone and base of treatable water (ft [m])[b]
Shale plays			
Antrim	600 to 2,200 [200 to 670]	70 to 120 [20 to 37]	300 to 1,900 [90 to 580]
Barnett	6,500 to 8,500 [2,000 to 2,600]	100 to 600 [30 to 200]	5,300 to 7,300 [1,600 to 2,200]
Eagle Ford	4,000 to 12,000 [1,000 to 3,700]	250 [76]	2,800 to 10,800 [850 to 3,290]
Fayetteville	1,000 to 7,000 [300 to 2,000]	20 to 200 [6 to 60]	500 to 6,500 [200 to 2,000]
Haynesville-Bossier	10,500 to 13,500 [3,200 to 4,120]	200 to 300 [60 to 90]	10,100 to 13,100 [3,080 to 3,990]
Marcellus	4,000 to 8,500 [1,000 to 2,600]	50 to 200 [20 to 60]	2,125 to 7,650 [648 to 2,330]
New Albany	500 to 2,000 [200 to 600]	50 to 100 [20 to 30]	100 to 1,600 [30 to 490]
Woodford	6,000 to 11,000 [2,000 to 3,400]	120 to 220 [37 to 67]	5,600 to 10,600 [1,700 to 3,230]

Hydraulic Stimulation Water Requirements and Waste Disposal

Substantial volumes of water are required to be sourced (and waste water disposed of) in hydraulic stimulation projects. The US EPA (2016) quote a median figure per well based on data from 2011 and 2103 in the range of 5.7 million litres, with the 10th and 90th percentiles being 0.28 to 23 million litres respectively. Recent estimates of water required per well in Western Australia are 7 million litres for exploration, 7-17 million litres during evaluation and 21 million litres during production (DMP 2015), which may require multiple hydraulic stimulations to reach ultimate gas recovery targets.

According to the United States EPA (2016), the amount of water required per well can vary significantly between and within an individual UCH deposit. Fresh water is typically desired, but brackish and saline water can be used in some circumstances. Some companies prefer a certain water chemistry, as defined by total dissolved solids and proportions of various chemical constituents such as anions (chloride, sulphate etc.) and cations (sodium, calcium, magnesium and potassium). Wastewater which returns to the surface is a mixture of these hydraulic fracturing fluids and formation water. This wastewater can often be highly saline (up to 7 times sea water) and may contain a large number of toxic chemicals and gases making hydraulic stimulation water reuse difficult (Vengosh *et al.* 2014). It is outside the scope of this report to review these chemicals and their potential impacts in detail, but the reader is directed to United States EPA (2016), Vengosh *et al.* (2014) and Cook *et al.* (2013) for detailed information. Coram *et al.* (2014) highlighted the large amount of concern and uncertainty over the health impacts of exposure to these chemicals, hence no comprehensive assessment of the fate and impact of the overwhelming majority of these chemicals on flora and fauna (including humans) exists.

The amount of return water, on a well by well basis, available for reuse or requiring disposal varies considerably between and within the various hydraulic fracturing projects. It is difficult to quantify

precisely the amount of injected fluids that return in the wastewater; there is not a clear distinction between hydraulic fracturing fluids and formation water in wastewater. Typical indicators that could be used (salinity and radioactivity, to name two) are not routinely monitored (US EPA 2016).

The amount of produced water as a percentage of the total amount of injected fluid is highly variable (US EPA 2016; Vengosh *et al.* 2014). The maximum is less than 85 per cent in all but one of the examples given in those compiled in US EPA (2016), and most values are less than 30 per cent. In rare cases, the amount of wastewater is greater than the amount of injected fluid, with the additional water coming from the formation (Nicot *et al.* 2014) or from a conductive pathway from an adjacent formation (Arkadakskiy and Rostron 2013).

Wastewater reuse (the use of wastewater from a previous well) is typically low with a median of five per cent (range 0 to 20 per cent). Reuse is most common in areas where disposal options are limited, as opposed to areas where water resource availability is limited. Transport costs (i.e. trucking or pipelines) and transport impact considerations are important additional drivers for not transporting contaminated waste water between well sites. Wastewater from other processes (i.e. acid mine drainage or wastewater treatment plant (sewage) effluent, for example) have also been used but there is very little information on how often and how much of these types of water are used (US EPA 2016). In one Western Australian well that was hydraulically fractured, over 600,000 litres of diesel used as stimulation fluid was unable to be recovered (WA:ERA 2012).

Other Environmental Impacts

It is outside the scope of this report to comprehensively present the other risk from development of tight gas resources. The reader is directed to Cook *et al.* (2013), who highlighted the other environmental risks that this anthropogenic activity can cause. Some examples are:

- habitat fragmentation due to land clearing and linear infrastructure (road and pipeline construction;
- hydrological impacts due to linear infrastructure (water excesses or deficits) due to natural surface water (sheet flow) impairment;
- increased road kill or traffic accidents from an increased road network and increased traffic;
- spread of dieback and other pathogens;
- spread of feral animals such as cane toads; and
- seismic impacts on groundwater ecology directly (i.e. stygofauna).

Western Australian Tight Gas

The areas in Western Australia that are prospective for tight gas are shown in Figure 10. Current publically available estimates of gas present in the most prospective geological units of the two most prospective areas are the northern Perth Basin (29-46 trillion cubic feet of recoverable gas) and the Canning Basin (73-147 trillion cubic feet of recoverable gas) (DMP 2015). Table 2 shows the summary data for the physical extent (of particular note is the depth) of these deposits included the target formations for hydraulic stimulation the northern Perth and Canning basins (Cook *et al.* 2013). Triche (2012) identified other prospective formations for tight gas deposits in the northern Perth and Canning basins (Figure 11).

It is important to note that, in line with deposits in the United States, the project life for tight gas projects is expected to be in the order of 30+ years (Figure 12). A brief review of the current level of understanding of these landscapes, including hydrogeology, biodiversity, cultural values and groundwater dependence of ecosystems will now be presented. A review of regulations relevant to the tight gas industry will then follow.

Table 2 - Basic and physical data of WA tight gas deposits currently under investigation for production (adapted from Cook *et al.* 2013).

Basin		Northern Perth	Northern Perth	Canning
Shale Formation		Carynginia Shale	Kockatea	Goldwyer
Geologic Age		Upper Permian	Lower Triassic	Middle Ordovician
Thickness (m)	**Interval**	92-458	92-915	92-736
	Organically Rich	290	702	396
	Net	76	70	76
Depth (m)	**Interval**	1220-5032	1007-5032	1007-5032
	Average	3264	3050	3660

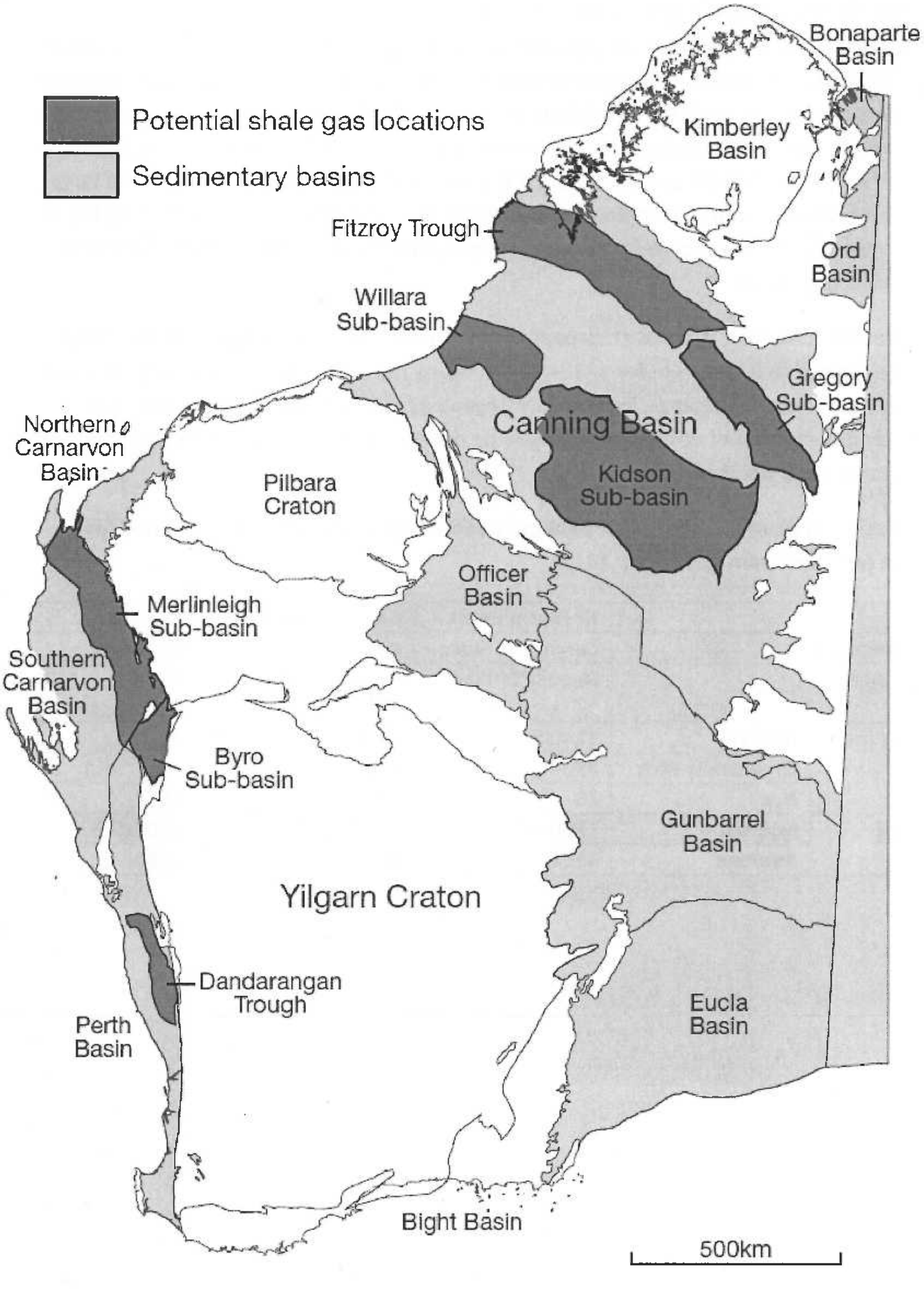

Figure 10 - Prospective tight gas areas (shale gas) in Western Australia (DMP 2015).

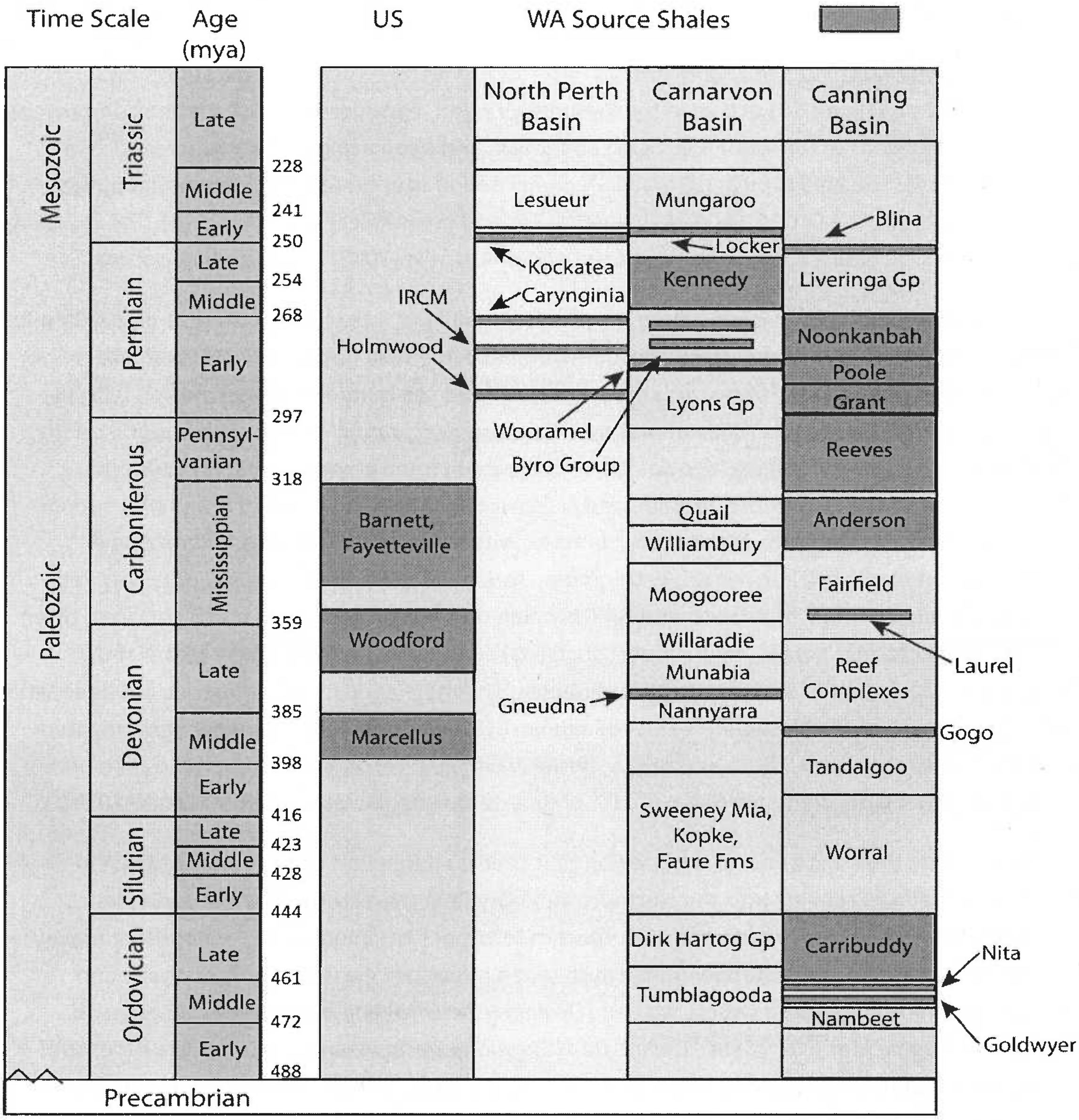

Figure 11 - "Source" shales in WA that may be prospective for tight gas production with US comparison (Triche 2012).

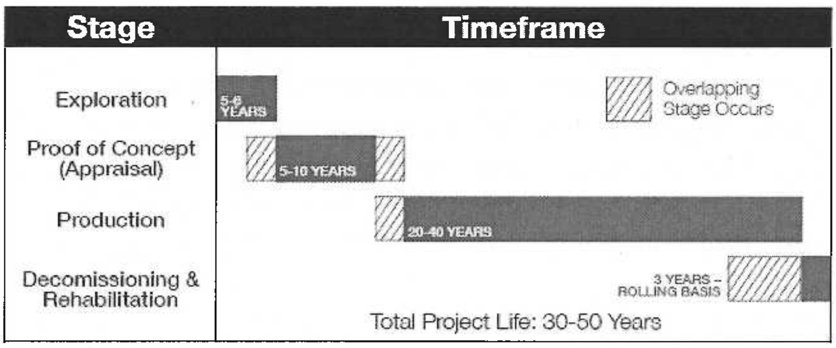

Figure 12 - A typical project timeline for tight gas deposits (DMP 2015).

Canning Basin

Ecology and the Natural Environment

The Canning Basin (Figure 10) occurs in the Kimberley region, considered one of the most important biogeographic regions in the world with high endemism and deep ecological divergences (Pepper and Keogh 2014). The area is biogeographically comprised of four bioregions: Dampierland, the Great Sandy Desert, the Ord Victoria Plain and the Tanami (Eco Logical Australia 2013). The following is taken from Cook *et al.* (2013), who cited Eco Logical Australia (2013) as the original source.

Dampierland is a semi-arid tropical bioregion in Western Australia that intersects part of the Canning Basin. It comprises four distinctive systems (Environment Australia (EA) 2000): (1) Quaternary sandplains overlying Jurassic/Mesozoic sandstones with red soil hummock grasslands on hills; (2) Quaternary marine deposits on coastal plains, with mangroves, samphire – *Sporobolus* grasslands, *Melaleuca acacioides* low forests, and *Spinifex* – *Crotalaria* strand communities; (3) Quaternary alluvial plains associated with the Permian and Mesozoic sediments of Fitzroy Trough that support tree savannas of *Crysopogon* – *Dichanthium* grasses, with scattered *Eucalyptus microtheca* – *Lysiphyllum cunninghamii*, interwoven with riparian forests of River Gum (*E. camaldulensis*) and *Cadjeput Melaleuca* fringe drainages; and (4) Devonian reef limestones in the north and east, often manifest as spectacular gorges, that support sparse tree steppe over *Triodia intermedia* and *T. wiseana* hummock grasses and vine thicket elements. The main agricultural industries are beef cattle (about 75 per cent of the bioregion is grazed) and horticulture. The region contains Ramsar-listed wetlands and 10 threatened flora and fauna species have been recorded. Dampierland is an under-represented bioregion, with only one per cent of its extent formally reserved (Cook *et al.* 2013).

The Great Sandy Desert is a vast arid bioregion that covers a large part of the Canning Basin in Western Australia, extending into the Northern Territory. It is characterised by red sand plains, dunefields and remnant rock outcrops. It is intact in terms of contiguous cover, comprising mainly tree steppe grading to shrub steppe in the south (open hummock grassland of *T. pungens* and *Plectrachne schinzii*, scattered Desert Walnut (*Owenia reticulata*) and bloodwoods, *Acacia* spp., *Grevillea wickhamii* and *G. refracta*). Desert Oak (*Casuarina decaisneana*) occurs in the far east of the region. Calcrete and evaporite surfaces traverse the desert, and include extensive salt lake chains with samphire low shrublands, and *Melaleuca glomerata* – *M. lasiandra* shrublands (EA 2000). Tourism, mining and mineral exploration are the main land uses in the Great Sandy Desert. Pastoral leases cover the far western and eastern edges – about seven per cent of the bioregion is grazed. The region contains 30 threatened fauna species, including 10 considered to be extinct (Cook *et al.* 2013).

The Ord Victoria Plain is a semi-arid bioregion coinciding with the Canning Basin in Western Australia, and includes ridges, plateaus and undulating plains on Cambrian volcanics and Proterozoic sedimentary rocks. The lithological mosaic has three main components: (1) Abrupt ranges and scattered hills mantled by shallow sand and loam soils supporting *Triodia* hummock grasslands with sparse low trees including Snappy Gum (*E. racemosa*); (2) Cambrian volcanics and limestones forming extensive plains with short grass (*Enneapogon* spp.) on dry calcareous soils and medium-height grassland communities (*Astrebla* and *Dichanthium*) on cracking clays. Riparian forests of River Gum fringe drainage lines; and (3) in the south-west, lateritised upland sandplains (EA 2000). Extensive grazing is the main industry with at least 80 per cent of the bioregion grazed. Despite this,

the native vegetation mosaic is reasonably intact across the extent of the bioregion. A total of eight threatened species have been recorded (Cook *et al.* 2013).

The Tanami is a tropical arid bioregion that traverses parts of the Canning and Georgina basins in Western Australia and the Northern Territory. It comprises mainly red Quaternary sandplains overlying Permian and Proterozoic strata which are exposed locally as hills and ranges. The sandplains support mixed shrub steppes of Corkbark Hakea (*Hakea suberea*), desert bloodwoods, acacias and grevilleas over *Triodia pungens* hummock grasslands. Wattle scrub over *T. pungens* hummock grass communities occur on the ranges. Alluvial and lacustrine calcareous deposits occur throughout. In the north they are associated with Sturt Creek drainage, and support *Crysopogon* and *Iseilema* short-grasslands often as savannas with River Red Gum (EA 2000). Over 1500 taxon have been recorded in the Tanami, including 26 threatened flora and fauna. About 25 per cent of the Tanami is suitable for domestic grazing. Feral camels, horses and donkeys are a major management issue, and the declared weed, *Parkinsonia*, is establishing around watering points of pastoral leases in the bioregion. The level of formal reservation is less than 10 per cent. There are also a number of important surface water features with groundwater connectivity, the most important of which is the Fitzroy River, now a target for development of irrigated horticulture industry (Cook *et al.* 2013).

The Fitzroy River Catchment is in the Dampierland bioregion and is made up of the two distinct habitat types: ranges and plains. The plains portion of the Catchment which occurs on the Canning Basin comprises plains of red sands and alluvials of grey-brown clays with low lying uplands of sandstone and limestone shallow soils (Beard 1990). The Catchment is characterised by acacia thickets with sparse trees, grasslands and savannahs. Spinifex steppes dominate the centre and east of the bioregion with a transition to sparse tree steppe over spinifex and hummock grasses in the north and east (Thackway and Cresswell 1995). Current conservation reserves represent less than five per cent of the Dampierland bioregion and the Fitzroy River has evidence of substantial surface water groundwater interaction, including deep and saline groundwater discharge (CSIRO 2009).

Aboriginal Cultural Heritage Considerations

The Canning Basin is a large part of the Kimberley Region, in which Aboriginal people make up 50 per cent of the population and 90 per cent of the people who live outside of major towns (Bergmann 2006). The Aboriginal traditional custodians of the Kimberley are culturally, linguistically, and socio-politically distinct (Toussaint *et al.* 2001), and this is reflected by the complex relationship that they share with the country they care for.

Aboriginal peoples' traditional knowledge and understanding of terrestrial and aquatic ecosystems is inter-related with their customary use of these landscapes. These ecosystems provide bush foods, art and craft materials, medicines and are culturally significant to the landscape. Water is a sacred and basic source and symbol of life (Langton 2006), and aquatic resources are part of the customary economy and an invaluable component of local experiences. The aquatic species themselves continue to be vital to the livelihoods of the people. Further, traditional fishing, hunting, and gathering activities significantly contribute to financial income and diet (Altman 1987; Jackson and Altman 2009).

The economic and cultural values of the Canning Basin river systems to the Aboriginal traditional custodians are currently poorly understood by environmental managers and water planners (A. Poelina pers. comm. 19 October 2015). Some of these values are difficult to analyse, making water

allocation decisions problematic (Jackson 2008). Few quantitative investigations on the use of resources by Aboriginal people have been conducted, and the values of non-traded goods and services in these societies have not been evaluated (Jackson *et al.* 2011).

Hydrogeology

Regional Hydrogeology

The hydrogeology of the Canning Basin (Australia's second largest sedimentary basin) is largely unknown. Detailed studies have been carried out only in: the extreme south west; West Canning Basin (DoW 2010; DoW 2012); around Broome, Dampier Peninsula and LaGrange Subarea (DoW, 2016a) and near Derby (DoW 2008). Elsewhere conditions are inferred from pastoral bores in the Fitzroy Trough and along the coast, and inland from widely spaced hydrocarbon exploration wells. The basin contains some 10 km of sediments ranging in age from Ordovician to Cretaceous, and can be subdivided into the Fitzroy Trough and Gregory Sub-basin (extending south east from Broome and encompassing the Fitzroy River Basin) and the Kidson and Willara Sub-basins, which underlie the Great Sandy Desert.

The Cretaceous Broome sandstone aquifer extends along the entire coast from the De Grey River to Cape Leveque, and inland by up to 150 km. It generally thickens towards the coast, reaching a maximum thickness of around 250m. The Broome Sandstone is an unconfined aquifer, recharged directly from rainfall and conformably overlying the largely impermeable Jarlemai Siltstone. Groundwater is generally fresh, but is brackish to saline towards the De Grey River, with salt water interfaces along the coast and around Samphire Marsh and Roebuck Plains where groundwater discharge supports springs and phreatophytic vegetation. The aquifer is used for Broome town water supply and for agriculture and stock watering (DoW 2010; Laws 1990).

The Jurassic Wallal Sandstone underlies the Jarlemai Siltstone in the west of the basin, and crops out beneath the Great Sandy Desert. It unconformably overlies various formations of Permian age which are not mapped. Together with the overlying Alexander Formation, it forms a 500m thick aquifer, unconfined inland, and confined along the coast where it is overlain by the Jarlemai Siltstone and Broome Sandstone. It is recharged by direct rainfall on the outcrop, and groundwater flow is towards the coast, or locally to King Sound. Groundwater discharge is presumably a considerable distance offshore, as the potentiometric head along the coast is artesian, up to 30m above sea level at Cape Keraudren. Groundwater in the extreme southwest of the basin is low, but salinity increases to brackish north of Samphire Marsh, and is around 2500 mg/L at Broome (Laws, 1990). The aquifer was investigated in the West Canning Basin for supply to Port Hedland, and is now being increasingly used between the De Grey River and Samphire Marsh for irrigation (DoW 2010; DoW 2012).

The Triassic Erskine Sandstone occupies a syncline extending south east of Derby. It is in contact with an overlying outlier of Wallal Sandstone at Derby, and is bounded beneath and around the margin by the underlying Blina Shale. Groundwater is recharged on the outcrop of the aquifer, with groundwater flow towards King Sound. Seawater interfaces occur in the aquifer around the Derby peninsula. The aquifer is used for Derby water supply and small scale horticulture. Shallow groundwater in areas underlain by Blina Shale is generally saline, suggesting some leakage potential (Smith 1992).

The Permian Liveringa Group contains 600m of various sandstone aquifers and fine grained formations, and crops out in the Fitzroy Trough. It overlies the largely impermeable Noonkanbah Formation. Groundwater varies in salinity from marginal to brackish and is used for stock and domestic supply, and was used for irrigation at Camballin (Phil Commander pers. comm. 8/02/2017).

The Permian Poole Sandstone and Grant Group form a major aquifer up to 2100m thick (Laws 1990; Laws 1991). They crop out as inliers in the Fitzroy Trough, in the Grant and St Georges Ranges, and underlie the greater part of the Great Sandy Desert, stratigraphically below the Noonkanbah Formation. In the Great Sandy Desert the Poole Sandstone and Grant Group are in contact with overlying Cretaceous sandstones. There is very little information on the hydrogeology. The water table is generally deep, but comes to the surface to discharge in salt lake chains occupying former drainage lines (palaeodrainages). Groundwater from these aquifers is used for community water supply and along the Canning Stock Route. At the Admiral Bay mineral deposit south-east of Broome, groundwater in the Grant Group is saline, but there is little information on salinity elsewhere (Phil Commander, pers. comm. 8/02/2017).

Very little is known of the aquifers stratigraphically below the Grant Group in the Kidson and Willara Sub-basins. In the eastern Fitzroy Trough there are various sandstones and Devonian limestone reefs which generally contain fresh groundwater and probably represent local flow systems, discharging to the major rivers. The hydrogeological conditions around the Goldwyer Formation are therefore unknown.

An alluvial aquifer, consisting of up to 25m of sands and gravels, stretches some 275 km along the Fitzroy River (Lindsay and Commander 2005). The Fitzroy Alluvium is recharged from the river during the wet season and from discharge of the Canning Basin regional aquifers, generally during the dry season. Groundwater discharge is particularly likely to come from the Liveringa Group that underlies a substantial part of the alluvium. Although exchange with regional aquifers leads to discharge to the river, most of the basin scale discharge is to and beyond the coast (CSIRO 2009). Surface water systems also interact with aquifer systems throughout the Canning Basin, however there is currently not a sufficiently detailed understanding in the context of water allocation planning for even the most studied, the Fitzroy River (Vogwill 2015). What has been shown is that groundwater is an important water supply to surface water systems and their dependent ecosystems (Lindsay and Commander 2005; CSIRO 2009; Harrington *et al.*, 2014).

Salinity in the Fitzroy River is often less 250 mg/L in the wet season and ranges as high as 900 mg/L in the dry season. Dry season salinity is likely related to groundwater salinity as baseflow dominates river input over runoff, and wet season salinity drops in response to dilution from rainfall runoff. The river salinity changes with location and is fresh (< 500 mg/L) between Fitzroy Crossing and Noonkanbah, marginal (500–1000 mg/L total dissolved solids) between Noonkanbah and Myroodah due to groundwater inflow salinity, and fresh again from Myroodah to Willare due to tributary inflows. The variations with location are related to groundwater discharge from the underlying formations such as the Noonkanbah Formation and Blina Shale (Lindsay and Commander 2005).

Geological and Structural Investigations as a Proxy for Hydrogeology

No regional scale study of the hydrostratigraphy (including hydrogeologically relevant faulting) of the Canning Basin exists. For reference, hydrostratigraphy is the structure and distribution of subsurface porous materials in reference to the flow of groundwater, often relating to stratigraphy while stratigraphy is (geology) the study of rock layers and the layering process (stratification). The most recent stratigraphic studies into the deep basin geology identified large gaps in terms of sedimentological and structural assessment due to a lack of data (Parra-Garcia *et al.* 2014). Consequentially they were only able to map to formation level (based on age) and there is a large amount of uncertainty around sediment type distribution, let alone structural features such as faults and shallow deep connectivity. Studies are underway but are difficult due to the lack of basin scale, detailed data. An example of the level of detail available in Parra-Garcia *et al.* (2014) is shown in Figure 13. Note the lack of a precise depth scale as there was not enough data to extrapolate the measured depths at drilled locations with the seismic (geophysical) interpretation. The faults as mapped by Parra-Garcia *et al.* (2014) were also not exhaustive. These were only the most major faults, and their study had no assessment of the permeability (or lack of permeability) of individual fault structures. This will only be possible with detailed hydrogeological studies such as flow mapping and aquifer testing near faults to look for boundary effects (barrier or conduit). More detailed investigations are required to address these considerable data gaps. This is particularly true in the Willara, Kidson and Gregory Sub-basins while the Fitzroy Trough has been the target of a more local scale investigation (Dentith *et al.* 2014).

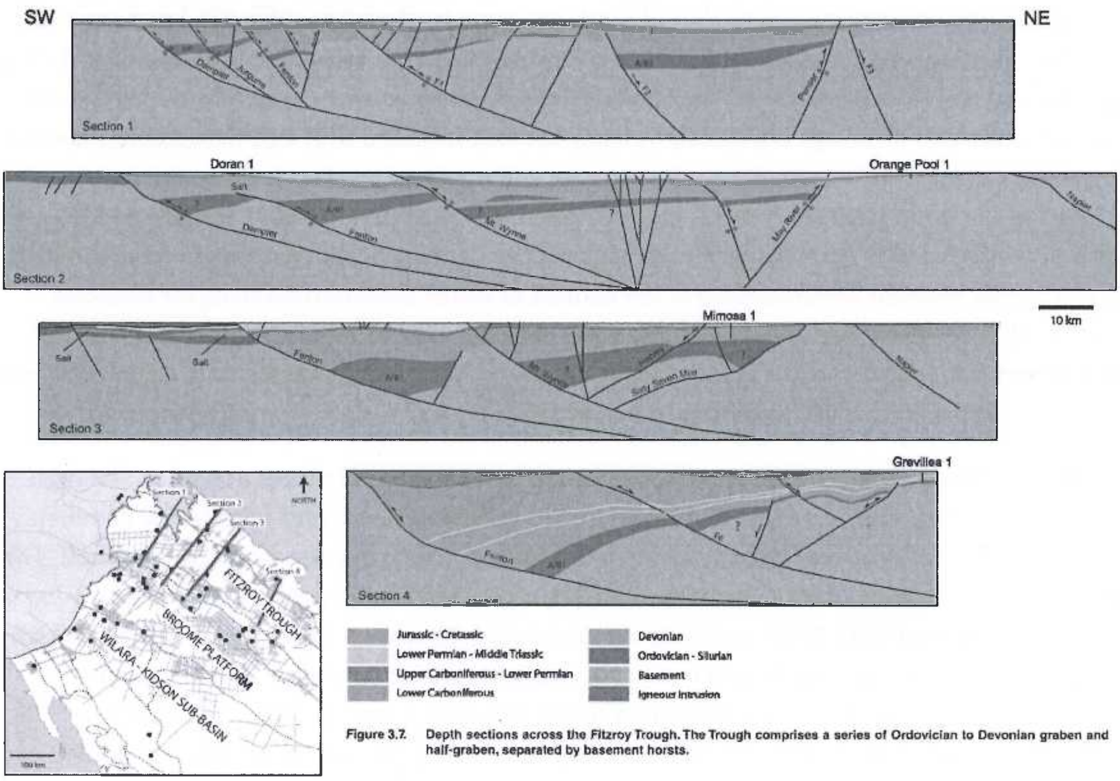

Figure 13 - Cross-section of the Fitzroy Trough in the Canning Basin (Parra-Garcia *et al.* 2014).

In their study of the CO_2 geosequestration potential of the Carboniferous–Permian Grant Group and Permian Poole Sandstone in the Fitzroy Trough, Dentith *et al.* (2014) had access to more targeted geophysical data. They subsequently were able to provide a more detailed interpretation of faulting and other structural controls over a limited area of the Canning Basin. These features are critical to the sealing potential of various geological layers from a CO_2 sequestration perspective. As part of this study, Dentith *et al.* (2014) assessed the faults present in the Noonkanbah Formation, Figure 14, an important seal for the Grant-Poole group and also a potential source shale that could become a target of hydraulic stimulation (Triche 2012). Dentith *et al.* (2014) also observed in some cases the propagation of deep faulting (Figure 14) into the Mesozoic sediments above the break up unconformity, which is typically where the fresh water aquifers occur. Note the much greater number of faults identified as compared to the regional scale interpretation (left hand side of Section 1 on Figure 13).

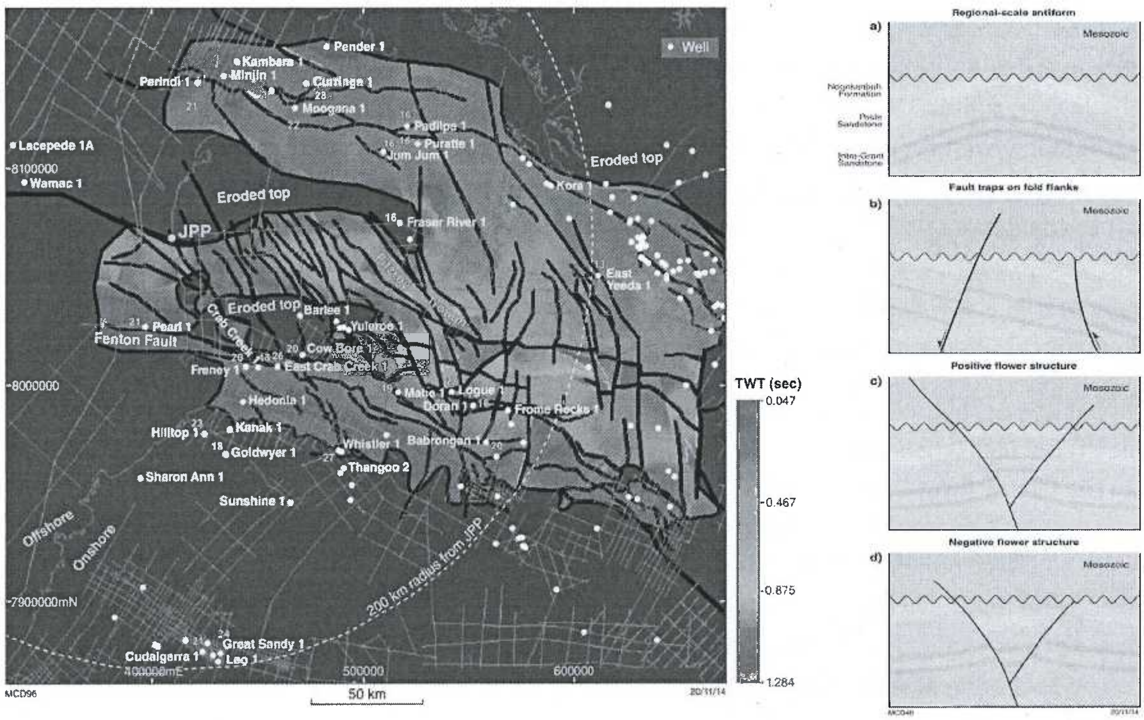

Figure 14 - Faults in the Noonkanbah Formation (left) and fault propagation into the Mesozoic Sediments (right) (Dentith *et al.* 2014).

Water Management

At the time of the release of the Kimberley Regional Water Plan working discussion paper (DoW 2009a), there were only 25 active groundwater licenses in the Fitzroy River catchment area. The licenses allowed total abstraction of less than two gigalitres (GL) per year and were granted for Aboriginal community bores, pastoral bores, and limited horticulture. The pastoral bores were for "diversified activities" (other than livestock and domestic use). Abstraction occurs from livestock and domestic bores of the pastoral industry to support tourism and to supplement the Aboriginal community supplies. Due to the historically low usage and demand, allocation limits have not been set across the Basin.

Current surface water management in the catchment appears focussed on collecting additional data and includes gauging stations at Willare, Fitzroy Crossing, Diamond Gorge, Phillips Range and MeNoSavy, with temporary monitoring at Mount Winifred and Mount Krauss. Additional stations to support flood management were set up at Fitzroy barrage, Christmas Creek, Margaret Gorge, Noonkanbah, Looma and Willare but there are still considerable data gaps (DoW 2009a).

Groundwater monitoring is almost non-existent outside of development areas such as the Fitzroy River, regional centres and large-scale mining operations. In the only substantial evaluation of the Fitzroy alluvial aquifer as a water resource, Lindsay and Commander (2005) stated that further field investigations need to be conducted to properly assess the potential for increased abstraction of groundwater.

Ecohydrology

The current state of mapping of groundwater dependent ecosystems (GDEs) in the Canning Basin is shown in Figure 15. Note the variability in type of GDE (dependent on surface expression of groundwater, subsurface availability of groundwater and cave/aquifer systems) and the extensive areas that have not even had a preliminary desktop assessment (cross-hatched areas). Some local scale investigations are underway, focussed on GDEs associated with the Broome Sandstone of the West Canning Basin (Wright *et al.* 2016), a small portion of the Canning Basin and one study in the Great Sandy Desert. Most of these have not been formally published, so cannot be referenced. Where results are available, high numbers of GDEs have been identified (Wright *et al.* 2016), with a high number (128) identified in the La Grange Groundwater Area alone.

Although the ecohydrology and groundwater dependence of ecosystems of the area is not well understood, CSIRO (2009) selected four environmental assets from the Kimberley, including two from the Fitzroy River Catchment, for the Directory of Important Wetlands in Australia (Environment Australia 2001), in order to qualitatively assess for changes to their hydrogeological regimes from climate and development effects. These wetlands are important for a variety of ecological reasons and because they have high cultural value, particularly to Aboriginal traditional owners. The following characterisation of these environmental assets is based on the description of the assets given by Environment Australia (2001).

The Camballin Floodplain is in the central reaches of the Fitzroy River and includes the Le Livre Swamp System and numerous other seasonal wetlands (Environment Australia 2001). Halse and Jaensch (1998) reported that the Camballin Floodplain is an important bird habitat and that there are at least 67 recorded species, with bird numbers often exceeding 20,000. The Fitzroy River channel is an important habitat for fish, especially as its large deep pools provide dry season refuges. The river contains a high diversity of fish, including some that are listed as threatened species, for example, the Northern River Shark and the Freshwater Sawfish (Storey *et al.* 2001; Morgan *et al.* 2002).

Geikie Gorge National Park is located in the upper Fitzroy catchment approximately 30 km upstream of Fitzroy Crossing. It is a permanent pool on the Fitzroy River about 13 km long and 100m wide. The gorge is an important refuge area for fish and other aquatic fauna during periods of drought (van Dam *et al.* 2008). The gorge's permanent water and food resources are valuable to the park's

traditional custodians, the Bunuba people, who are involved in sharing its cultural values with visitors.

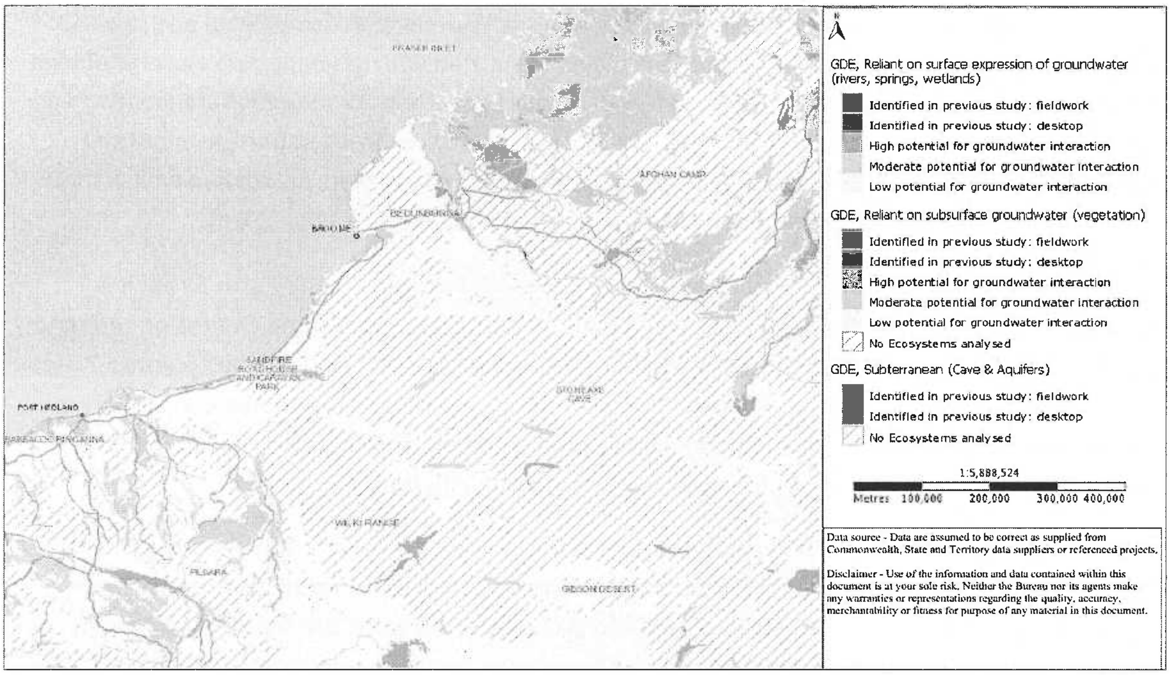

Figure 15 - Groundwater dependent ecosystems of the Canning Basin (http://www.bom.gov.au/water/groundwater/gde/map.shtml).

Northern Perth Basin

Ecology and the Natural Environment

The northern Perth Basin occurs in the Mid-West region, an area which contains important biodiversity (Rutherford *et al.* 2005; Cook *et al.* 2013). The Midlands area (a part of the Mid-West region) in particular has been noted to have exceptional flora species richness. Griffin (1994) estimated that this area contains about one-fifth of the floristic diversity of the entire state as understood in 1994. Griffin *et al.* (1990) found such high floristic diversity in their study, they considered the area has few parallels globally. The area contains three important biogeography regions— Carnarvon, Geraldton Sandplains and Yarloo (Environment Australia 2000). The following is adapted from Cook *et al.* (2103).

Carnarvon is an arid bioregion in Western Australia that traverses part of the Southern Carnarvon Basin and the northern part of the northern Perth Basin. It comprises Quaternary alluvial, aeolian and marine sediments that overlie Cretaceous strata. It supports a mosaic of saline alluvial plains with samphire and saltbush low shrublands, Bowgada (*A. ramulosa var. linophylla*) low woodland on sandy ridges and plains, Snakewood (*A. xiphophylla*) scrubs on clay flats, and tree to shrub steppe over hummock grasslands on and between red sand dune fields. Limestone strata with *A. startii / bivenosa* shrublands outcrop in the north, where extensive tidal flats in sheltered embayments support mangrove communities (Environment Australia 2000). The often sparse vegetation is largely contiguous. The bioregion supports extensive cattle and sheep grazing. About 85 per cent of the bioregion is grazed, with unmanaged goats contributing to total grazing pressure (Cook *et al.* 2013).

Located over part of the Southern Carnarvon Basin and the northern part of the northern Perth Basin, the semi-arid Geraldton Sandplains bioregion supports mainly proteaceous scrub-heaths on the sandy earths of an extensive, undulating, lateritic sandplain mantling Permian to Cretaceous strata (Environment Australia 2000). It supports extensive York Gum (*E. loxophleba*) and Jam (*A. acuminata*) woodlands that occur on outwash plains associated with drainage. It is a centre of high endemism, particularly for flora and reptiles, and various vegetation communities are identified as being 'at risk' in the absence of reservation. The bioregion also comprises nationally important wetlands. Grazing is practiced across at least 80 per cent of the bioregion, and dryland cultivation and cropping and associated vegetation clearing is also prevalent (Cook *et al.* 2013).

Yalgoo Bioregion in Western Australia is an arid to semi-arid bioregion in the Perth Basin. It is characterised by low woodlands to open woodlands of *Eucalyptus*, *Acacia* and *Callitris* on red sandy plains of the Western Yilgarn Craton and southern Carnarvon Basin. It includes the Toolonga Plateau of the southern Carnarvon Basin. It is rich in ephemeral species (Environment Australia 2000). Tenure is predominantly pastoral leasehold and sheep grazing is the main enterprise type. The region supports a rich diversity of flora and fauna, including 23 listed taxa (Cook *et al.* 2013).

Groundwater dependence of ecosystems of the northern Perth Basin have only been assessed at a preliminary level (Rutherford *et al.* 2005). Numerous river systems and wetlands exist as well as vegetation and caves in areas of shallow depth to groundwater (Figure 16). Most groundwater dependence is inferred due to a lack of site specific investigations. The environmental water requirements of these ecosystems, hence the level of groundwater dependence (i.e. total, partial etc.), is unknown (Rutherford *et al.* 2005; DoW 2009) - let alone an assessment of the impact of declining groundwater levels or water quality changes. Some preliminary studies of the area's major river systems (the Murchison, Chapman, Greenough, Irwin, Arrowsmith, Coonderoo, Hill, Moore Rivers and Gingin Brook) have shown variable groundwater interaction (i.e. groundwater recharge or groundwater discharge) along the reach of most rivers.

Initially it was thought that groundwater, which supported these ecosystems, was from the shallow aquifers. But in recent years, studies have shown an increased importance of discharge from the deeper semi-confined and confined aquifers as an important support mechanism for many groundwater dependent ecosystems (DoW 2016b). Development pressures are increasing in the northern Perth Basin, particularly in the Jurien and Arrowsmith groundwater areas, where previously there were only low levels of groundwater use and little need for concern over impacts to groundwater dependent ecosystems. It is now necessary to raise the level of management response to correspond with the increasing level of risk to ecosystem values (DoW 2009).

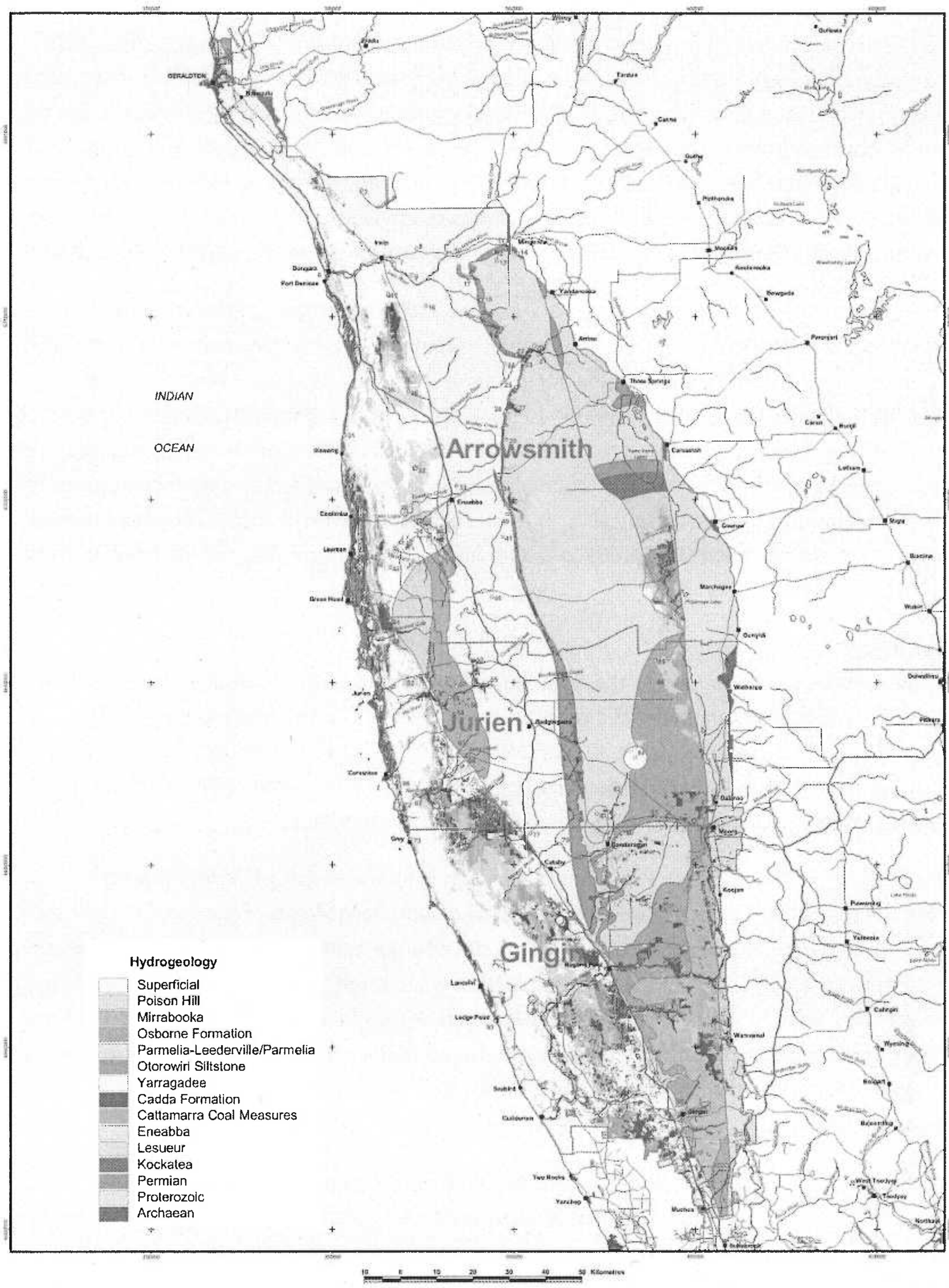

Figure 16 - Potential GDEs of the northern Perth Basin (Rutherford *et al.* 2005).

Aboriginal Cultural Heritage Considerations

The Aboriginal cultural heritage value and significance of the northern Perth Basin is difficult to determine as no publications are available. In 2009, DoW mapped the location of sites that were in the Department of Aboriginal Affairs Aboriginal Sites Register in the northern Perth Basin, but this may not be representative of the actual sites of Aboriginal cultural significance (DoW 2009). More generally, Dreamtime stories have long been and continue to be considered sacred to Aboriginal people (Jones 2015). Many of these Dreamtime stories relate to water features in the landscape, so their protection will contribute to the preservation of cultural values in the northern Perth Basin.

Like other parts of the south-west of Western Australia, cultural heritage protection has been eroded due to the institutional cultural heritage management. In 2012, for example, the definition of "sacred" was reinterpreted to only include sites "devoted to a religious use rather than a place subject to mythological story, song or belief" Jones, (2015). Large numbers of previously registered Aboriginal heritage sites in the Department of Aboriginal Affairs Aboriginal Sites Register have been removed and large number of sites have been blocked from being added to due to changes to the definitions (including extensive technical term re-interpretation) (Jones 2015). This was found in 2015 to be a "misconstruction" by Justice John Chaney in the Supreme Court of Western Australia Jones, (2015).

Hydrogeology

The northern Perth Basin (defined as the area of the Perth Basin north of Gingin Brook) contains a sequence of variably interconnected sedimentary units (Figure 17). The hydrogeology of the northern Perth Basin is complex (DoW 2010a; DoW 2016b). Numerous authors have completed studies in the area, but these have all been compiled by the recent review (DoW 2016b). DoW (2016b) presented the current reconnaissance level of understanding.

The hydrogeology of the northern Perth Basin is known from a network of widely spaced government exploratory bores, from private bores and hydrocarbon exploration wells. The basin contains as much as 15 km thickness of sediments close to the eastern margin along the Darling Fault, and thins to around 2 km at the coast near Jurien. Sedimentary rocks are relatively flat lying and undeformed close to the Darling Fault, but are increasingly faulted and tilted in the Hill River area, east of Jurien (DoW 2016b). The basin contains two major aquifers, the Parmelia Aquifer and the Yarragadee Aquifer, in which low salinity groundwater extends to depths of around 3000m (Commander 1974).

There are seven main regional aquifer systems within the northern Perth Basin sedimentary sequence: the Superficial, Mirrabooka, Leederville, Leederville–Parmelia, Yarragadee, Cattamarra and Eneabba–Lesueur Aquifers. There are three minor local scale aquifers within Permian age sediments being the Wagina, Irwin–High Cliff and Nangetty Aquifers. The Tumblagooda Sandstone is another minor aquifer which appears to have both intergranular and fracture porosity. Local, small supplies of groundwater can be sourced from the Proterozoic metasediments and basement, with the fissured Noondine Chert being a significant aquifer (DoW 2016b).

Superficial sands and limestone underlie the coastal plain and form the Superficial Aquifer, which is up to 25m thick. Groundwater is recharged by rainfall, by ephemeral streams and there is also upward discharge in places from the underlying confined aquifers. The Tamala Limestone exhibits karst features, with caves and groundwater conduits. The water table is typically in the Superficial

Aquifer and is generally shallow, supporting wetlands and phreatophytic vegetation (Rutherford *et al.* 2005), but some areas are unsaturated, with the water table in the Mesozoic aquifers below, but some of the ephemeral wetlands are perched. Groundwater generally becomes increasingly brackish to saline northwards, and saline groundwater occurs near the coast associated with salt lakes. Fresh groundwater resources are limited, but have been used for Jurien and Cervantes water supply (DoW 2016b).

The Cretaceous Parmelia Aquifer occurs below the Dandaragan Plateau, between the Dandaragan Scarp and the Darling and Urella Faults. It is up to 400m thick and is bounded below by the Otorowiri Siltstone, and in the south is overlain by the Leederville Aquifer and the Kardinya Shale aquiclude. It contains low salinity groundwater, except in places along the eastern margin, especially along the chain of salt lakes along the Coonderoo River where groundwater discharge is inferred to take place. Groundwater recharge takes place directly from rainfall infiltrating the sandy soils. Groundwater flows south from a groundwater divide west of Coorow, and north of this discharge occurs to the Arrowsmith River and springs along the Dandaragan Scarp. The aquifer is used for town supply to Mingenew, Three Springs, Carnamah/Coorow, Dandaragan and Moora, for stock and domestic water on farms, and for irrigation (DoW 2016b).

The Jurassic Yarragadee Formation is the most important and widespread aquifer in the northern Perth Basin extending from the metropolitan area almost as far north as the Greenough River. It is up to 3000m thick, outcrops between the coastal plain and the Dandaragan Scarp (except in the Hill River area where older formations occur), and extends below the coastal plain and to the Darling and Urella faults in the east below the Otorowiri aquiclude. Groundwater is recharged by rainfall and local runoff where this aquifer outcrops. Groundwater flows north from a groundwater divide near the Hill River to eventually discharge offshore south of Dongara, and south to discharge to the ocean south of Ledge Point. Locally, north of the Irwin River, groundwater flow is south-westward towards the coast. Around Badgingarra and to the east of Eneabba, and on the Victoria Plateau north of the Irwin River, the water table is deep, as much as 150m below surface (DoW 2016b).

Low salinity groundwater extends to the base of the Yarragadee Aquifer, suggesting the meteoric flow reaches depths of at least 3000m in some areas. Groundwater in the upper part of the aquifer is generally fresh to marginal, but locally saline close to the Arrowsmith and Irwin Rivers. Groundwater from the Yarragadee Aquifer is used for town water supply to Geraldton, Eneabba and Badgingarra, by the mineral sand industry at Cooljarloo and Eneabba, and for stock and domestic supply, and irrigated agriculture (DoW 2016b).

The early Jurassic Cattamarra and Eneabba Formations and the underling Lesueur Sandstone outcrop at the surface in the Hill River area where they are intensely faulted. In the Hill River area, groundwater in the Lesueur and Eneabba is generally fresh, but the Cattamarra Aquifer contains mainly brackish to saline groundwater. In the Dandaragan Trough, below the Yarragadee Aquifer, electric logs from oil wells indicate high salinity, suggesting that the groundwater is stagnant, and less connected to a meteoric groundwater flow system. Groundwater from the Lesueur Aquifer is used for Jurien and Greenhead-Leeman town water supply, irrigation, and stock and domestic supply, though on farms south-west of Eneabba, groundwater in the Cattamarra Aquifer is brackish to saline (DoW 2016b).

The Triassic Kockatea Shale occurs directly below the 25m thick Superficial Aquifer at Jurien, and was reported to contain saline groundwater. East of the Beagle Fault, it is directly overlain by the fresh water bearing Lesueur Sandstone and Woodada Formation. Progressively eastwards, where the Yarragadee occurs at the surface, the Kockatea Shale underlies saline groundwater in the Cattamarra, Eneabba and Lesueur aquifers. The Permian Highcliff Sandstone and Irwin River Coal Measures reach the surface north of the Greenough River, where they are local sources of low salinity groundwater. To the south, in the Dandaragan Trough, where they are confined by the Kockatea Shale, groundwater is saline (DoW, 2016b).

Hydraulic connection between aquifers can be restricted across faults, but in some cases faults appear to be groundwater conduits. Low permeability clay/shale beds within the aquifer units can also restrict groundwater flow but the precise nature of flow restrictions is unknown at most localities. Low permeability units (aquitards) can restrict connectivity between the aquifers, with the main regional aquitards (the Kardinya Shale and South Perth Shale) hydraulically isolating parts of the unconfined Superficial and Mirrabooka Aquifers from the underlying confined Leederville and Leederville-Parmelia Aquifers. Groundwater in the Leederville-Parmelia Aquifer is regionally isolated from the deeper Yarragadee Aquifer by the intervening Otorowiri aquitard. The Carnac Formation in the lower part of the aquifer contains substantial clay. The Leederville Aquifer is separated from the underlying Yarragadee Aquifer by the South Perth Shale over most of its extent. The Kockatea Shale is a widespread aquitard separating the Eneabba–Lesueur Aquifer from deeper Permian aquifers, but is present at a great depth in the basin except over the Beagle Ridge, an area over the southern Yarra Yarra Terrace in the east, and along the northern margins of the basin (DoW 2016b).

Extensive faulting is present in those sediments which occur beneath the Gondwana break up unconformity, a major stratigraphic feature which represents the period when Gondwana started to break up as a function of rifting and sea floor spreading about 155-120 million years ago in the north west and south west parts of the Perth Basin respectively (Falvey and Mutter 1981). As previously noted, the status of these faults as conduits or barriers to groundwater flow is highly variable and has not been widely investigated. There has also been little assessment of how much continued movement on these faults has resulted in fault propagation into the Mesozoic sediments above the break up unconformity, as in the Canning Basin. The location of only major faults has been mapped, using regional scale geophysics. It is likely that significant numbers of other smaller fault systems, typically structurally related to major fault systems, will exist but will require more detailed local studies to map in any detail including their propagation above the Gondwana break up unconformity. In the Southern Perth Basin, a local scale investigation identified a large number of faults propagating to near the surface (Figure 18) (WA: ERA 2012). Leyland (2012) also noted the importance of faulting for structural control and groundwater flow in the Leederville Aquifer in the central Perth Basin.

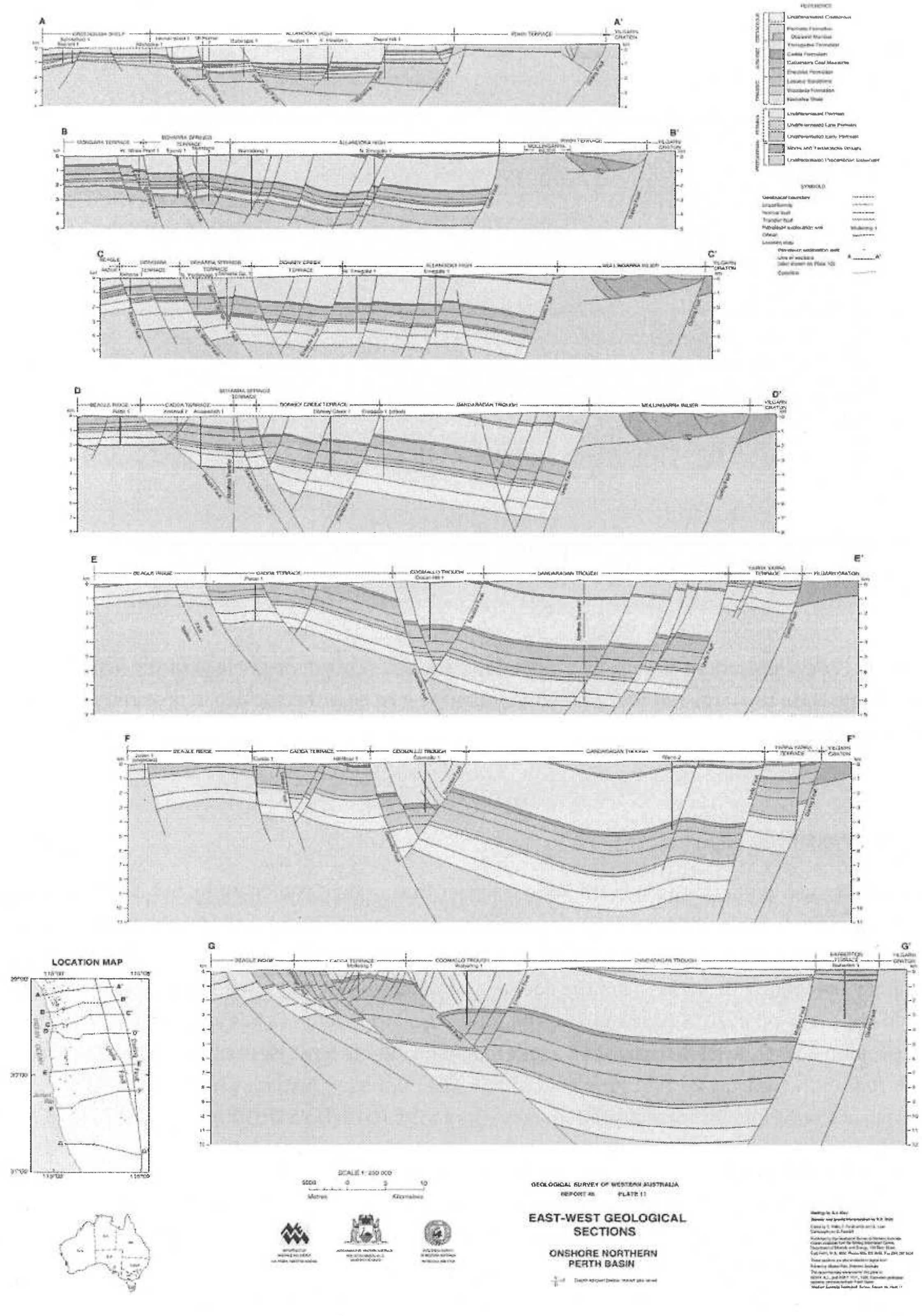

Figure 17 - Deep geology of the northern Perth Basin (Mory and Iasky 1996).

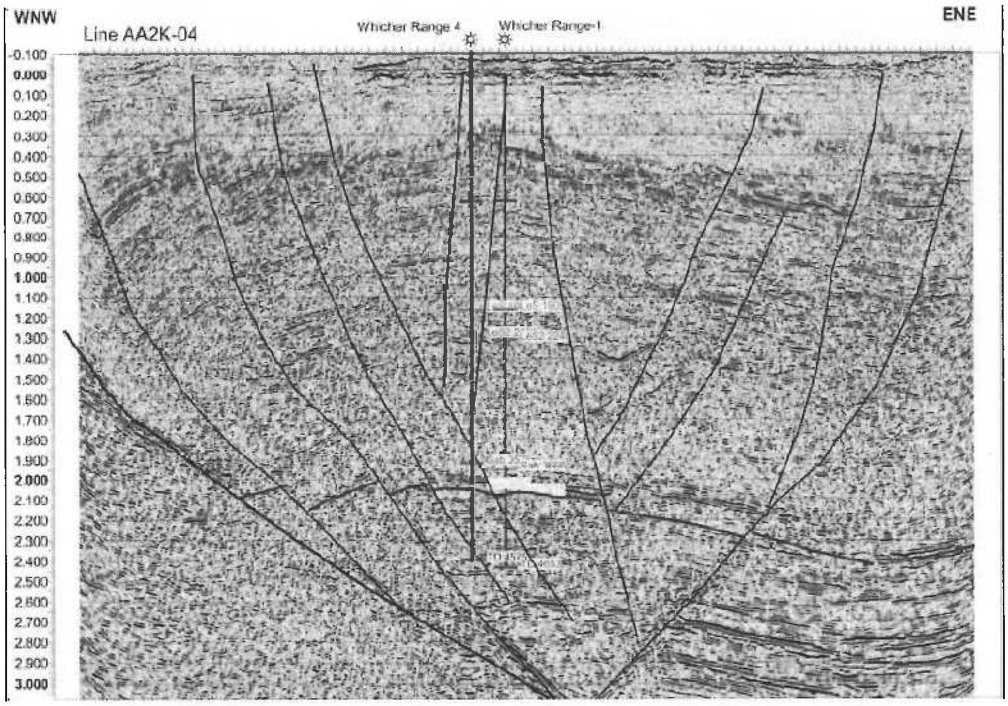

Figure 18 - WNW-ESE oriented seismic profile depicting the subsurface geology of the Whicher Range Field. Note the large number of faults propagating to near the surface in proximity to wells (WA: ERA, 2012).

Water Management

Groundwater use in the northern Perth Basin is higher than in the Canning Basin, but is still relatively low. The Gingin, Jurien and Arrowsmith Groundwater Areas are all being actively managed (DoW 2015; DoW 2010a; DoW 2010b). The Gingin Groundwater Area has the greatest level of use with an allocation limit of 187 GL across all of the aquifers, of which 140 GL was already licensed and 30 GL were being assessed in 2015 (DoW, 2015). The Jurien Groundwater Area has an allocation limit of 94.6 GL, with 64.4 GL available across all aquifer for allocation to new users as at 2010 (DoW 2010a). The Arrowsmith Area has an allocation limit of 184.9 GL, with approximately half of that (97.9 GL) available across all aquifer for allocation to new users as at 2010 (DoW 2010b).

Water that is abstracted from the aquifers of the area support a number of town water supplies, as well as agriculture and mining. Freshwater (defined as water less than 1000 mg/L total dissolved solids) occurs in the aquifers often to depths of over 1000m, presumably becoming more brackish and saline at greater depth however data is limited below 1000m (DoW 2015; DoW 2010a; DoW 2010b). Groundwater is also used by the environment with approximately 17 per cent of the landscape containing potential GDEs (Rutherford *et al.* 2005). Groundwater monitoring across all Groundwater Areas is modest and is mostly focussed on the shallower pats of the aquifers (DoW 2015; DoW 2010a; DoW 2010b) with very little quantitative understanding of the reliance of GDEs

on regional groundwater (Rutherford *et al.* 2005). The allocation plans (DoW 2015; DoW 2010a; DoW 2010b) primarily use a simple percentage of recharge method to determine the amount of water reserved to maintain the environment, but it is unknown how well this has worked as detailed studies of GDEs are not available. A number of the preliminary investigations in Rutherford *et al.* (2005) identified faults potentially discharging deep groundwater in proximity to GDEs.

Regulation

Currently the unconventional gas industry in Western Australia is under the same regulations as the conventional oil and gas industry with the Department of Mines and Petroleum (DMP) as the lead agency. Projects are assessed on a site by site and project by project basis, hence do not account for cumulative impacts. Other state agencies have various roles including conducting environmental impact assessments when tight gas activities may result in significant impacts. Native title holders are not required to approve or reject activities until the production phase. There is currently no requirement for post well abandonment monitoring (DMP 2015).

The legislation relevant to the onshore oil and gas industry in Western Australia, as well as the agencies responsible and their roles, are given in detail in DMP (2015). This is a complicated regulatory environment with multiple agencies having at times somewhat overlapping jurisdiction without clear boundaries, particularly in the water and environmental aspects. Given the report herein is focused on impacts to the environment and water resources, the relevant regulations for those aspects will now be briefly presented. Note that these are mostly State Government agencies except for the Commonwealth Department of Environment. Also note that with the exception of the Allocation Planning Process under the *Rights in Water and Irrigation (RiWI) Act 1914*, there is no capacity for these regulations to manage cumulative impacts of multiple projects/issues. All other regulations are typically focused on the impact of a single specific project/activity.

- Department of Mines and Petroleum (DMP) administers the following legislation in this context: *Petroleum and Geothermal Energy Resources Act 1967*; *Petroleum Pipelines Act 1969*; *Petroleum (Submerged Lands) Act 1982; Occupational Safety and Health Act 1984; Environmental Protection Act 1986* (delegated Authority for native vegetation clearing); *Dangerous Goods Safety Act 2004.* These acts cover safety regulation, environmental regulation, native vegetation clearing and resource management and administration.
- Department of Environment Regulation (DER) administers the following legislation in this context: *Environmental Protection Act 1986*; *Contaminated Sites Act 2003*; *Waste Avoidance and Resource Recovery Act 2007.* These acts cover regulating activities with potential impacts on the environment, developing and implementing policies and strategies that promote environmental outcomes and reducing the environmental impact of waste.
- Department of Parks and Wildlife (DPaW) administers the following legislation in this context: *Conservation and Land Management Act 1984*; *Wildlife Conservation Act 1950; Biodiversity Conservation Act 2016.* DPaW has primary responsibility for managing the State's national parks, marine parks, State forests and other reserves, which cover more than 27 million hectares, for conserving and protecting native animals and plants, and for managing many aspects of the access to and use of the State's wildlife and natural areas.
- Department of Water (DoW) administers the following legislation in this context: *Rights in Water and Irrigation Act 1914*; *Metropolitan Water Supply, Sewerage and Drainage Act 1909*; *Country Areas Water Supply Act 1947*; *Water Agencies (Powers) Act 1984*; *Waterways*

Conservation Act 1976. These acts cover licensing of systems to take water, and regulate public drinking water protection in both groundwater and surface water systems. DoW also provides expertise and advice, and prepares policies, plans and guidelines about protecting and managing water resources.

- Environmental Protection Authority (EPA) enforces the *Environmental Protection Act 1986* which covers: conducting environmental impact assessments; preparing statutory policies for environmental protection; preparing and publishing guidelines for managing environmental impacts; and providing strategic advice to the Minister for Environment.
- The Commonwealth Department of the Environment administers the *Environment Protection and Biodiversity Conservation Act 1999*.

Drilling Water Bores, Conventional/Unconventional Hydrocarbon and Mineral Exploration Wells

In Australia, anyone who drills a bore to access groundwater from confined aquifers for water supply for agriculture, irrigation, stock/domestic use and dewatering bores must be licensed, and the type of licence depends on the type of aquifer and drilling method used (Australian Drilling Industry Training Committee (ADITC) 2010). There are three classes of drilling licenses: Class 1 – restricted to drilling operations in single non-flowing aquifer systems such as water table aquifers; Class 2 – in addition to operating in Class 1 conditions, permits drilling operations in multiple on-flowing aquifer systems such as confined aquifers; and Class 3 – in addition to operating in Class 1 & 2 conditions, permits drilling operations in flowing aquifer systems such as artesian aquifers. In Western Australia, DoW, under the *RiWI Act 1914*, issues groundwater licences in all proclaimed groundwater areas and for all artesian water bores in the State. Water from sub-artesian bores can be taken without a licence in unproclaimed areas, so do not necessarily meet the minimum construction requirements. DoW sometimes includes the 'Minimum Construction Requirements for Water Bores in Australia' as a condition in the 26D permit to construct, but this does not make it legally enforceable. Drillers are required to 'perform all work' in confined aquifer under the 'Minimum Construction Requirements for Water Bores in Australia' (National Uniform Drillers Licensing Committee (NUDLC) 2012).

A driller who drills for exploration or production purposes in the oil, gas and mining industries does not have to be licensed by the same scheme as water production, but does need to be qualified. This qualification, the Australian Qualifications Framework (AQF) is a Federal framework which comprises a series of qualifications formally named "Certificate I, II, III and IV, Diploma and Advanced Diploma" (ADITC 2011). The unconventional gas industry is governed by the *Petroleum and Geothermal Energy Resources Acts 1967* which requires all petroleum exploration and production to be carried out in a proper and workmanlike manner and in accordance with 'good oilfield practice'.

'Good oilfield practice' is a long held industry concept that is stated as 'all those things that are generally accepted as good and safe in carrying out exploration or recovery operations' Manifold (2010). The obvious flexibility in this allows for innovation or optimisation during operations (Manifold 2010). However, this also allows different interpretations of regulations and standards, so the concept of 'good oilfield practice' and the subsequent application and engineering will vary from site to site and between operators. The concept of 'good oilfield practice' also appears to be focused on safety and minimising gas explosions and the extent to which 'good oilfield practice' protects the groundwater resources or environment is not well understood. Unconventional wells are also subjected to pressure much greater than are conventional wells or water supply wells, increasing the

risk of well integrity failure. The large number of exploration and production wells required for tight gas projects further amplifies this risk.

The Australian Drilling Industry Association (ADIA) recommends that all drillers should be certified/licensed and that this would help ensure aquifers are protected across the different industries (ADITC 2011), and this has occurred in other Australian jurisdictions such as New South Wales. With mining and oil/gas wells this lack of licensing, particularly with respect to well abandonment, has the potential to leave a legacy of inappropriately decommissioned wells. Wells that may meet 'good oilfield practice' may have a low risk of blow outs etc., but it is uncertain if their well design will provide sufficient safeguards in the context of groundwater and environmental protection. Based on water and environmental impacts observed in oil fields (conventional and unconventional) around the world (US EPA 2016), this appears to not be the case in many examples.

Water Allocation Planning Process

Of particular interest in the context of an issue like unconventional hydrocarbon projects, which as previously discussed have been shown overseas to have a risk of impacting water resources and the environment at both a local and regional scale, is the *Rights in Water and Irrigation (RIWI) Act 1914*. The *RIWI Act* was updated post the National Water Initiative (NWI) to provide guidance on Federal expectations in the context of the allocation planning process DoW (2011). The Western Australian allocation planning process is an important part of meeting the State Government's statutory responsibility to manage water. There are five clauses of the NWI that are specific to allocation planning. These are:

- Clause 36 – allocation decision making,
- Clause 37 – meeting ecological and resource security outcomes,
- Clause 38 – deciding when to plan,
- Clause 39 – the content of a plan as per Schedule E; and
- Clause 40 – implementing the plan.

It must be noted that, in general, the inclusion of these clauses by the NWI were not intended to be particularly prescriptive, therefore requiring state and territory governments to determine the timing and rigor of their own impact assessment used in allocation planning.

The Western Australian DoW administers surface and groundwater allocation by issuing licences under clauses 5C and 26D of the *RIWI Act*. Water allocation plans themselves, however, are not statutory documents but are the Department's statement of how they will support licence assessment, and how much water has (and can) be allocated in a proclaimed Groundwater Area (DoW 2011).

DoW (2011) expanded on the purpose and process by which this is undertaken.

The purpose is to:

- maximise the amount of water available to allocate,
- maintain the integrity of the resource and the environment; and
- establish the required licence conditions for a local area, to protect other water users and the environment.

Their process is further clarified to:

- apply a transparent and consistent process to develop water allocation plans,
- seek advice from stakeholders throughout the planning process,
- put the necessary effort and funding into an area, depending on the current level of allocation and the risk to the resource and its users,
- use the best-available information; and
- provide for ongoing plan review and, if required, adapt our management to meet plan objectives.

The allocation planning process is an iterative one in that the required level of understanding of a water resource (including impacts on the environment) increases as the level of use or threat to the environment increases.

Knowledge and Impact Assessment Needs

The allocation planning process assesses risk to the environment and the water resource use sustainability in order to determine allocation limits. However, different levels of scientific rigor are applied depending on the amount of use as a proportion of the allocation limit. The Category/Response Model is used to assess the required level of management response (assessment) (R1-R4) as function of level of use (C1-C4), as shown in Table 3. Table 4 further summarises the level of investigation required as a Management Response (DoW 2011) and is shown conceptually in Figure 19.

The level of uncertainty during the early parts (C1-R1) of this iterative allocation planning process is high (Figure 19). Consequentially there is considerable uncertainty over the allocation limit, and no plan is produced, only an allocation limit. The level of uncertainty then becomes reduced as the level of scientific rigor is increased. For other areas (C2–C4 and R2-R4), DoW produces two types of water allocation plans (DoW 2011):

(1) Standard plans, which are developed for medium-demand areas (C2); these require a low level of planning investment. C2 plans are based on the use of existing information, applying simple, local management rules, and existing State-wide policies.

(2) Intensive plans are developed where demand is high (C3 and C4), during which new studies are commissioned to reduce uncertainty in the allocation limit. These will include water resource and ecohydrological modelling and broad stakeholder consultation. An important part of C3 level planning is to establish environmental water regimes or environmental water requirements (EWRs). Over one-half of the proclaimed water areas in the State are at, or approaching, full allocation (C3) (DoW 2011).

Although this process is considered to be generally sound, the level of scientific investigation and subsequent rigor in the allocation limit can create issues in areas where there are rapid changes in water demand/licences. Figure 19 shows a problematic (A) and ideal (B) water use versus allocation limit trajectory. Under trajectory A, the level of allocation rises rapidly during the initial period where the links between cause and effect are poorly understood. This has the potential to jeopardise the sustainability of the resource, risking loss of human value associated with impacts to dependent biota and water. Under this trajectory there may be a need for an urgent correction accompanied by

environmental, social and economic consequences. Trajectory B is the desired course where the level of use stays within not only the allocation limit but the uncertainty of it at every level of management response. There will always be some level of uncertainty and risk but this process is about minimising this risk and making the process as transparent as possible.

Table 3 - Category/response water allocation planning model (DoW 2011).

Category (C)				Response (R)						
Licensed % of allocation limit		Impact from further licences	Risk to in-situ values	Licences required	Plan type	Maximum availability from resource	New information developed for plan	Allocation limits protect in-situ values	Specific rules protect values	Specific regimes protect values
C1	Low 0 < 30	Low	Low	R1 ✓	x	x	x	✓	x	x
C2	Medium 30 < 70	Med	Med	R2 ✓	Standard	x	x	✓	x	x
C3	High 70 < 100	High	High	R3 ✓	Intensive	✓	✓	✓	✓	✓
C4	Over >100	V high	V high	R4 ✓	Intensive	✓	✓	✓	✓	✓

Table 4 - Work required in allocation plan development (DoW 2011).

		Resource assessment		Values			
Response	Aim	Surface water	Groundwater	Ecological	Economic	Social	Cultural
R1 Limits only no plan	Basic approach to avoid potential impact	Flow estimate from gauge data or regional model	Basic rainfall recharge, throughflow or discharge estimate	Existing info Regional mapping	Existing use info Licence analysis	Existing info	Existing info Important sites
R2 Standard plan	Standard approach to avoid impacts and prepare for C3	Flow estimate from gauge data or regional model	Detailed recharge, throughflow or discharge or regional model	Existing info Important sites Risk areas	Existing use info Licence analysis	Existing info	Existing info Important sites
R3 Intensive plan	Detailed approach to maintain C3 status and begin impact management	Flow estimate from gauge data or calibrated, localised model	Regional model and/or local models	Environmental water requirements Buffer zones Scenarios Risk maps	Use analysis Current and future use trends	Sites Flow/level requirements Risk maps	Sites Flow\level requirements Risk maps
R4 Intensive plan	Detailed approach to return resource to C3	Flow estimate from gauge data or calibrated, localised model	Regional model and/or local models	Environmental water requirements Buffer zones Scenarios Remediation measures	Impact/ cost analysis for recoup	Sites Flow/level requirements Remediation measures	Sites Flow/level requirements Remediation measures

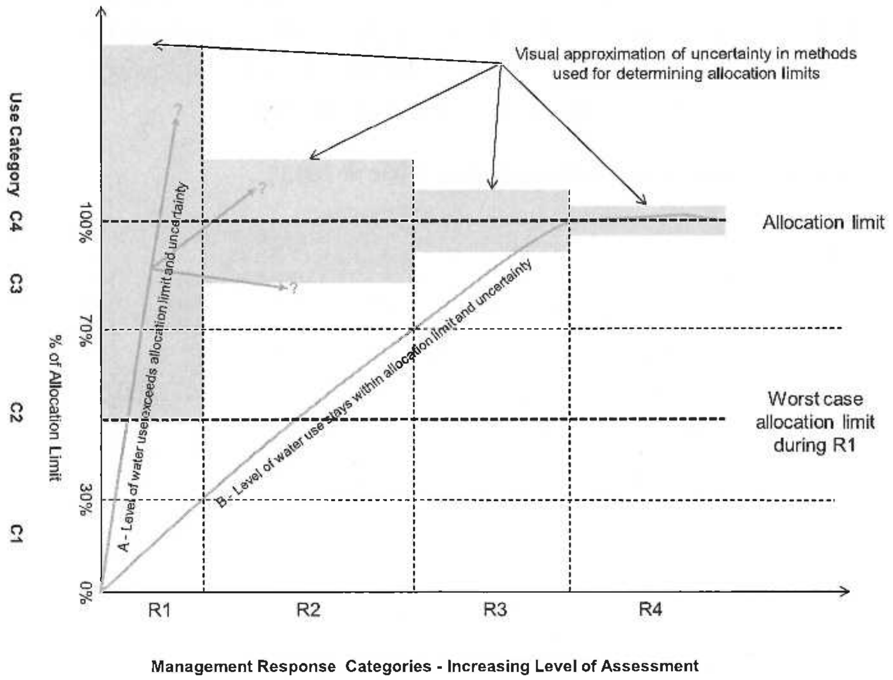

Figure 19 – Visual interpretation of the category/response water allocation planning model including approximate uncertainty at each stage of Management Response.

Undertaking the Resource Assessment in the allocation planning process requires application of a number of scientific techniques of increasing complexity (Tables 3 and 4). Basic desktop style evaluations at low levels of resource evaluation give way to detailed flow gauging, assessments of surface water/groundwater interaction, numerical modelling, ecohydrological assessment and precise determination of groundwater dependence of ecosystems, including EWR's. The methodology for determining the level of assessment required is given in DoW (2009b). H3 (highest level) assessments are resource intensive and challenging projects that require long-term data sets but in brief require detailed hydrogeological assessment including installation and testing of investigation bores and modelling. A detailed explanation of the requirements of a H1-H3 level of investigation is given in Appendices A1-A3 in DoW (2009b). In brief, H3 level activities require surface water groundwater interaction and regional scale numerical modelling, including an understanding of GDE environmental water requirements.

Estimate of the Amount of Water Required

An important context for the water resource and environmental impact of tight gas is the amount of water required and the amount of effluent disposal required. Cook *et al.* (2013) stated that "Because shale gas production in Australia is in its infancy, the average volume of water needed to hydraulically fracture Australian shales is not yet known". It is a difficult question to answer as it depends on required water quality, the size of the gas field in terms of recoverable gas, amount of gas produced per well, lifetime of project wells, amount of reused water from previous wells amongst many other factors which are not available in the public domain. However, to put together an estimate of the water required for the northern Perth and Canning basins a simple indicative analysis has been completed.

To produce this analysis of the order of magnitude of water required a number of assumptions be made. O'Sullivan and Paltsev (2012) presented data of ultimate recovery of gas (or UR) per well in Pennsylvania as 100 x 10^6 or 10^8 m^3/day for a 30 year well with the variability from 50 to 150 x 10^6 m^3/day. One thousand cubic feet (1 Mcf) = 28.26 m^3 so 1m^3 = 0.03538 Mcf, therefore UR per well is 10^8 x 0.03538 = 3.538 x 10^6 in Mcf. One trillion cubic feet (Tcf) = 1 x 10^9 Mcf, so the number of wells per Tcf is 1 x 10^9 divided by 3.538 x 10^6 = 282.6 wells per Tcf for the 100 x 10^6 UR case. Fifty x 10^6 gives 565.3 wells per Tcf and 150 x 10^6 gives 188.4 wells per Tcf.

Each well needs 0.04 GL (40 million litres) over the life of the well (DMP 2015), so 1 Tcf requires 282.6 x 0.04 = 11.3 GL over the life of the project. If we assume well life of 30 years (to match with O'Sullivan and Paltsev (2012)), 1 Tcf requires 11.3/30 = 0.3769 GL/year. This number is 0.7537 for the 50 x 10^6 m^3/day UR case and 0.2512 for the 150 x 10^6 m^3/day UR case. In terms of waste requiring disposal, we can assume 30 per cent return of hydraulic fracturing fluids to the surface (Engelder *et al.* 2014). Table 5 shows the water required in GL/year under the lower (150 x 10^6 m^3/day UR), middle (100 x 10^6 m^3/day UR) and upper (50 x 10^6 m^3/day UR) scenarios.

The estimates of water required under even this simple analysis (Table 5) are variable but are also significant quantities of water which would significantly increase groundwater use in the northern Perth Basin and a more significant increase of groundwater use in the Canning Basin. Neither does this estimate include water required for work camp potable requirements, treatment facilities, pipeline construction, civil construction, dust suppression etc., so should be seen as a very low estimate, in the context of the full range of anthropogenic activities required for an unconventional gas project. Based on the figures from Cook *et al.* (2013) and DMP (2015), the total gas resource estimates are for the Goldwyer Formation only in the Canning Basin and the Carynginia Shale and Kockatea Formation in the northern Perth Basin. However, many other prospective tight gas reservoirs exist in these basins (Triche 2012). Once the tight gas industry has started in these areas (including constructing large amounts of infrastructure) it is likely that other sources will be developed so more water for hydraulic stimulation will be required and more waste will require disposal.

Table 5 - Estimate of water required.

Lower	Gas Resource Estimate (Tcf)			Water per year (GL)			Waste per year (GL)		
Basin	**Low[1]**	**High[1]**	**Highest [2,3]**	**Low**	**High**	**Highest**	**Low**	**High**	**Highest**
Northern Perth	29	46	59	7.28	11.56	14.82	2.19	3.47	4.45
Canning	73	147	229	18.34	36.93	57.52	5.50	11.08	17.26
Middle	**Gas Resource Estimate**			**Water per year (GL)**			**Waste per year (GL)**		
Basin	**Low[1]**	**High[1]**	**Highest [2,3]**	**Low**	**High**	**Highest**	**Low**	**High**	**Highest**
Northern Perth	29	46	59	10.93	17.34	22.24	3.28	5.20	6.67
Canning	73	147	229	27.51	55.40	86.31	8.25	16.62	25.89
Upper	**Gas Resource Estimate**			**Water per year (GL)**			**Waste per year (GL)**		
Basin	**Low[1]**	**High[1]**	**Highest [2,3]**	**Low**	**High**	**Highest**	**Low**	**High**	**Highest**
Northern Perth	29	46	59	21.86	34.67	44.47	6.56	10.40	13.34
Canning	73	147	229	55.02	110.79	172.60	16.51	33.24	51.78

Note that 1, 2 and 3 refer to references for gas resource estimate. 1 is (DMP 2015), 2 is (Cook *et al.* 2013) and 3 is (Triche 2012).

Individual Site Impact Assessment

This section highlights issues with the level of publically available hydrogeological impact assessment at sites in Western Australia that have been hydraulically stimulated. In general it appears as though sites did not undergo detailed impact assessment as they were assumed to be at low to no risk of impact. Originally it was intended to work on a site in the northern Perth Basin or Canning Basin, however the data publically available on the DMP's Petroleum and Geothermal Information System (WAPIS) contains nothing which can be effectively assessed as to its rigor from a hydrogeological impact assessment perspective. The DMP's Environmental Assessment and Regulatory System (EARS) can only be accessed by a registered company, and will only display applications lodged by that company (http://www.dmp.wa.gov.au/Environmental-Assessment-and-1471.aspx). Environmental impact assessments should be publically available. Given the larger amount of material publically available for the Whicher Range site in the Southern Perth Basin, it was chosen for assessment.

In Calenergyu Resources Australia (2013), a Whicher project Environment Plan Summary, the only mention of risk to aquifers come in their hydrogeology section which stated: "The Yaragadee is a mostly confined regional aquifer. In EP408 (one of the unconventional gas wells) the Yaragadee Aquifer was intersected from 186m to 932m, and was subsequently isolated behind 3 permanently cemented barriers." There is no reference to risk to any aquifers (potable or not) in their Table 6.2, Risk Identification and Assessment.

During drilling of Whicher 5 (the well which was hydraulically stimulated), substantial amounts of free water entered the hole at approximately 3900m, in Sue Group sediments - the target for hydraulic stimulation. This water came from a groundwater bearing "open fracture", which presumably is a fault, and the water was strongly red coloured, believed due to the presence of iron oxide (Amity Oil 2004). The oil and gas industry has often suggested that faults/fractures at this depth should not allow water flow due to pressure from the overlying sediments and water. Deep faults in the Perth Basin typically propagate to at least the top of the pre-break up unconformity sediments, potentially higher. The Yarragadee Formation is a pre-breakup unconformity unit.

Geophysical seismic data in the main tool used by the oil and gas industry to map faults in the subsurface. Interpretations of these data in 2004 did not include any reference to this permeable fault encountered during drilling, nor did faults mapped typically propagate from the Sue Group up to close to the surface (Figure 20). A 2012 reinterpretation of faulting over a very similar cross section is shown in Figure 21. In particular, note the much greater vertical extent and continuity of faults mapped in 2012, with faults now intersecting the target zone for hydraulic stimulation. This potentially connects the target zones for hydraulic stimulation to shallow freshwater aquifers such as the Yarragadee and Leederville.

In efforts to produce gas from this well, diesel was used as a hydraulic stimulation fluid as water was not considered suitable (WA: ERA 2012). The total diesel injected during the hydraulic stimulation experiment was 7450 bbl (1184550 litres assuming 1 bbl = 159 litres), from which a total of 3546 bbl (563814 litres) were recovered after 36 days of production (Department of Industry and Resources (DIR), 2008). This leaves 620736 litres of diesel in the ground. No pre-hydraulic stimulation monitoring is stated to have been put in place in any of the aquifers, hence no monitoring was completed during stimulation and no post well abandonment monitoring has been completed. The

Whicher Range occurs in proximity to the Margaret River (Ten Mile Brook Dam) Priority 1 (highest level of protection) Drinking Water Protection Area. It is currently unknown what has happened to this more than 600,000 litres of diesel and, given the issues raised in this document, the author suggests a follow up study.

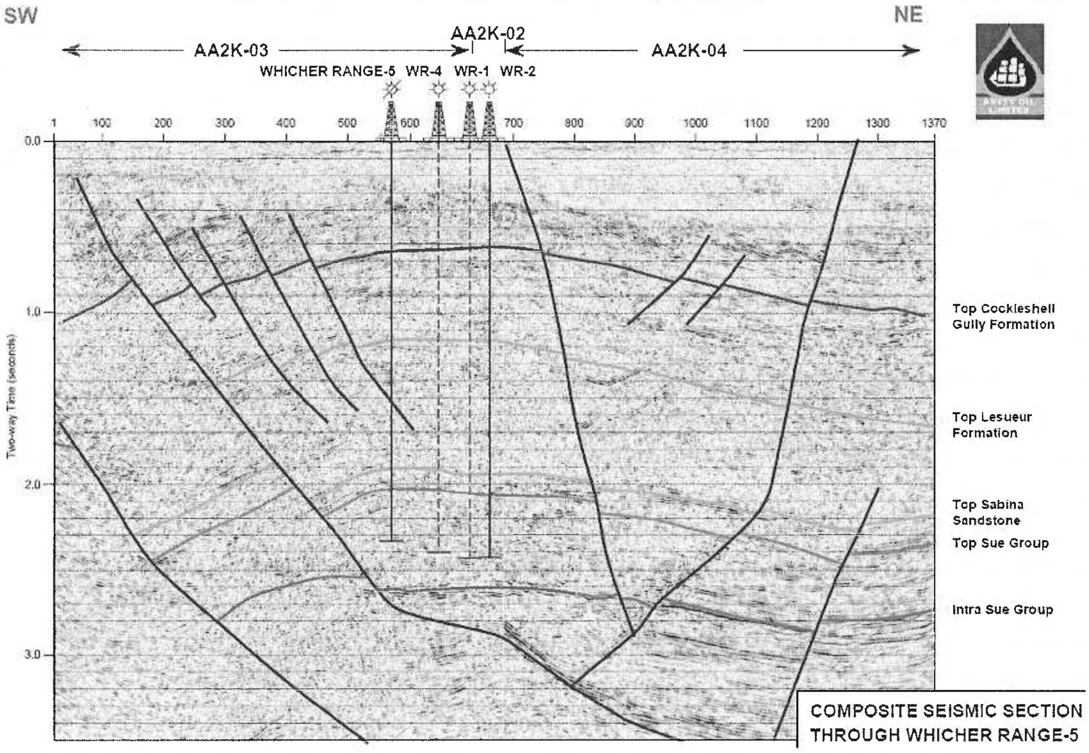

Figure 20 - Whicher Range composite seismic section, circa 2004 (Amity Oil 2004).

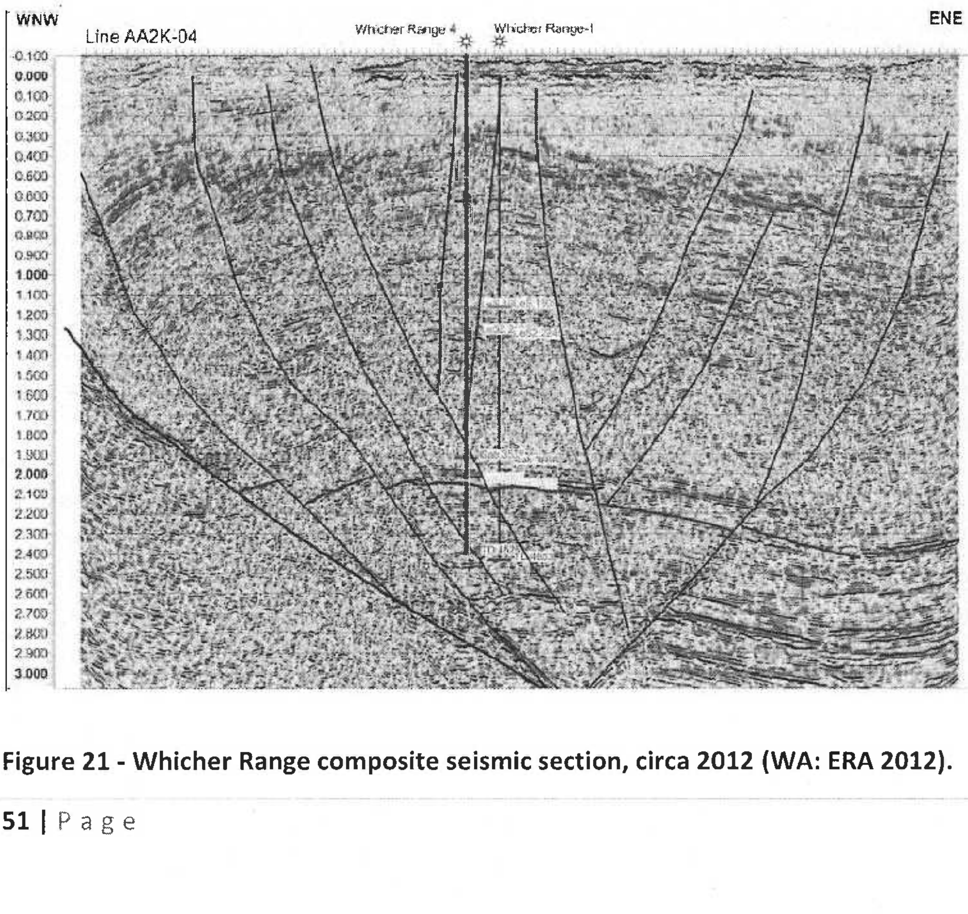

Figure 21 - Whicher Range composite seismic section, circa 2012 (WA: ERA 2012).

Discussion

Cook *et al.* (2013) stated in the Australian context that "Shale gas production is no different from any other development of the landscape and like most other land uses, it poses some risks to the condition of the water, soil, vegetation and biodiversity, and has the potential to impact on the capacity of natural resources to supply human, as well as ecological needs into the future." The current review reinforces that premise.

There is uncertainty about the magnitude of environmental impacts from the tight gas industry. While comprehensive studies are few and far between, this should not be interpreted as tight gas extraction having no potential for impacts. It should be interpreted as the tight gas industry not applying enough resources to its assessment of risk to groundwater and the environment. If there is no significant impact potential, this should be provable. Based on the primarily peer reviewed scientific literature assessed as part of this report, exploration alone has capacity to impact groundwater resources and the environment (albeit on a local scale) near sites that are hydraulically stimulated. Note that this includes areas hydraulically connected to hydraulic stimulation sites through fault and other potential conduits. The development of a full production scale tight gas industry in Western Australia has the potential for regional scale impacts, as have been seen in other jurisdictions.

The conventional oil and gas industry has caused impacts, but these are not well documented. In 1992, 200,000 of the 1.2 million abandoned oil and gas wells in the United States were leaking (Davies *et al.* 2014). No Australian comparable study exists to the best of the author's knowledge; however, there are some local examples of well failure. Hovea 8, a well in the northern Perth Basin, was shut in 2011 due to casing corrosion during production, only eight years into its operational life (http://www.originenergy.com.au/files/Quarterly_Report_30_June_2011.pdf). In the Robe River oilfield of the Carnarvon Basin during the 1980's, some old wells were bleeding gas and saline water (Phil Commander pers. comm. 8/02/2017) but no specific study or data are available. It is assumed that all of these wells followed 'good oilfield practice'.

Given that conventional oil and gas wells are not exposed to the same level of repeated structural stress as unconventional wells, it would follow that unconventional wells would fail at least as much as conventional wells. The much higher number of wells required for tight gas projects further amplifies this risk. Cook *et al.* (2013) identified well integrity and abandonment as issues where the current regulations are not sufficient to mitigate the risk to water resources and the environment to an acceptable level in the context of the unconventional gas industry. This is complicated due to the well density and duration of production inherent in these projects.

In terms of geological understanding, there are significant gaps in how well we understand the geology (particularly the structural geology) of the northern Perth and Canning Basins. In particular, our understanding of the Canning Basin is in its infancy with regional scale studies unable to map the geology below formation level to determine the distribution of lithologies within these formations (Parra-Garcia *et al.* 2014). The distribution of mapped faults across the Canning Basin in Parra-Garcia *et al.* (2014) is likely to be a significant under-estimate of the faults present, as when more local scale studies are available, like Dentith *et al.* (2014), Leyland (2012) and WA:ERA (2012), the number of mapped faults is very likely to increase.

Given our understanding of the hydrogeology is inherently based on our geological understanding, it follows that there are even more significant gaps in terms of how well we understand the hydrogeology of these prospective areas. This is particularly true in the context of the distribution of faults and fractures both through natural and potentially induced/reactivated features. Their status as conduits or barriers to groundwater flow will likely require some aquifer testing in proximity to faults to determine their hydraulic barrier or conduit effects. Selley (1992) noted there are natural, high permeability geological pathways for the migration of buoyant fluids, which are typically associated with structural features such as faults and folds. Gassiat *et al.* (2013) concluded that diffuse contamination with hydraulic stimulation fluids over long timeframes is possible and that the important implications are that hydraulic fracturing should not be carried out near potentially conductive faults, and impacts should be monitored for long timespans. Cook *et al.* (2013) further commented that there is a high degree of uncertainty about groundwater impacts due to a lack detailed understanding of deep stratigraphy, faults and discontinuities, stress distribution and deep hydrogeological processes generally, and that a medium to high risk of aquifer impacts exists and that sensitive areas (such as National Parks and other conservation estates) should not be hydraulically fractured.

Our level of understanding of groundwater dependent ecosystems is even more limited. Many relevant areas have not been assessed or assessed at only a reconnaissance level. There is limited understanding of the implication of altered water regimes to these ecosystems, let alone linking them to Aboriginal and other cultural values, which are also not well documented in these areas.

The following data (Table 6) have been compiled to provide perspective on the depth of target formations versus the depth of fresh groundwater. The depth to fresh groundwater (defined as less than 1000 mg/L) comes from figures in DoW (2016b) and Commander (1981) for the northern Perth Basin, and from Ghassemi *et al.* (1990) for the Canning Basin. There may be fresh groundwater below this depth level in both Basins but hydrogeological investigations of deep aquifers are limited. This is due to the current modest level of use in these areas which means that generally the shallowest of sources have been utilised. When comparing these numbers to Table 1, there are United States tight gas projects with similar separation between target formations and fresh groundwater to those being proposed in Western Australia.

Table 6 - Depth of target formations versus the depth of fresh groundwater.

Basin	**Northern Perth**	**Northern Perth**	**Canning**
Target Formation	**Caryngina Shale**	**Kockatea Fm**	**Goldwyer**
Depth Range (Cook *et al.* 2013) in m	1220 – 5032	1007 – 5032	1007 – 5032
Depth Average (Cook *et al.* 2013) in m	3,264	3,050	3,660
Depth to base of fresh known groundwater (approx in m)	1000	1000-3000	1500
Distance between production zone and groundwater (range in m)	220 – 4032	7 – 4032	0 - 4032
Distance between production zone and groundwater (avg. in m)	2,264	2,050	2,160
Aquifer	Yarragadee	Yaragadee	Grant-Poole

In terms of current level of water use versus water required for hydraulic stimulation of the tight gas resource currently identified, this report's estimates of the water required suggests an

unconventional gas industry will require a significant increase in water use in the northern Perth Basin and a dramatic increase in the Canning Basin. There are also risks of surface and subsurface contamination over broad areas as a result of the full range of activities involved in a production scale tight gas industry.

The current level of water allocation planning in the northern Perth Basin is low, at R1 to R2 level of management. Three Groundwater Areas have been proclaimed with interim allocation limits determined based on simple percentage of recharge methodology. The Canning Basin is essentially unmanaged with the exception of the proclaimed groundwater areas that are at R1 to R2 level of management, but lower than the northern Perth Basin. In the context of increased groundwater use, these areas will be pushed towards requiring an R3 level of management, let alone in the context of tight gas exploration and production which has potential for water quality contamination. An R3 level of management is commensurate with H3 level of investigation. An H3 level of investigation is a resource intensive and challenging project that requires long-term data sets and detailed hydrogeological assessment including installation and testing of investigation bores and modelling. In the context of this report, surface water-groundwater interaction and regional scale numerical modelling would be required, including an understanding of GDE environmental water requirements and their links to cultural values. A detailed explanation of the requirements of a H1-H3 level of investigation are given in Appendices A1-A3 in DoW (2009b) but some important aspects of these investigations will now be discussed in the context of the current level of understanding.

Surface water groundwater interaction in the northern Perth and Canning basins is an important knowledge gap that should be filled before water allocation/management can increase to an R3 level of use. As detailed in previous sections, the northern Perth Basin has a reconnaissance level investigation identifying GDEs while extensive areas of the Canning Basin remain unassessed. The water management issues surrounding surface and groundwater interaction were first comprehensively summarised by Winter *et al.* (1998). In this discussion paper (a United States Geological Survey circular), the impact of surface and groundwater use on surface water groundwater interaction in the United States was summarised, including water quality impacts from land use and impacts to the environment.

There have also been major issues in wider Australia, particularly in the Murray-Darling Basin, relating to the over allocation of groundwater and surface water separately without adequate identification of their interaction. During the last five to ten years there has been a considerable effort in the Murray-Darling Basin to protect the water resource and environment, at a substantial cost to the Australian tax payer (Murray-Darling Basin Authority (MDBA) 2010). This has primarily come in the form of recouping water entitlements from irrigators of the Murray-Darling Basin, with a cost of $1.5 billion from 2008-09 to 2010-11 alone (Connell and Grafton 2011). Numerical modelling, including surface water groundwater interaction, is an important part of being able to responsibly allocate water resources. Once correctly parameterised and calibrated, numerical models are the best tools we have to assess future impacts of water use, but this analysis should include uncertainty.

Surface water and groundwater modelling are widely accepted techniques for assessing hydrological impacts, and the best practice guideline for the application of groundwater modelling in Australia is Barnett *et al.* (2012). Although these are not formal guidelines or standards, they are a point of

reference for what is considered to be good practice in this field. Groundwater modelling is frequently applied to assess the impact of regional scale groundwater development and changes in surface water – groundwater interaction, including subsequent impacts to dependent ecosystems.

Although it is outside the scope of this report to summarise the contents of Barnett *et al.* (2012), their statements on two particularly pertinent issues are highlighted. The first one is the length of data available for calibration versus the length of model predictions. "Transient water resource management models will be run for the duration of the planning period. Where long-term sustainability is a management objective, the model should be run over a longer time frame than the immediate planning period, limiting the duration of predictive model runs to less than five times the duration of the calibration is recommended wherever possible" (Barnett *et al.* 2012). It is important to note at this point that the duration of proposed tight gas projects is longer than any of the current planning horizons in any of the allocation plans for the relevant areas.

No comprehensive data set exists that covers surface water - groundwater interaction within the context of the associated ecohydrology and the impacts on the system's biota and other culturally significant assets. Hence, it is difficult to see how a robust allocation limit can be determined across all relevant areas at even at R2, let alone an R3 level of management response in the next several years. Effectively, Barnett *et al.* (2012) advised that to make 50+ year predictions requires at least 10 years' worth of detailed data to for calibrating detailed models. Given that the Western Australian Government is collecting new information in these areas, there is a suggestion that the Department of Water considers the current investigations are working towards an H3 level of investigation.

The second issue to be discussed from Barnett *et al.* (2012) is the use of coupled surface water - groundwater flow models. "Guiding Principle 11.6: A modelling approach based on linking or coupling surface water models to groundwater flow models should be used when surface water dynamics are significantly affected by exchange flows" (Barnett *et al.* 2012). This suggests that a high level of impact assessment, R3 (or H3 in the context of an individual project) including coupled surface water groundwater interaction modelling, is required if the potential of impacts exists with increased allocation and potential contamination both on resource sustainability and dependent ecosystems.

Groundwater and surface water dependent ecosystems of high conservation value have the potential to be impacted by the proposed tight gas industry. There are considerable gaps in our understanding of the distribution of biota and other culturally important assets, let alone their vulnerability to impacts due to altered hydrological regimes. Richardson *et al.* (2011) described the process of assessing impacts, including determining Environmental Water Requirements (EWRs), the intrinsic water quantity and the quality needs of individual biodiversity assets. It also described the transition from EWRs to Environmental Water Provisions (EWPs), which are a water quantity and quality regime that will protect a subset of the dependent biodiversity assets. EWPs are determined through an extensive stakeholder consultation covering Aboriginal cultural heritage and western values including trade-offs between social and economic implications of resource use, an important part of the allocation planning process. This requires long-term ecohydrological data sets, robust EWRs and deterministic tools based on distributed models or expert opinion to document and predict the cause and effect. Recent work by Warfe *et al.* (2013) highlighted the linkages between a system's biota, social values and flow regime. The current low level of EWR data in the public

domain suggests it will be difficult to determine broad EWPs with any level of scientific rigor as trade-offs between economic, social and environmental values are not clear.

In a regulatory context, DMP (2015) stated that water licenses required for water supply to support hydraulic stimulation **may** be required to adhere to the guidelines for impact assessment from Operational Policy 5.12, "Hydrogeological reporting associated with a groundwater well licence" (DoW 2009b). It would seem prudent that all water supply approvals **do** follow that guideline and the approval process for an individual well to be hydraulically stimulated should include the same level of rigor, not just its water supply. There should also be detailed monitoring of groundwater heads and chemistry at multiple depths near hydraulically stimulated wells pre, during and post tight gas well installation, hydraulic stimulation and production, to ensure well integrity is maintained. It is counter-intuitive that a driller for a water well requires a higher level of licensing than a tight gas well, which is much deeper and often will intersect multiple aquifers across a greater range in depths than water well drilling. It is also difficult to see how the current Western Australian regulatory environment can cope with cumulative impacts of the tight gas industry. There are also issues in terms of a lack of suitable monitoring network across groundwater, surface water and environmental systems to pick up impacts let alone understanding the links and risks to social values which can only happen at R3 level of management.

Cumulative impacts of poorly understood anthropogenic activities have been an issue in many other contexts in Western Australia. Secondary salinity in the Wheatbelt, as a result of land clearing and agriculture, is a suitable example of broadly distributed water resource and environmental impacts caused by an anthropogenic activity. Land clearing had unpredicted consequences and is very difficult and expensive to remediate. Each act of land clearing likely only has a small impact, but combined they have caused some of the worst water resource and environmental impacts in the State. The environmental consequences of the hydrological impact of secondary salinity have been magnified by the other issues inherent in land clearing specifically: habitat fragmentation and linear infrastructure (road and pipeline construction); hydrological impacts from this linear infrastructure (water excesses or deficits) due to natural surface water (sheet flow) impairment; increased road kill or traffic accidents from an increased road network and increased traffic; spread of dieback and other pathogens; and spread of feral animals. This will also likely be the case with a tight gas industry.

Cumulative impacts in the east Pilbara's Weeli Wolli Creek Catchment due to surface water diversion, groundwater dewatering and water disposal are another suitable example of anthropogenic activity which has created unforseen impacts. The substantial number of mines, operated by various mining companies, creates a regulatory situation in which individual mine approvals went ahead, but the lack of incorporation of cumulative impacts during the individual project approval process is making post mortem regulation of this situation difficult. Management of the groundwater related impacts on Gnangara Mound is another Western Australian regulatory situation which has taken 20 or more years to achieve a high level of rigor. This is an area where an initially insufficient understanding of cause and effect in terms of land and water use versus environmental impacts has required a substantial and expensive effort to manage.

The difficulties we collectively have in terms of understanding the risks of the tight gas industry as expressed herein are considerable. There is a modest current level of understanding, but there is risk

of impacts, a medium to high risk according to Cook *et al.* (2013). This is also the case in other jurisdictions in Australia and globally. This has led some of these other jurisdictions (Figure 22) to declare a moratorium on tight gas activities (including exploration) while additional data is collected and subsequent assessment is completed.

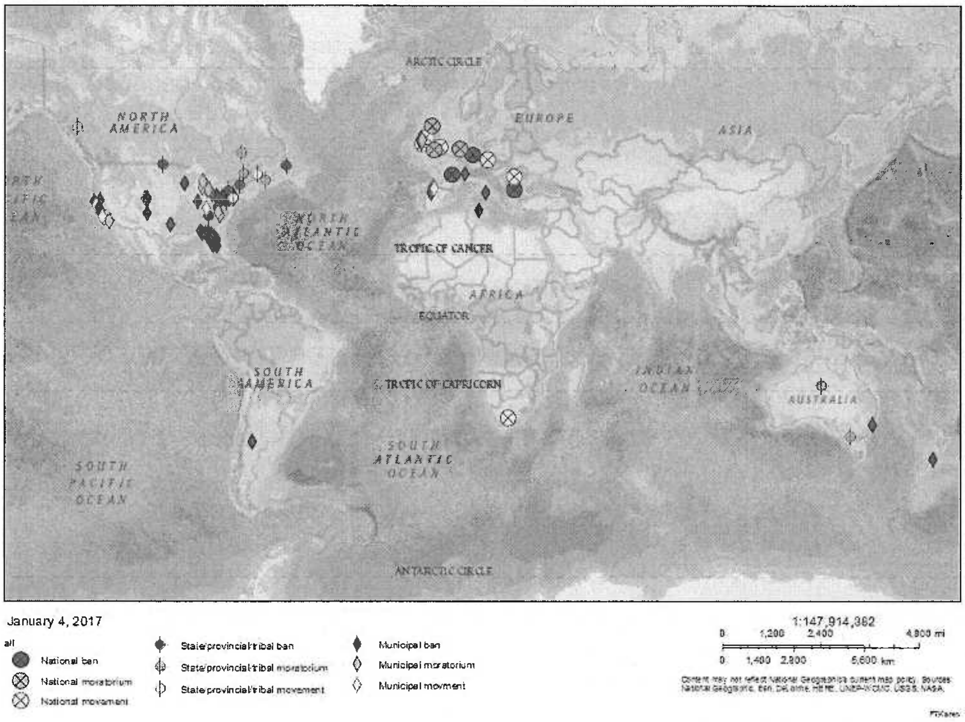

Figure 22 - Map of jurisdictions where hydraulic fracturing is currently banned (FracTracker Alliance 2017).

There is potential for economic benefit to Western Australia from tight gas, however, it is not currently possible to comprehensively understand if the risks outweigh the benefits, or vice versa. To robustly and defensibly understand the risk of impact of a fully developed tight gas industry in Western Australia could also increase our understanding of the potential economic and other benefits. It would require large numbers of scientists across multiple fields in government, academia and industry working for long time frames to collect the data required across the geology, hydrogeology, biodiversity and social values of these areas so environmental impacts of the proposed activities can be balanced across social, environmental and economic values as is required in much of the relevant legislation. Not only would this provide a rigorous and defensible impact assessment in the context of tight gas, it would help with many other areas such as water resource and environmental management generally including the risk posed by existing activities such as dryland and irrigated agriculture, pastoral activity, mining and existing oil and gas projects etc. It would also help us adapt our water resources to climate variability.

Cook *et al.* (2013) suggested tight gas impacts would be worse here than in the United States. Data being collected by unconventional hydrocarbon companies could also be analysed in more detail in this context. For example, thermogenetic gas is measured during well drilling and water quality

(salinity) estimates are possible from down hole geophysical logs, but these are rarely analysed or reported in this context (Fiona Mullen pers. comm. 07/02/2017).

Although it is outside the scope of this report to provide precise detail on what would be required, this would be an expensive and long term proposition, funding of which Cook *et al.* (2013) says should come from proponents. Given the fact that a tight gas industry is still some time away from being economic (DMP 2015), we need to act quickly to get the monitoring networks in place to collect appropriate long term baseline datasets against which future impacts can be measured, if this industry is going to proceed.

Recommendations

The US EPA (2016) stated that "In places where we know activities in the hydraulic fracturing water cycle have occurred or are occurring, data that could be used to characterize the presence, migration, or transformation of hydraulic fracturing-related chemicals in the environment before, during, and after hydraulic fracturing were scarce. Specifically, local water quality data needed to compare pre- and post-hydraulic fracturing conditions are not usually collected or readily available. The limited amount of data collected before, during, and after activities in the hydraulic fracturing water cycle reduces the ability to determine whether these activities affected drinking water resources".

The following recommendations will help prevent Western Australia from making the same mistakes.

1. Require that industry proponents fund the investigations necessary to present a robust and defensible understanding of the impact risk (incorporating geology, hydrogeology, environment and Aboriginal cultural heritage, including their linkages) in Western Australia, prior to undertaking tight gas exploration or production activities. This needs to account for project-specific impacts as well as cumulative impacts of a fully-developed tight gas industry.
2. Require that groundwater take be licensed and impact assessed, particularly given the risk of impact from water supply and tight gas wells in the proclaimed Groundwater Areas of the northern Perth and Canning basins. DMP (2015) stated that it only *may* require licensing.
3. Modify the Western Australian regulatory environment to incorporate the issues explored herein, in particular the issues around drilling, monitoring, project approvals and cumulative impacts. The DoW allocation planning process is an example of a regulatory framework managing cumulative impacts. Given the risk of water and environment related impacts, DoW should have a more significant role in the approval process for the unconventional hydrocarbon industry, not just its water supply.
4. Upgrade groundwater allocation plans for the relevant areas to intensive plans as soon as possible and prior to any additional tight gas exploration or production activities.
5. Augment good oilfield practice (in terms of drilling practice and regulation) with hydrogeological best practice, particularly in the context of unconventional gas wells that pose risks to confined aquifers.
6. Require post well abandonment monitoring across relevant aquifers. Further, in consideration of the long time frames for some impacts to be revealed, a trust fund

approach would ensure that resources are available for post abandonment monitoring and well failure remediation.

7. All costs for impact assessment and baseline monitoring should be borne by UCH proponents, not the tax payer, in line with the recommendations by Cook *et al.* (2013). The example of Palat *et al.* (2015), where government bore the costs of a project assessment, is unacceptable.
8. Audit all existing oil and gas wells in the State, in terms of well leakage and well integrity. This will provide an understanding of the impact of existing activities as well as invaluable data on long-term well integrity in a Western Australian context.
9. Choose a number of representative existing conventional oil and gas wells, and unconventional wells that will be drilled and stimulated, for detailed hydrogeological investigations. This should include faults and other potential flow conduits, and these sites should be monitored for long term water quantity and quality impacts. The investigations would require the installation of nested piezometers (monitoring wells installed in different depths) across all aquifers (both potable and non-potable) across the full vertical extent of the tight gas wells. Monitoring networks (both local and regional) should be in place for at least 12 months prior to any hydraulic stimulation activity to ensure appropriate baselines are collected.
10. The recommendations in Cook *et al.* (2013) are comprehensive across all areas of UCH projects in Australia and the reader is suggested to review them also. They recommended that baseline studies are completed before exploration activities are undertaken and that a precautionary approach is applied due to the serious nature of potential impacts.
11. Declare a permanent moratorium on drilling and related exploration or production activities in conservation estate and public drinking water source areas. The risks associated with surface activities alone in the hydraulic stimulation process justify this, let alone the risks of hydraulic stimulation and well failure, which are difficult to currently quantify.
12. Make the Environmental Assessment and Regulatory System (EARS) and EARS2 publically available. The community has the right to know the environmental impact assessment under which tight gas exploration projects are being approved.

A moratorium on further exploration or production experiments is a regulatory option which will ensure protection of the environment and groundwater resources until such time as baseline studies are completed so the impact of all activities (including both exploration and production) can be rigorously assessed. However, a permanent moratorium is recommend over conservation estate and public drinking water source areas, given the considerable risk that even surface activities hold in the context of the biodiversity values or long term water supply security that these areas are created to protect.

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RESEARCH ARTICLE

Toward an Understanding of the Environmental and Public Health Impacts of Unconventional Natural Gas Development: A Categorical Assessment of the Peer-Reviewed Scientific Literature, 2009-2015

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Abstract

The body of science evaluating the potential impacts of unconventional natural gas development (UNGD) has grown significantly in recent years, although many data gaps remain. Still, a broad empirical understanding of the impacts is beginning to emerge amidst a swell of research. The present categorical assessment provides an overview of the peer-reviewed scientific literature from 2009–2015 as it relates to the potential impacts of UNGD on public health, water quality, and air quality. We have categorized all available original research during this time period in an attempt to understand the weight and direction of the scientific literature. Our results indicate that at least 685 papers have been published in peer-reviewed scientific journals that are relevant to assessing the impacts of UNGD. 84% of public health studies contain findings that indicate public health hazards, elevated risks, or adverse health outcomes; 69% of water quality studies contain findings that indicate potential, positive association, or actual incidence of water contamination; and 87% of air quality studies contain findings that indicate elevated air pollutant emissions and/or atmospheric concentrations. This paper demonstrates that the weight of the findings in the scientific literature indicates hazards and elevated risks to human health as well as possible adverse health outcomes associated with UNGD. There are limitations to this type of assessment and it is only intended to provide a snapshot of the scientific knowledge based on the available literature. However, this work can be used to identify themes that lie in or across studies, to prioritize future research, and to provide an empirical foundation for policy decisions.

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Introduction

Shale and tight gas development (known to nontechnical stakeholders as "fracking" and referred to herein as unconventional natural gas development, UNGD) continues to be the focus of controversy. Amidst economic and geopolitical considerations, the potential environmental and public health impacts of UNGD have received substantial attention in policy, media, and public debates. Claims of ground water contamination and adverse health outcomes have been widely cited and disputed, but what does the science actually show?

While research continues to lag behind the rapid scaling of UNGD, there has been a surge of peer-reviewed scientific papers published in the past several years (Fig 1). By the end of 2015, over 80% of the peer reviewed scientific literature on shale and tight gas development has been published since January 1, 2013 and over 60% since January 1, 2014. This suggests an emerging understanding of the environmental and public health implications of UNGD in the scientific community. Yet, although numerous hazards and risks have been identified in studies to date, many data gaps remain. Notably, while there is now a far more substantive body of science than there was several years ago, there is still only a limited amount of epidemiology that explores associations between risk factors and health outcomes in human populations [1].

In this assessment we provide an overview, a current snapshot, of the scientific knowledge on potential environmental public health hazards, elevated risks, and outcomes associated with the development of shale and tight gas. We include only published, peer-reviewed literature available on the subject. More nuanced and systematic peer-reviewed public health review articles that provide greater levels of appraisal and analysis with in-depth narrative are available [2–4]. This particular assessment is intended to provide a broad understanding of the scientific literature in order to support the following goals:

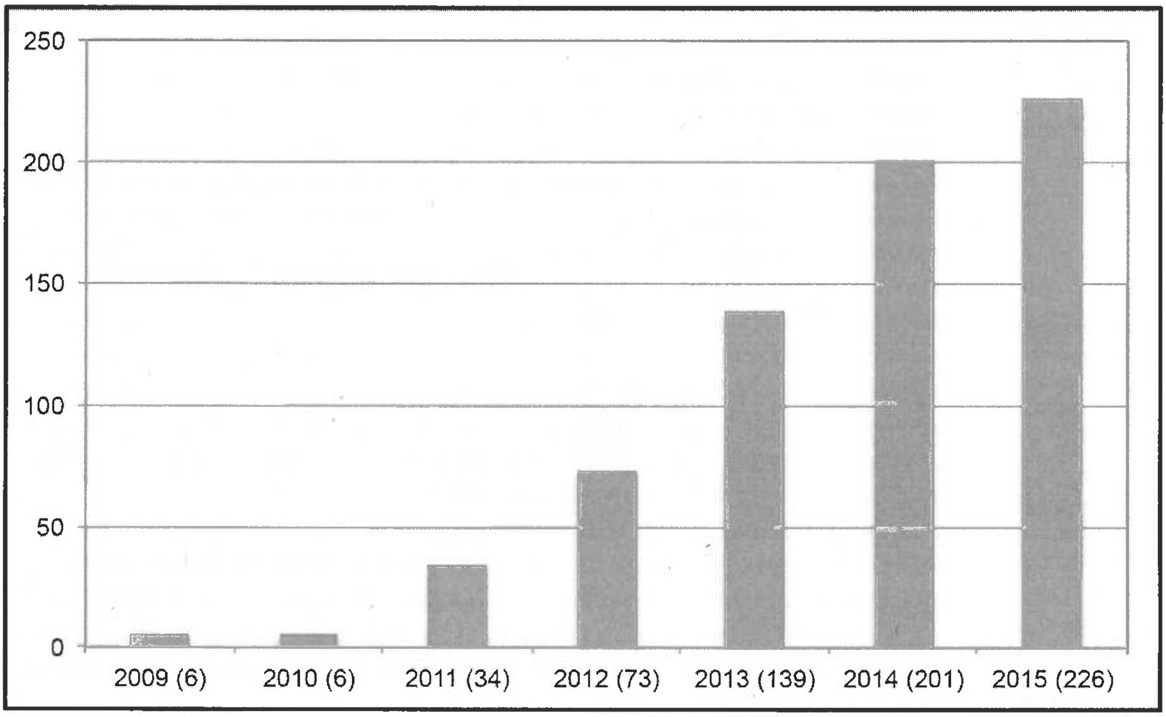

Fig 1. Number of publications that assess the impacts of UNGD per year, 2009–2015. At least 685 papers have been published in peer-reviewed scientific journals that are relevant to assessing the impacts of UNGD. The number of papers published per year has continually risen and at least 226 were published in 2015 alone.

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- To understand the weight and direction of the scientific literature
- To provide comprehensive lists of studies in a field
- To identify themes that lie in or across individual studies
- To map and categorize existing literature for further review
- To prioritize future research and investigations

As activities continue to expand, counties, states, and nations are in a unique position to learn from experiences and scientific assessments conducted where UNGD is already underway [5,6]. While responsible energy policies require more than empirical data inputs [7,8], legislative and regulatory activities will benefit from the emerging body of science on the environmental and public health implications of UNGD. This assessment can be viewed as a summary of the peer-reviewed literature in order to help facilitate research efforts and inform policy discussions at the federal, state, and local levels.

Methods

Database assemblage and review

This assessment was conducted using the PSE Database on Shale and Tight Gas Development (available at: http://psehealthyenergy.org/site/view/1180 and referred to herein as the PSE Database). This near exhaustive collection of peer-reviewed scientific literature on the impacts of UNGD is divided into 12 topics: air quality, climate, community, ecology, economics, general, health, regulation, seismicity, waste/fluids, water quality, and water usage. We assembled this database over three years using a number of search strategies, including the following:

- Systematic searches in scientific databases across multiple disciplines:
  - PubMed (http://www.ncbi.nlm.nih.gov/pubmed/)
  - Web of Science (http://www.webofknowledge.com)
  - ScienceDirect (http://www.sciencedirect.com)
- Searches in existing collections of scientific literature on unconventional natural gas development, such as the Marcellus Shale Initiative Publications Database at Bucknell University (http://www.bucknell.edu/script/environmentalcenter/marcellus), complemented by Google (http://www.google.com) and Google Scholar (http://scholar.google.com)
- Manual searches (hand-searches) of references included in peer-reviewed studies and government reports that directly pertain to unconventional natural gas development.

For scientific literature search engines we used a combination of Medical Subject Headings (MeSH)-based and keyword strategies, which included the following terms as well as relevant combinations thereof:

> shale gas, shale, hydraulic fracturing, fracking, drilling, natural gas, air pollution, methane, water pollution, health, public health, water contamination, fugitive emissions, air quality, climate, seismicity, waste, fluids, economics, ecology, water usage, regulation, community, epidemiology, Marcellus, Barnett, Fayetteville, Haynesville, Denver-Julesberg Basin, unconventional gas development, and environmental pathways.

Our database and this assessment excluded technical papers on UNGD not applicable to determining its potential impacts. Examples of literature that we excluded are engineering papers on optimal drilling strategies, petroleum reservoir evaluations, estimation algorithms of absorption capacity, patent efficacy assessments, and fracture models designed to inform stimulation techniques. Because our assessment is limited to papers subjected to external peer-review, it did not include government reports, environmental impact statements, policy briefs, white papers, law review articles, or other grey literature. Our assessment also excluded studies on some forms of UNGD, such as coalbed methane/coal seam gas as well as other forms of fossil fuel extraction that specifically exclude shale and/or tight gas development (e.g., tarsands, oil shale, etc.). While we are sure that we include the vast majority and certainly the most seminal studies on the environmental public health dimensions of UNGD in leading scientific journals, it is possible that a small number of publications are missing. As such, we refer to the literature database as *near* exhaustive.

The PSE Database has been used and reviewed by academics, experts, and government officials throughout the United States and internationally and has been subjected to public and professional scrutiny before and after this assessment. It represents the most comprehensive public collection of peer-reviewed scientific literature on shale and tight gas development available. Again, many of the publications in this database are discussed in greater detail in published review articles [2–4] and government reports [9,10].

Scope of assessment

Definitions. There has been significant confusion about the environmental dimensions of UNGD (often termed "fracking") because of the lack of uniform, well-defined terminology and boundaries of analysis [11]. The public and the media often use the term "fracking" as an umbrella term to refer to the entirety of UNGD (and often other forms of oil and gas development), including processes such as land clearing, well stimulation, hydrocarbon production, storage and transportation, and waste disposal. On the other hand, the oil and gas industry and many in the scientific community generally use the term as shorthand for one particular type of well stimulation method used to enhance the production of oil and natural gas: hydraulic fracturing.

The PSE Database and this assessment are focused on UNGD in its entirety, and not only the method of well stimulation. Environmental and public health assessments that include only the latter should have a limited role in policy discussions. In order to understand the environmental and public health dimensions of UNGD any reasonable approach must engage beyond a narrow view of only the well stimulation process of hydraulic fracturing, especially when the scientific literature indicates that other UNGD processes warrant greater concern. As such, the boundaries of our assessment include scientific literature on hydraulic fracturing *and* the associated operations and ancillary infrastructure required to develop and distribute unconventional natural gas. Although we use the term UNGD to refer to shale and tight gas development, some of the studies included in this report may either include data from, or be applicable to, other forms of UNGD enabled by hydraulic fracturing. Again, those focused solely on coal seam gas are beyond the scope of this assessment.

Inclusion and exclusion criteria. The temporal focus of this assessment was between 1 January 2009 and 31 December 2015 in order to capture what we believe to be the entirety of the published peer reviewed science on environmental public health dimensions of UNGD for this time period. We did not include papers released in 2015 ahead of print that will be published in 2016. We included original studies that evaluate environmental and public health hazards, risks, and impacts of UNGD, narrowly defined as shale or tight gas development (Table 1).

Table 1. Inclusion and Exclusion Criteria.

	Included	Excluded
Type of unconventional fossil fuel development	shale gas, tight gas	coal bed methane (coal seam gas), tar sands (oil sands), shale oil, shale (tight) oil*
Type of publication	scientific, peer-reviewed, original research	review articles, commentaries, government reports, environmental impact statements, white papers, law review articles, and other grey literature
Date of publication	published between 2009 and 2015	published prior to 2009 or since January 1, 2016
Type of original research	re: hazards, risks, and/or impacts to public health, water quality, and air quality	re: hazards, risks, and/or impacts to climate, community, ecology, economics, regulation, seismicity, water usage; baseline data; research methodology; technical papers (optimal drilling strategies, estimation algorithms of absorption capacity, etc.)

* Some of the air quality studies in Western oil and gas fields included unconventional fossil fuel development types other than shale and tight gas.

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The majority of publications in the PSE Database are not considered in this assessment and we excluded the following topics: climate, community, ecology, economics, regulation, seismicity, waste/fluids, and water usage. Although many of these topics also have public health implications (e.g., climate change, economics, water usage, etc.), we have focused this assessment on original research that directly pertains to 1) public health, 2) water quality, and 3) air quality. We excluded some studies that may be located in the three topics used in this assessment, such as those that only provide baseline data or address research methods but fail to assess hazards, risks, or associated impacts.

As previously mentioned, we restricted the studies included in this assessment to those published from 1 January 2009 through 31 December 2015. There are studies on conventional forms of oil and natural gas development that are relevant to the public health dimensions of UNGD, but to maintain greater consistency we excluded those prior to 2009 from the assessment. For example, we did not include a study published in *The Lancet* that examined the association between testicular cancer and employment in agriculture and oil and gas development published in 1984 [12].

Relatedly, the scope of some of the studies we included in this assessment may go beyond shale and tight gas and could potentially include other forms of both conventional and unconventional oil and gas development. For instance, some of the top-down, field-based air pollution studies that gauge leakage rates and emission factors in Western oil and gas fields [13,14]. We included studies not exclusively related to UNGD only when the focus of the studies is relevant and they were published within our specified timeframe. For instance, studies that measured VOC emissions in a region with shale gas development as well as other forms of conventional and unconventional oil and gas development were included in this assessment.

Lastly, we only included original research in our assessment. We considered research original if it measured potential or actual health outcomes or complaints and air quality and water quality assessments related to UNGD. We excluded literature that attempted to determine public opinion or that considered methods for future research agendas.

Categorical framework

We have created binary categories for each topic in an attempt to identify and group studies in an intuitive way that focuses on the indication of what might be considered to be a relevant or significant impact. Some of the studies categorized belong in more than one topic. For instance, studies that contain data that are relevant to both air quality and public health are included in both of these topics [15–17].

As with any scientific analysis there is also a qualitative component in our operational definitions and methods of categorization (Table 2). It is possible that some may disagree as to

Table 2. Categorical Framework.

Topics	Categories	
	A	B
Public Health	Findings that indicate public health hazards, elevated risks, or adverse health outcomes	Findings that indicate no significant public health hazards, elevated risks, or adverse health outcomes
Water Quality	Findings that indicate potential, positive association, or actual incidence of water contamination	Findings that indicate minimal potential, no association, or rare incidence of water contamination
Air Quality	Findings that indicate elevated air pollutant emissions and/or atmospheric concentrations	Findings that indicate no significantly elevated air pollutant emissions and/or atmospheric concentrations

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what constitute findings that indicate a public health hazard or elevated risk. To address this concern we have listed specific criteria of what would qualify a study for inclusion in a particular category within each relevant section below. Examples include statistically significant positive associations between UNGD or a particular health outcome or measurements documented above recommended air quality standards. In some cases, the relative significance of an impact related to UNGD is based on the interpretation of the evidence by the authors of the study. Readers may also refer to the tables included in the appendix for citations and categorization of the studies, which are listed alphabetically by author in each topic (S1 Appendix).

Our approach often does not account for various nuances in the results of particular studies. For instance, some studies may contain findings of both positive associations and no associations between UNGD and particular health outcomes. In our assessment we chose to include a study with any positive finding or indication of a particular impact in Category A. As such, a study that found an association between UNGD and health endpoint X, but no association with health endpoints Y and Z, would still be included in Category A.

Public Health. Studies that assess public health risks and endpoints, including epidemiologic investigations, continue to be particularly limited compared to studies of public health hazards. To date, most of the peer-reviewed health oriented publications are commentaries and literature reviews. In this topic we included original research that considers the question of public health in the context of UNGD. Of course, empirical findings in other categories such as air quality and water quality are relevant to public health. However, in this topic we only include those studies that directly consider the health of human populations and individuals as well as studies that examine animal health as they can provide sentinel information for human health risks.

In this topic we consider research "original" if it measures potential or actual health outcomes or complaints (i.e., not health research that only attempts to determine public opinion or consider methods for future research agendas). In addition to epidemiology, we included studies in this topic that focus primarily on environmental monitoring, but which also contain significant discussion about public health risks or outcomes [15,18,19]. In some of these cases, we have cross-listed the study within the water or air quality topic.

For the public health topic, we placed a study in category A or B based on whether or not it provided evidence, documentation, or acknowledgment of any of the following that are attributed to UNGD:

- A positive association with at least one adverse health outcome (e.g., birth defects, hospitalization)
- A positive association with a known human health risk (e.g., elevated benzene concentrations)

- Increased health risks from exposure to pollutant emissions
- A positive association with reported health symptoms in randomized survey proximity analysis
- Self-reported health symptoms or complaints in humans or animals;
- Toxicological concerns in the context of protective limitations (e.g, monitoring impediments)
- Explicit health concerns based on documented environmental contamination (e.g., endocrine disruption chemicals, high PAH levels in ambient air, etc.)

Water Quality. The allocation of water quality studies to binary categories is more complex than those focused on human health in that some rely on empirical field measurements, while others explore mechanisms for contamination or use modeled data to assess or predict water quality risks. Some of these studies explored only one aspect of UNGD, such as waste disposal or the well stimulation process enabled by hydraulic fracturing. These studies did not always indicate whether or not UNGD as a whole is associated with water contamination and are therefore limited in their utility for gauging water quality impacts. Nonetheless, we included all original research, including modeling studies as well as those that consider contamination mechanisms and/or exposure pathways. We excluded studies that explored only evaluative methodology or baseline assessments prior to UNGD as well as papers that only comment on or review previous studies. Here we were only concerned with actual findings in the field or modeling studies that specifically address the risk or potential occurrence of water contamination.

For this topic, we placed a study in category A or B based on whether or not it provided evidence, documentation, or acknowledgment of any of the following that are attributed to UNGD:

- A positive association with water contamination (e.g., proximity analysis showing increased concentrations of methane, heavy metals, salinity, etc.)
- Elevated surface or groundwater pollutant concentrations resulting from fluid releases or wastewater treatment/disposal
- Plausible contamination pathways and potential for water quality impacts from risk assessment/analysis of failure mechanism (e.g., casing and cement impairment)
- Plausible contamination pathways and potential for water quality impacts from modeling or geochemical evidence
- Water quality impacts based on analysis of microbial communities
- A significant quantity of reported incidents of water contamination relative to development activity

Air Quality. The papers included in the air quality assessment are those that specifically address air pollutant emissions and atmospheric concentrations from UNGD at either a local or regional scales. These papers primarily include measurements of local and regional emissions and atmospheric concentrations of non-methane volatile organic compounds, hazardous air pollutants, and tropospheric ozone attributable to upstream natural gas, and sometimes oil, activities since atmospheric measurements usually account for both.

Although methane is a precursor to global background tropospheric ozone concentrations we excluded studies that focus exclusively on methane emissions from this topic. We do, however, include studies that measure emissions of methane *and* non-methane volatile organic compounds (VOC), given the known health-damaging dimensions of a number of VOCs (i.e., benzene, toluene, ethylbenzene, xylene, 1,3 butadiene, acetaldehyde, etc.) and the role of light alkane VOCs in the production of the respiratory irritant, tropospheric (ground-level) ozone. We included a few studies that explore the public health risks associated with air pollutant emissions in both the air and the public health categories.

For this topic, we placed a study in category A or B based on whether or not it provided evidence, documentation, or acknowledgment of any of the following that are attributed to UNGD:

- Measurement(s) or estimation(s) of emissions or atmospheric concentration in excess of recommended air quality standards (e.g., NAAQS, federal ozone standards, etc.)
- Emission estimates that are significantly elevated above state emission inventory estimates
- Public health risks due to toxic air emissions or ambient air concentrations
- Measurement of emissions and/or atmospheric concentrations highly elevated over regional background

Results

Public Health

Based on our criteria, we included 31 original research studies relevant to UNGD and public health hazards, risks, and health outcomes. Of these 31 studies, 26 (84%) contain findings that indicate public health hazards, elevated risks, or adverse public health outcomes and 5 (16%) contain findings that indicate no significant public health hazards, elevated risks, or adverse health outcomes associated with UNGD (Fig 2). The vast majority of all papers on this topic indicate the need for additional study, particularly large-scale, quantitative epidemiologic research.

Water Quality

Based on our criteria, we included 58 original research studies relevant to shale gas development and water quality. Of these 58 studies, 40 (69%) have findings that indicate potential, positive association, or actual incidence of water contamination associated with UNGD, while 18 (31%) have findings that indicate minimal potential, no association, or rare incidence of water contamination (Fig 2).

Air Quality

Based on our criteria, we included 46 original research studies relevant to questions involving associations between UNGD and air pollutant emissions and atmospheric air pollutant concentrations. Of these 46 studies, 40 (87%) have findings that indicate that UNGD increased air pollutant emissions and/or atmospheric concentrations, while 6 (12%) of the studies contain findings that provide no indication of significantly elevated air pollutant emissions and/or atmospheric concentrations (Fig 2).

Discussion

In this assessment, we reviewed the findings of original peer-reviewed research that evaluates associations between UNGD and air quality, water quality, and public health to determine the direction of the scientific literature. For each topic we found that the majority of original

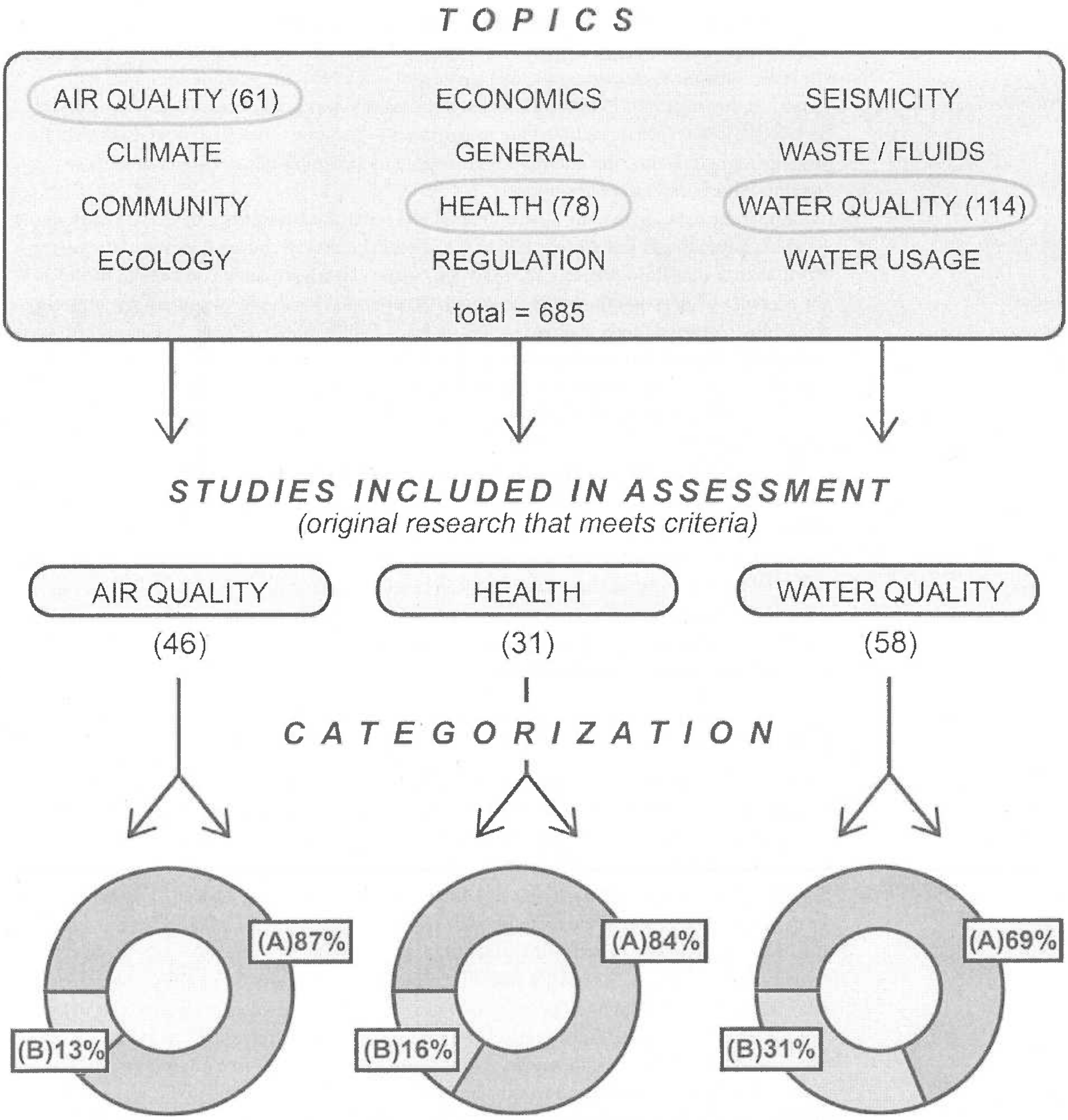

Fig 2. Selection Process and Results. This assessment draws from the peer-reviewed literature for three topics in the PSE Database: Air Quality, Health, and Water Quality. Of the 61 publications in air quality, 46 met our criteria; of the 78 publications in health, 31 met our criteria; and of the 114 publications in water quality, 58 met our criteria. From here we placed the original research that met our criteria into one of two categories (see Table 2). Our results indicate that 84% of public health studies contain findings that that indicate public health hazards, elevated risks, or adverse health outcomes, 69% of water quality studies contain findings that indicate potential, positive association, or actual incidence of water contamination, and 87% of air quality studies contain findings that indicate elevated air pollutant emissions and/or atmospheric concentrations.

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research indicate hazards, elevated risks, or potential impacts from UNGD on the outcome of interest. These results suggest that UNGD may contribute to an environmental public health burden, which is consistent with numerous scientific review articles and government reports.

A review of the research included in this assessment can help identify themes that emerge in study design, methodology, hypotheses, scope, findings, and recommendations. With regard to the latter, one one theme that continually emerged was a recommendation for additional empirical investigations to better understand the risks to water, air, and public health presented by UNGD. Other themes included the recognized need among researchers for baseline studies to allow for before and after comparative assessments and longitudinal data to determine potential short- and long-term impacts.

Numerous data gaps on the environmental and public health impacts of UNGD exist, many of which have already been recognized in the scientific literature. Several notable data gaps are worth mentioning, however, and the following remain largely unknown: the extent to which the presence of stray-gas in aquifers indicates the potential for chemical contamination from hydraulic fracturing fluids; changes in well integrity failure rates over time; the legacy effects and relative contribution of air pollutants emissions from aging and abandoned wells; exposure data to characterize the frequency, duration, and degree of exposure to various stressors; community health risks from physical hazards (e.g., light and noise); and the overall magnitude of human-health risks.

The need for quantitative epidemiological research on this subject is widely recognized in the scientific community, but it is difficult to conduct until exposure parameters are better determined and reported cases of health outcomes are analyzed. Many epidemiological studies are expensive, time consuming, and often rely on data that are difficult to obtain. The fact that potential exposures would have taken place before background data could be collected only complicates the issue. Although there is quite a bit of evidence of hazards and elevated risks, drawing conclusions about the magnitude of health burdens attributable to UNGD remains difficult from an epidemiological perspective.

Limitations

There are limitations to this assessment that relate to both its methods and the interpretation of its findings. As previously mentioned, the type of binary categorization we used may not account for the nuances of findings in many of these studies. Relatedly, this type of categorization effectively ranks the quality of the studies included in this article equally, despite clear differences in the weight and merit that should be ascribed to each study, based on either its design or interpretation of the evidence. Our work, however, was not intended to provide commentary on the quality of each study since here we are primarily concerned with the overall weight of the evidence. The quality and subsequent weight that should be given to a particular study are influenced by a number of factors, such as its design, methodology, and execution. We have only broadly surveyed original research across three different topics, including, but not limited to, qualitative epidemiology, risk analysis, in situ measurements, and modeling studies. There are strengths and weaknesses with each empirical method and it was not our aim to consider these attributes on an individual basis. Ultimately, this assessment relied on the peer-reviewed process itself in its consideration of the quality of the work. While not all peer-reviewed studies are of equal merit, this appeared to be the most simple, useful, and appropriate standard for quality control and consideration given our purposes.

Our selection criteria influence the categorization process and certain data inputs are gained or lost by our decisions to include or exclude particular type of studies. By only including original research on air quality, water quality, and public health, we are not accounting for all of the studies that may be pertinent to each topic (e.g., the existence or absence of elevated public health hazards, etc.). For instance, climate change, water usage, and economic gains may all influence environmental and public health outcomes. We have excluded these topics from our

analysis and have chosen to focus only on the three that have consistently received the most attention among environmental public health researchers. Additionally, by not including government reports that do not appear in peer-reviewed journals we may be missing useful data and analysis that can inform UNGD public health implications as well as air and water quality concerns.

The majority of studies included in this assessment were conducted to determine whether or not adverse effects from UNGD exist. These types of investigations may, by their very nature, produce reporting or design bias. This is an inherent limitation of the scientific discipline; scientists are not immune from value judgments that shape research and scientific reasoning, including hypotheses to be tested, boundaries of analysis, and interpretation of evidence. Biases are difficult to account for in this context and we have chosen to rely on the peer-review process in this determination.

Furthermore, while the PSE Database is–to our best knowledge–exhaustive, our literature search may not have captured every relevant peer-reviewed scientific paper. Some journal articles are not always available in electronic databases or may be captured at a later time. As UNGD continues to gain the attention of the scientific community in other parts of the world, more and more research on the subject has been published in relatively obscure journals that may not be readily available. While we are confident that our MeSH-terms account for nearly all of the research on this topic, there is a possibility that some studies that use different or less traditional terminology may have been missed. We did our best to account for what may not have been initially discovered in an online database with manual searches of the scientific literature over a several year period.

Differences in geography, geology, petroleum reservoir type, and regulatory regime may also render some studies less relevant when interpreted across geographic space. Our assessment is only concerned with current empirical evidence in the peer-reviewed literature and we do not consider different regulatory regimes that could potentially influence environmental and public health outcomes in positive or negative ways. For instance, technological improvements such as universal deployment of reduced emission completions may mitigate some existing air pollutant emission issues.

Despite its limitations, our assessment provides a general understanding of the weight of the scientific evidence of possible impacts arising from UNGD that are relevant to environmental public health. It demonstrates that the weight of the scientific literature indicates that there are hazards and elevated risks to human health as well as possible adverse health outcomes.

Finally, it must be understood that all forms of energy production and industrial processing have environmental impacts. Our assessment is only focused on assessing the available science on the environmental and public health dimensions of the development of natural gas from shale and tight formations. We make no claims about the level of impact that should be tolerated by society–these are ultimately value judgments that incorporate more than empirical findings.

Supporting Information

S1 Appendix. List of studies included and excluded in assessment by topic.
(DOCX)

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Author Contributions

Conceived and designed the experiments: JH. Performed the experiments: JH SBCS. Analyzed the data: JH SBCS. Contributed reagents/materials/analysis tools: JH SBCS. Wrote the paper: JH SBCS.

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MINES AND PETROLEUM — GAS LEAK — YULLEROO

4424. Hon Robin Chappie to the Attorney General representing the Minister for Mines and Petroleum:

(1) With regard to the gas leak at Yulleroo 2 in January 2015, did the Department of Mines and Petroleum (DMP) officers either take readings of the leak with a gas meter themselves or witness Buru Energy or others take readings?

(2) If no to (1), why not?

(3) If the DMP took or witnessed readings, what were they measured at?

(4) The Minister has stated (Question on notice 3173) that there was a leak at Yulleroo 2 in 2013, what was the:

   (a) cause of the leak; and

   (b) action taken by Buru Energy to rectify it?

(5) Was there an incident report for the 2013 gas leak at Yulleroo 2?

(6) If no to (5), why not?

(7) If yes to (5), will the Minister table the incident report?

(8) If no to (7), why not?

(9) Did TKM Wellhead Services fix the leak?

(10) When did the DMP inspect the Yulleroo 2 well after the gas leak that was reported in 2013?

(11) How many inspections have been carried out at Yulleroo 2 since the well was drilled?

(12) Will the Minister table the inspection reports?

(13) If no to (12), why not?

(14) How many incident reports have been received since the Yulleroo 2 well was drilled?

(15) Will the Minister table the incident reports?

(16) If no to (15), why not?

(17) Was an incident report received from Buru Energy in late 2013?

(18) If yes to (17), what was the incident about?

(19) If yes to (17) will the Minister table the incident report?

(20) If no to (19), why not?

(21) The Minister has stated (Question on Notice 3173) that the gas leak at Yulleroo 2 in 2013 was reported by Buru Energy on 18 April, 2013. Is the Minister aware that the leak was reported to the DMP by an Environment Officer – Industry Regulation, Department of Environment and Conservation on the 17 April, 2013?

(22) If no to (21), why not?

(23) If yes to (21), why did the Minister not state this in his answer to Question on Notice 3173?

(24) Is the Minister aware that the Department of Environment and Conservation officer who reported the Yulleroo 2 leak to the DMP on 17 April 2013 could hear a hissing noise and smell a methane gas like odour?

(25) Did DMP officers inspect the gas leak at Yulleroo 2 in April 2013?

(26) If no to (25), why not?

(27) Were readings of the leak at Yulleroo 2 in April 2013 taken?

(28) If no to (27), why not?

(29) If yes to (27) what were the readings?

(30) Is the Minister aware that Schlumberger undertook work on Yulleroo 2 in May 2013?

(31) If no to (30), why not?

(32) What was the nature of the work Schlumberger undertook in May 2013 on Yulleroo 2?

(33) Will the Minister table all the reports associated with Schlumberger's work in May 2013 on Yulleroo 2?

(34) If no to (33), why not?

(35) Has the Minister ruled out the potential for the gas leak at Yulleroo 2 in 2015 to have been caused by Buru Energy or contractors?

(36) If yes to (35), on what evidence is this based on?

Hon Michael Mischin replied:

The Department of Mines and Petroleum (DMP) advises:

(1) DMP officers witnessed Buru Energy taking the reading. Buru Energy personnel utilised a certified gas detector, in the presence of a DMP inspector.

(2) Not applicable.

(3) The detector indicated no gas present at various distances approaching and at the wellhead until the damaged valve was manipulated when minor readings were noted, these readings are detailed in the tabled investigation report.

(4) (a) A grease nipple connected to the annulus pressure gauge was found to have a very slight intermittent leak. This was due to hardened grease stopping a check valve within the nipple closing and preventing the leakage of gas to the environment.

(b) A new grease nipple was installed.

(5) Yes.

(6) Not applicable.

(7) Yes. [See tabled paper no 4877.]

(8) Not applicable.

(9) Yes.

(10) 7 January 2015.

(11) Three.

(12) Yes. [See tabled paper no 4877].

(13) Not applicable.

(14) Two.

(15) Yes. [See tabled paper no 4877].

(16) Not applicable.

(17) Yes.

(18) Issues raised by the Department of Environment and Conservation on the Yulleroo 2 and Yulleroo 4 well sites and Buru Energy's investigation results.

(19) Yes. [See tabled paper no 4877].

(20) Not applicable.

(21) No. The Minister was not aware of this notification.

(22) This was an omission by DMP.

(23) Not applicable.

(24) Yes. [See tabled paper no 4877].

(25) No.

(26) Please refer to Legislative Council Questions on Notice 3173.

(27) No.

(28) Buru Energy personnel identified the small intermittent leak with soapy water not a gas detector.

(29) Not applicable.

(30) Yes.

(31) Not applicable.

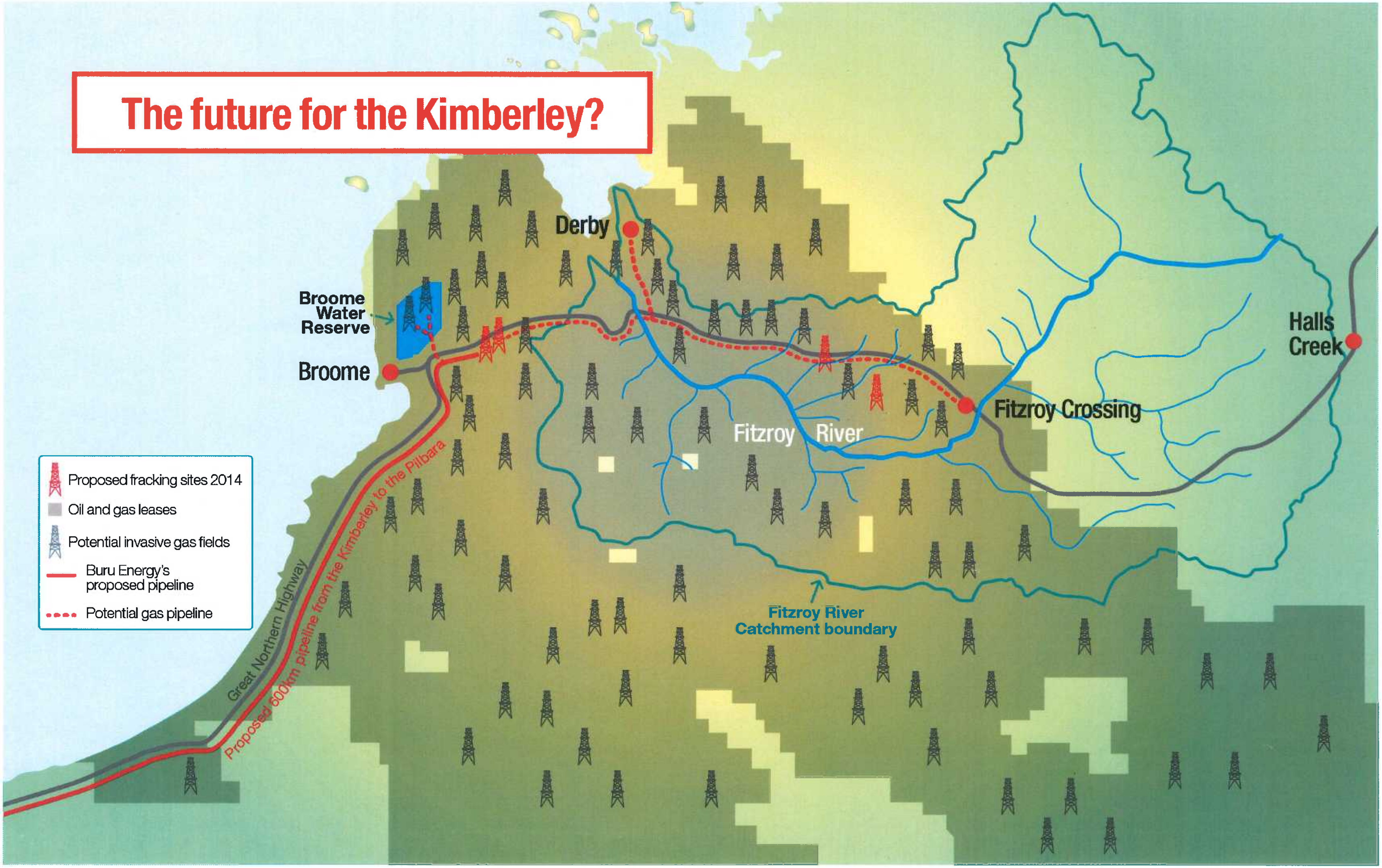
(32) [See tabled paper no 4877.]

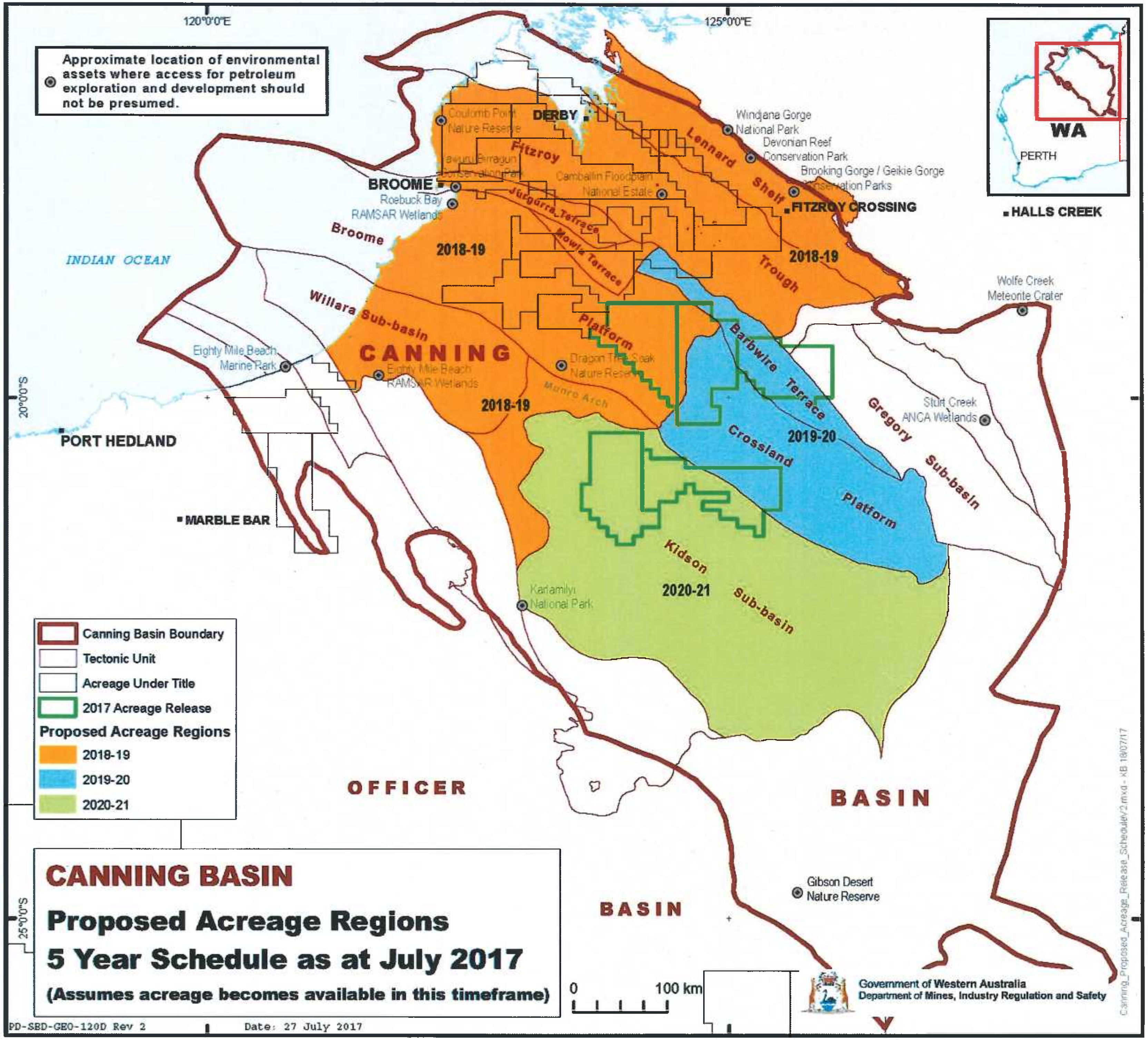
(33) Yes. [See tabled paper no 4877.]

(34) Not applicable.

(35) There was no direct evidence available to determine who caused the damage or when it was done.

(36) Not applicable.


The future for the Kimberley?
Derby
Broome Water Reserve
Broome
Halls Creek
Fitzroy Crossing
Fitzroy River
Fitzroy River Catchment boundary
Great Northern Highway
Proposed 600km pipeline from the Kimberley to the Pilbara
Proposed fracking sites 2014
Oil and gas leases
Potential invasive gas fields
Buru Energy's proposed pipeline
Potential gas pipeline



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Approximate location of environmental assets where access for petroleum exploration and development should not be presumed.
WA
PERTH
HALLS CREEK
DERBY
BROOME
FITZROY CROSSING
PORT HEDLAND
MARBLE BAR
INDIAN OCEAN
Coulomb Point Nature Reserve
Roebuck Bay RAMSAR Wetlands
Camballin Floodplain National Estate
Windjana Gorge National Park
Devonian Reef Conservation Park
Brooking Gorge / Geikie Gorge Conservation Parks
Wolfe Creek Meteorite Crater
Eighty Mile Beach Marine Park
Eighty Mile Beach RAMSAR Wetlands
Sturt Creek ANCA Wetlands
Karlamilyi National Park
Gibson Desert Nature Reserve
Fitzroy
Lennard Shelf
Jurgurra Terrace
Mowla Terrace
Trough
Broome
Willara Sub-basin
Platform
Barbwire Terrace
Munro Arch
Crossland Platform
Gregory Sub-basin
Kidson Sub-basin
CANNING
2018-19
2018-19
2018-19
2019-20
2020-21
OFFICER
BASIN
BASIN
Canning Basin Boundary
Tectonic Unit
Acreage Under Title
2017 Acreage Release
Proposed Acreage Regions
2018-19
2019-20
2020-21
CANNING BASIN
Proposed Acreage Regions
5 Year Schedule as at July 2017
(Assumes acreage becomes available in this timeframe)
0
100 km
Government of Western Australia
Department of Mines, Industry Regulation and Safety
PD-SBD-GEO-120D Rev 2
Date: 27 July 2017

Incidences with existing Kimberley fracking wells discovered by third party community members

Image 1: Photographic evidence showing Buru Energy fracking ponds overflowing from Yulleroo wells in 2013.NEWS: http://www.abc.net.au/local/stories/2014/03/21/3969043.htm

Image 2: Photographic evidence of Yulleroo 2 gas well leaking extremely high levels of gas 2015. Questions in parliament show could have been leaking for over 2 years, as an incident was reported in 2013.

http://www.abc.net.au/news/2016-01-29/activist-guilty-of-trespass-after-filming-fracking-gas-leak/7126228

Image 3: Dead dingo in Buru Energy fracking pond, found in 2014 by community members.

http://www.watoday.com.au/wa-news/wa-gas-explorer-creates-death-trap-for-native-animals-20141214-126u3r.html

THOUGHTS ON FRACKING ENQUIRY

As a businessman who has had large successes from engaging in commodity markets, I see prime risks in companies and governments investing in fossil fuels at the current time. Huge global factors are at play, and returns on fossil fuel investments are continuing to diminish. Although company directors may choose to take the associated risks, I believe firmly that the WA government should not. History will judge it harshly, at precisely a time when the social licence for fracking activity is patently lacking.

I realise this may be outside of the scope of this enquiry, however in investment decisions the macro-risks always come first, and these are the financial paybacks on projects.

WORLD FACTORS

On 22 April 2016, 175 nations sign the Paris Agreement at the UN on Earth Day: more than any other treaty in history.

On 26th June 2017 250 US mayors endorse switch to 100% renewable energy by 2035 (in defiance of Trump's fossil fuel agenda)

On 11 Jan 17, >600 US companies and financial institutions have now signed open letter to Trump supporting Paris
There is a surge in corporate planning for cost of carbon:
607 big companies, incl our own BHP, now use an internal price

On 12 Dec 2017 Funds managing $26 trillion pledge to pressure worst 100 companies on emissions, = 2/3rds global total (https://www.ft.com/content/beaf6560-df03-11e7-a8a4-0a1e63a52f9c)

On 3rd Oct 2017, the Catholic church makes record faith-based divestment from fossil fuels (http://www.theguardian.com/environment/2017/oct/03/catholic-church-to-make-record-divestment-from-fossil-fuels)

On 26th November 17, Norwegian Central Bank, manager of the oil fund, tells government it should divest from oil and gas (http://www.theguardian.com/business/2017/nov/16/oil-and-gas-shares-dip-as-norways-central-bank-advises-oslo-to-divest)

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So today global society is waking up to a new imperative: to cut the current c. 50 billion tonnes a year of carbon dioxide emissions and their equivalent in other greenhouse gases to zero – within a few decades!

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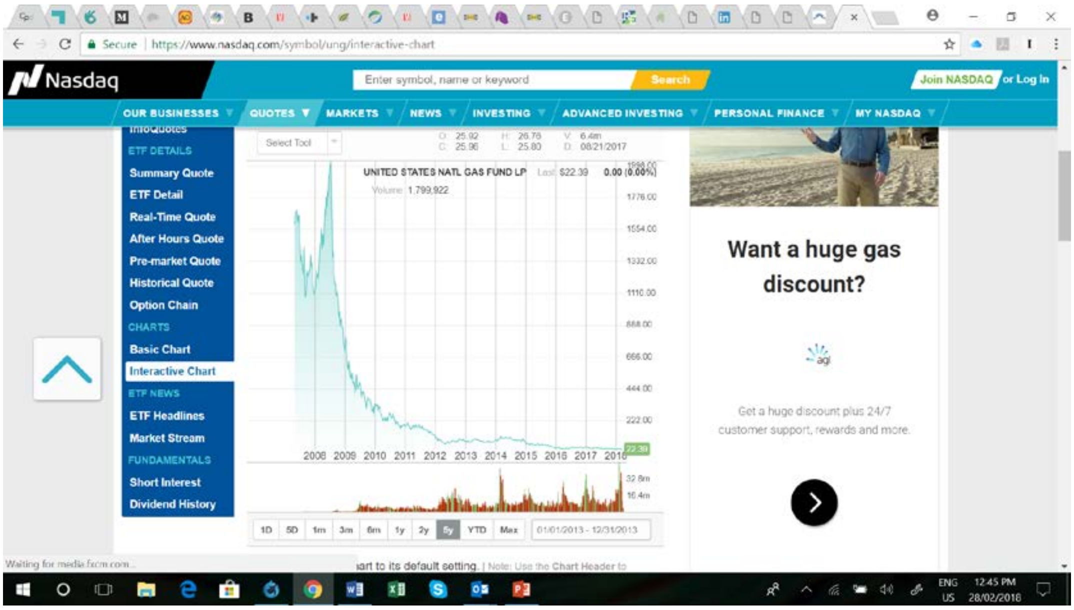
U.S. National Average Natural Gas Price on the NYMEX peaked at over $13 ten years ago. Today it trades at $2.70

The US Natural Gas fund ETF on the NASDAQ trades at $22. It was $2,000 in 2008 and has been steadily declining ever since



Burus share price over 10 years:

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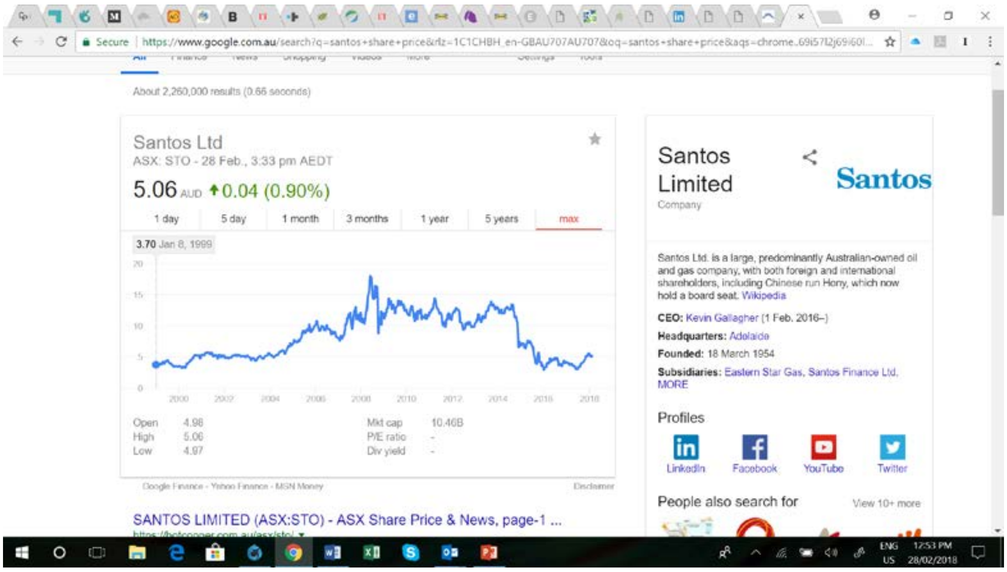

AJ Lucas share price:

So, given the view that fossil fuel exploration and investments are in decline globally, and that the gas price has been in long-term decline, and that gas companies have seen their net values decline substantially over 10 years, we should ask:

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Alternative industries to be supported

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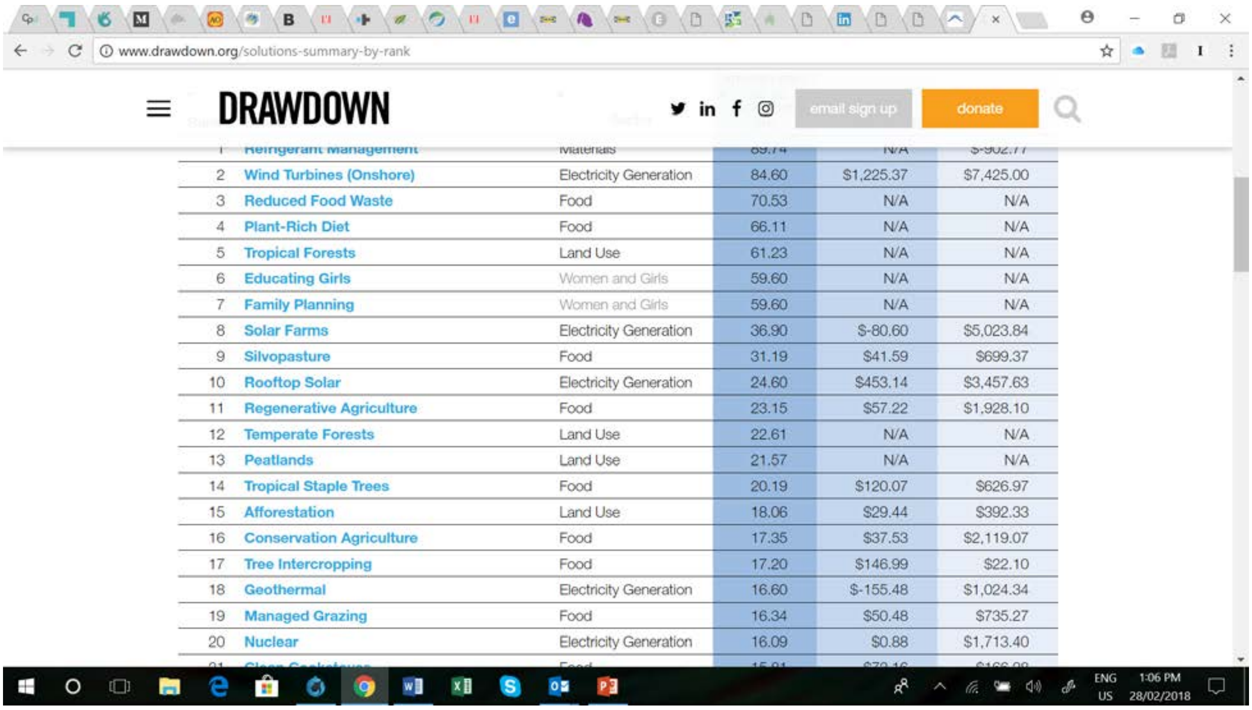

1	Refrigerant Management	Materials	89.74	N/A	$-902.77
2	Wind Turbines (Onshore)	Electricity Generation	84.60	$1,225.37	$7,425.00
3	Reduced Food Waste	Food	70.53	N/A	N/A
4	Plant-Rich Diet	Food	66.11	N/A	N/A
5	Tropical Forests	Land Use	61.23	N/A	N/A
6	Educating Girls	Women and Girls	59.60	N/A	N/A
7	Family Planning	Women and Girls	59.60	N/A	N/A
8	Solar Farms	Electricity Generation	36.90	$-80.60	$5,023.84
9	Silvopasture	Food	31.19	$41.59	$699.37
10	Rooftop Solar	Electricity Generation	24.60	$453.14	$3,457.63
11	Regenerative Agriculture	Food	23.15	$57.22	$1,928.10
12	Temperate Forests	Land Use	22.61	N/A	N/A
13	Peatlands	Land Use	21.57	N/A	N/A
14	Tropical Staple Trees	Food	20.19	$120.07	$626.97
15	Afforestation	Land Use	18.06	$29.44	$392.33
16	Conservation Agriculture	Food	17.35	$37.53	$2,119.07
17	Tree Intercropping	Food	17.20	$146.99	$22.10
18	Geothermal	Electricity Generation	16.60	$-155.48	$1,024.34
19	Managed Grazing	Food	16.34	$50.48	$735.27
20	Nuclear	Electricity Generation	16.09	$0.88	$1,713.40

Let's note that items 2, 4, 5, 8, 9, 10, 11, 12, 14, 15, 16, 17, 19 – i.e. 13 of the top 20 - are very well suited to conditions in WA. Indeed, we have unique advantages in many of those activities.

What are our business and government leaders doing in investigating more intensively?

When will we have an enquiry into Drawdown solutions and the benefits of job creation in WA?

SOCIAL LICENCE

Speaking outside Cuadrilla's Preston New Road site near Blackpool on the 454th day of protests John Ashton, formerly the UK's Special Representative for Climate Change at the Foreign Office, told the crowd that had gathered despite near-zero temperatures said:
"We're not here to defend a field. We're here to defend our country because what happens in that field over the next few months is going to be important for our country, important for our lives and the lives or our children.
"**Do we want a country where the choices that are made are choices that are made with us or - choices that are inflicted upon us? That's what this whole moment in our history is about.**
"The struggle over fracking is the struggle over whether we do politics with us - or politics that gets done to us."

I ask the same question of you the committee members. Are you dinky-di or is this process merely a charade? Do you really have blank canvases on which to draw your findings?

We have exactly the same choices, right here in WA. And people at large have made that choice: focus groups show they overwhelmingly do not want a fracking industry to be developed in this state: not in the Kimberley, not around Carnarvon, not in the Perth Basin and not in the South West.

Gas is ***not*** a strategic asset like oil once was. Our energy needs are being democratised by having our own rooftop generators, electric heaters and soon our own electric vehicles. We do not want to be told we need a new fossil-fuel industry in our part of the world.

Mr Ashton criticised the shale gas industry for promoting itself as a solution to climate change.
"They said 'We can be in favour of fixing the climate and we can be in favour of fracking'.
"Well, for six years, I was Her Majesty's Special Envoy on Climate Change.
"The one thing I do know something about is climate change. Take it from me: you can be in favour of fracking or you can be in favour of climate change [action], but you certainly can't be in favour of doing both at the same time."

I personally believe, having been reading about the subject diligently for six years – including many scientific reviews - that one of the most important things you can do for action on climate change is stopping the fracking industry. Therefore, this struggle for social licence to frack **is** a struggle on the front lines against accelerated climate change.

Norman Pater
Mob: 0417-788818

Session 2 Table 3
Anthony Sutton – EPA
Helen = Services
Mining & Industrial
Impact Assessment

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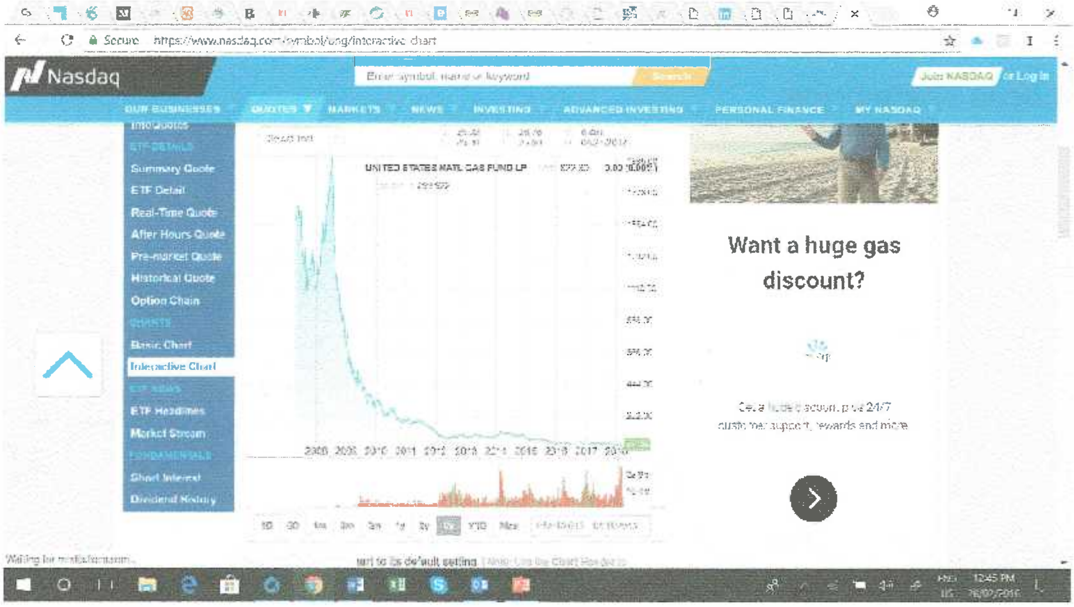

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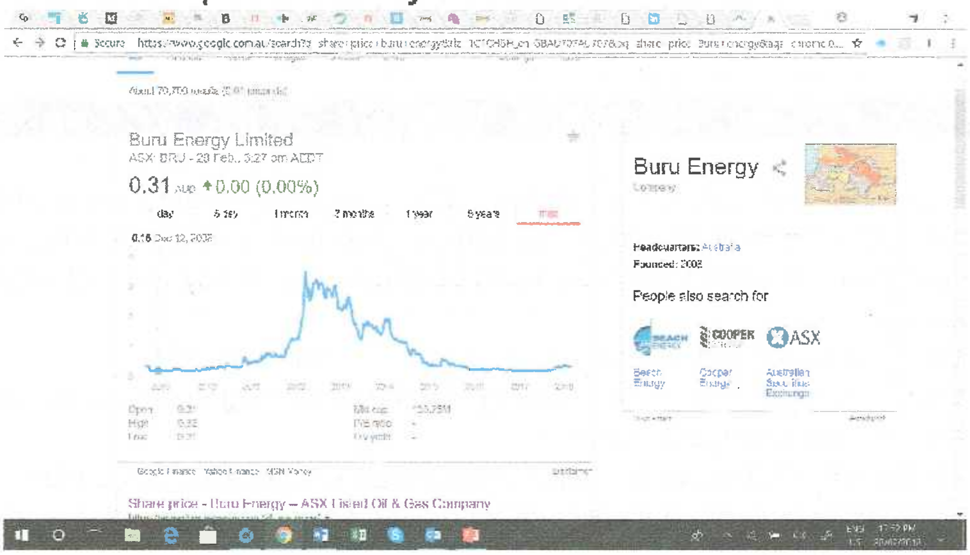

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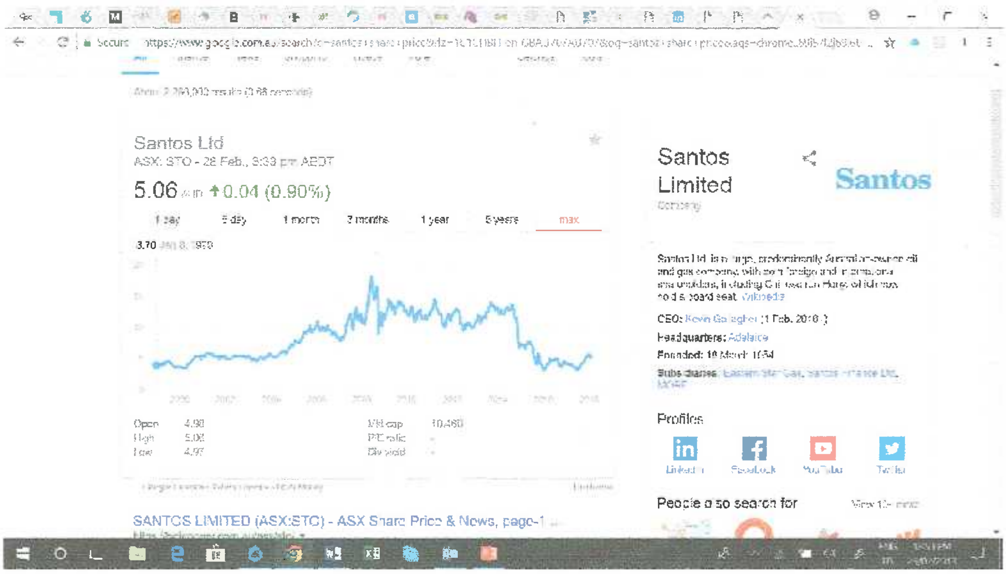

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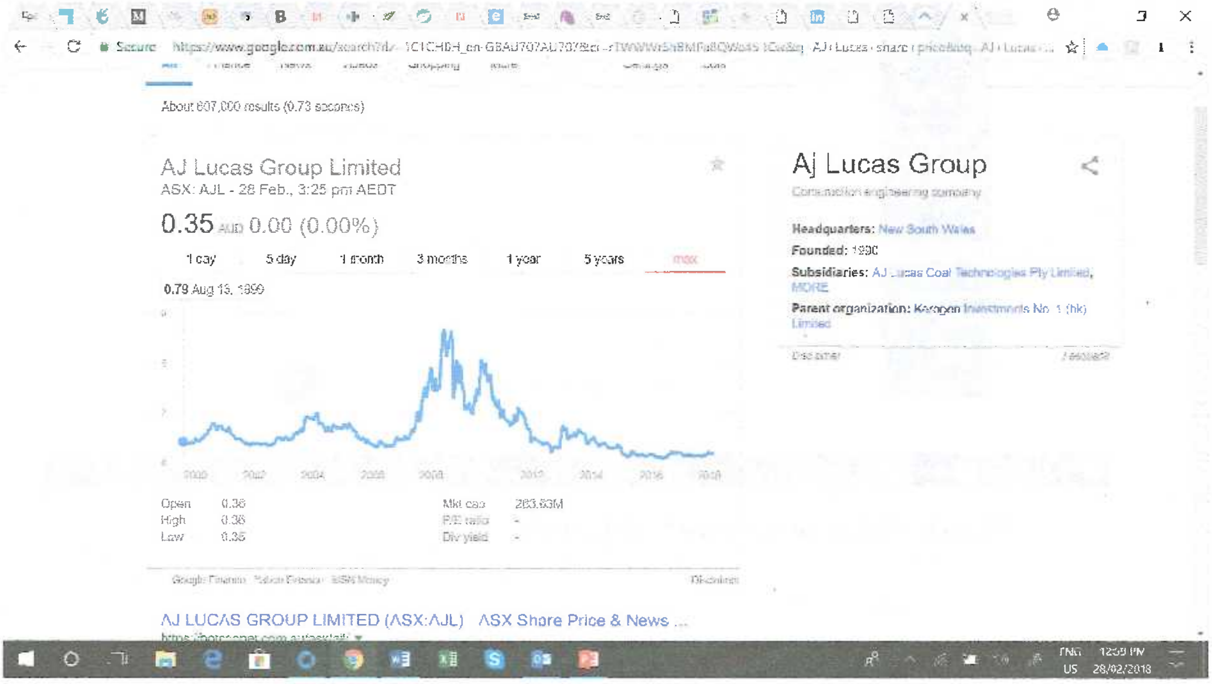

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Perth Session 2
Table 5

Sustainable Energy NOW
www.sen.asn.au

Summary Response to Scientific Inquiry into Hydraulic Fracture Stimulation

SEN opposes the development of unconventional gas fracturing due to **environmental risks** involved with exploring and producing from these sources

Future unconventional gas supplies are not needed because:

- **Renewables are cheaper** and with substantially less environmental impact/risk, and improved energy reliability & security
- **Fuel switching** from gas to electricity from renewable sources will reduce gas demand
- Current and future predicted **oversupply of conventional gas** domestically and internationally
- On-going **reliance on natural gas is unsustainable** while renewables are sustainable

SEN asserts that **unconventional gas sources will be uncompetitive** compared with conventional gas sources, because of added costs associated with fracking and infrastructure needs to transport the gas

SEN asserts that **risks associated with fracking** unconventional gas reserves **are unacceptable**:

Exploration and development phases

- Hydraulic fracturing will result in **gas seepage at high initial pressures** during well completion and upon fracturing. These pressures reduce over time.
- High risk of small exploration companies making opportunistic '**contrived value propositions**' based on potentially uncompetitive resources
- Historically, **monitoring of gas exploration is less rigorous** than production
- Small exploration companies **may not be able to meet contingent liabilities** associated with issues during Exploration

Production phase

- The most recent fugitive emissions accounting shows that methane has a Global Warming Potential >100 times that of CO_2 over 20yrs, resulting in **unconventional gas being as bad or worse than burning coal**
- Climate science indicates the need to **leave the vast majority of fossil fuel reserves in the ground** to have a 50/50 chance of staying below 2° C
- The 2017 National Greenhouse Gas Inventory shows **emissions from crude oil and gas have doubled** in Australia since 2017

If fracking is allowed, then the regulatory regime must protect the public purse, by:

- Requiring that, **to obtain Exploration Licenses, proponents must have Investment grade Public Liability insurance** including coverage of environmental consequences specific to the proposed exploration.
- Providing **no indemnification or limits of liability** of Exploration proponents.
- Requiring **extensive monitoring of all wells by government** with **cost recovery from industry**
- Requiring **bonds as surety for remediation**, and **enforceable penalties** for breaches of regulations
- Requiring proponents to **include a price on carbon emissions** in their financing applications

About Sustainable Energy Now Inc.

SEN is a non-profit association advocating for the utilization of sustainable energy sources within Western Australia. SEN brings together a mix of multidisciplinary knowledge and capability, providing impartial advice on renewable energy.

SEN's working teams consist of volunteers whose professional backgrounds include science, business, education and the environment. The teams have committed thousands of hours to developing evidence-based solutions toward transitioning WA's energy use from fossil fuels to renewables for the good of humanity, the economy and the environment, as a way for WA to play its part in the global transition to a more sustainable future.

SEN has developed sophisticated modelling software which combines NASA weather data, Geographical Information System data and the US Department of Energy technology models to calculate detailed renewable generation capacity and determine transmission network requirements. Related software then calculates balanced, costed renewable energy scenarios for each hour of the year for any grid scenario.

Representation

Ian Porter SEN Chair	40 years of experience in the oil, gas, nuclear and conventional power industries in roles ranging from R&D, project management, business development and energy technology commercialisation.
Steve Gates Convenor, SEN Tech Team	Mechanical Engineer and WA Volunteer of the Year (2016/17), consultant, with 35 years' experience, including offshore oil and gas, defence, manufacturing and agricultural projects
Dr Rob Phillips Convenor, SEN Policy Team	Retired educational design academic. Experienced project manager; scientist and science educator, technical writer.

Sustainable Energy Now (SEN) is a voluntary group of some 200 members and associates, many of whom are professionals in the engineering, science, educational, business and IT fields. Its goal is to promote renewable energy in Western Australia.	Contact details: PO Box 341 West Perth, WA 6872 contact@sen.asn.au www.sen.asn.au

Submission to: Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia 2017

Richard J Hobbs: environmental impacts of linear infrastructure associated with fracking

I am making a brief submission to the inquiry that will touch on an aspect of the environmental impact of fracking that is not covered in existing materials, namely the impacts of linear infrastructure.

Before detailing this aspect of impact, I wish to state that there are many other environmental impacts that have been well documented and are covered in other submissions to this panel. I have read, and agree with, most of the work that touches on my areas of expertise, namely biodiversity conservation, restoration, landscape ecology and ecosystem management.

Fracking, similar to other types of resource extraction, is often considered to have a relatively small development footprint. This is because the actual extraction pads cover a relatively small area. However, the assessment of the footprint and its impact needs also to take into account the linear infrastructure associated with the actual extraction infrastructure.

Where fracking has occurred elsewhere, it is accompanied by the development of a relatively dense network of roads, tracks and so on. To date, the impact of linear infrastructure has been poorly incorporated into environmental impact assessments (Alamgir *et al.*, 2018). And yet, studies from a range of locations in Australia and elsewhere clearly indicate that linear infrastructure can have significant impacts in terms of landscape fragmentation, reduced habitat suitability for key fauna species, altered surface hydrology and other features (see Raiter *et al.* (2014) for a review and examples).

Our own work, in relation to mining infrastructure in the Great Western Woodlands, has clearly demonstrated both the extent and impact of roads and tracks associated with mining development (Raiter *et al.*, 2017; Raiter *et al.*, 2018)
Our research indicated that most of the direct development footprint in the GWW is unmapped linear infrastructure, only detectable through manual digitisation. Across the 160,000 km^2 GWW, the estimated development footprint is 690 km^2, of which 67% consists of linear infrastructure and the remainder is 'hub' infrastructure. An estimated 150,000 km of linear infrastructure exists in the study area, equating to an average of ~1 km per km^2. Beyond the direct footprint, a further 4,000–55,000 km^2 (3–35% of the region) lies within offsite risk zones (Raiter et al 2017).

We also examined the impacts of tracks and roads on surface hydrology in the GWW. We found a high level of association between linear infrastructure and altered surface hydrology, with erosion and pooling 5 and 6 times as likely to occur on-road than off-road on average (1.06 erosional and 0.69 pooling features km^{-1} on vehicle tracks, compared with 0.22 and 0.12 km^{-1}, off-road, respectively). Erosion

severity was greater in the presence of tracks, and 98% of crossings of ephemeral streamlines showed some evidence of impact on water movement (flow impedance (62%); diversion of flows (73%); flow concentration (76%); and/or channel initiation (31%)). Infrastructure type, pastoral land use, culvert presence, soil clay content and erodibility, mean annual rainfall, rainfall erosivity, topography and bare soil cover influenced the frequency and severity of these impacts.

We concluded that linear infrastructure frequently affects ephemeral stream flows and intercepts natural overland and near-surface flows, artificially changing site-scale moisture regimes, with some parts of the landscape becoming abnormally wet and other parts becoming water-starved. In addition, linear infrastructure frequently triggers or exacerbates erosion, leading to soil loss and degradation. Where linear infrastructure densities are high, their impacts on ecological processes are likely to be considerable (Raiter et al 2018).

Studies elsewhere have indicated that high densities of linear infrastructure affect habitat suitability and significantly fragment the landscape (studies cited in Raiter et al 2014, for instance, relating to caribou in Canada).

Hence, from our work and work elsewhere, resource extraction activities such as fracking that involve multiple extraction points are inevitably going to involve extensive networks of linear infrastructure. Although seldom accounted for in standard environmental impact assessments, it is increasingly clear that the footprint of such linear infrastructure can be large compared to the actual extraction points, and is likely to have substantial environmental impacts.

References

Alamgir, M., Campbell, M.J., Sloan, S., Phin, W.E., & Laurance, W.F. (2018) Road risks and environmental impact assessments in Malaysian road infrastructure projects. *Jurutera, The Institution of Engineers, Malaysia*, **2018**, 13-16.

Raiter, K.G., Possingham, H.P., Prober, S.M., & Hobbs, R.J. (2014) Under the radar: Mitigating enigmatic ecological impacts. *Trends in Ecology and Evolution*, **29**, 635-644.

Raiter, K.G., Prober, S.M., Hobbs, R.J., & Possingham, H.P. (2017) Lines in the sand: quantifying the cumulative development footprint in the world's largest remaining temperate woodland. *Landscape Ecology*, **32**, 1969-1986.

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Environmental Science & Technology

Article

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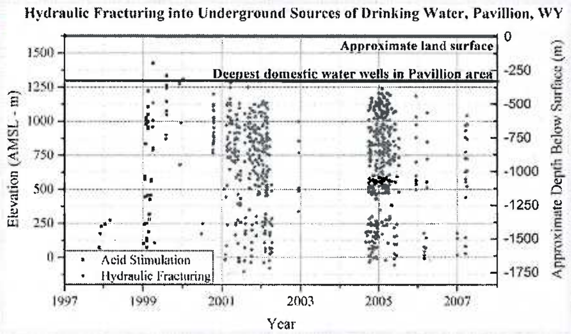
Impact to Underground Sources of Drinking Water and Domestic Wells from Production Well Stimulation and Completion Practices in the Pavillion, Wyoming, Field

Dominic C. DiGiulio*[†] and Robert B. Jackson[†,‡,§]

[†]Department of Earth System Science, [‡]Woods Institute for the Environment, and [§]Precourt Institute for Energy, Stanford University, Stanford, California 94305, United States

Ⓢ *Supporting Information*



ABSTRACT: A comprehensive analysis of all publicly available data and reports was conducted to evaluate impact to Underground Sources of Drinking Water (USDWs) as a result of acid stimulation and hydraulic fracturing in the Pavillion, WY, Field. Although injection of stimulation fluids into USDWs in the Pavillion Field was documented by EPA, potential impact to USDWs at the depths of stimulation as a result of this activity was not previously evaluated. Concentrations of major ions in produced water samples outside expected levels in the Wind River Formation, leakoff of stimulation fluids into formation media, and likely loss of zonal isolation during stimulation at several production wells, indicates that impact to USDWs has occurred. Detection of organic compounds used for well stimulation in samples from two monitoring wells installed by EPA, plus anomalies in major ion concentrations in water from one of these monitoring wells, provide additional evidence of impact to USDWs and indicate upward solute migration to depths of current groundwater use. Detections of diesel range organics and other organic compounds in domestic wells <600 m from unlined pits used prior to the mid-1990s to dispose diesel-fuel based drilling mud and production fluids suggest impact to domestic wells as a result of legacy pit disposal practices.

■ INTRODUCTION

Between 2005 and 2013, natural gas production in the U.S. increased by 35% largely due to unconventional gas production in shale and tight gas formations.[1] Between 2013 and 2040, natural gas production is expected to increase another 45% with production from tight gas formations in particular increasing from 4.4 to 7.0 trillion cubic feet (59%) primarily in the Gulf Coast and Dakotas/Rocky Mountain regions.[1] Tight gas formations already account for 26% of total natural gas production in the United States today.[2]

In the U.S. Code of Federal Regulations (CFR), there are two federal regulations for protecting groundwater resources for present and future use relevant to oil and gas extraction – "Underground Source of Drinking Water" (USDW) and "usable water." A USDW is defined in 40 CFR 144.3 in requirements for the Underground Injection Control program promulgated under Part C of the Safe Drinking Water Act (SDWA) as "an aquifer or its portion: (a)(1) Which supplies any public water system; or (2) Which contains a sufficient quantity of ground water to supply a public water system; and (i) Currently supplies drinking water for human consumption; or (ii) Contains fewer than 10 000 mg/L total dissolved solids; and (b) Which is not an exempted aquifer." With the exception of use of diesel fuels, the Energy Policy Act of 2005 ("EPAct") exempted hydraulic fracturing from the SDWA, thereby allowing injection of stimulation fluids into USDWs. However, under Section 1431 of the SDWA, the Administrator of EPA may take action if impact to a USDW "may present an imminent and substantial endangerment to the health of persons."

The term "usable water" applies to lands containing federal or tribal mineral rights regulated by the Bureau of Land Management (BLM). This term is applicable to the Pavillion Field because tribal mineral rights are associated with more than half of production wells there. In the BLM Onshore Oil and Gas Order No. 2, usable water is defined as water containing ≤10 000 mg/L total dissolved solids (TDS) – a definition maintained in the March 2015 BLM rule on hydraulic fracturing (43 CFR 3160). In 43 CFR 3160, BLM retained a threshold for groundwater protection at 10 000 mg/L stating, "Given the increasing scarcity and technological improvements in water treatment, it is not unreasonable to assume aquifers with TDS levels above 5000 ppm are usable now or will be usable in the future." However, on September 30, 2015, the U.S. District Court for Wyoming granted a

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preliminary injunction filed by the States of Wyoming and Colorado to stop implementation of the BLM rule based on the assertion that the EPAct precludes BLM rulemaking.[3]

In 2004, EPA[4] documented the widespread use of hydraulic fracturing in USDWs colocated in formations used for coal bed methane (CBM) recovery. EPA[4] acknowledged likely groundwater contamination as a result of this activity but stated that the attenuation factors of dilution, adsorption, and biodegradation would reduce contaminant concentrations to safe levels prior to reaching domestic wells that are generally shallower than production wells. Thus, EPA[4] distinguished impact to USDWs from impact to domestic wells. In 2014, while defining the chemical abstract numbers of fluids designated as diesel fuels, EPA revised its position and stated that injecting stimulation fluids directly into USDWs "presents an immediate risk to public health because it can directly degrade groundwater, especially if the injected fluids do not benefit from any natural attenuation from contact with soil, as they might during movement through an aquifer or separating stratum."[5]

The Pavillion Field (Figure 1) is located east of the Town of Pavillion in Fremont County, WY, in the west-central portion

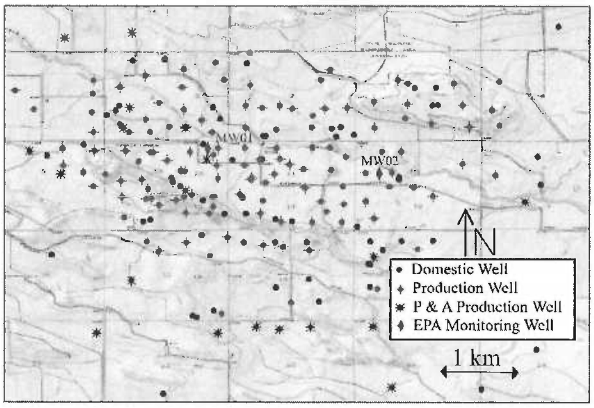

Figure 1. Central portion of the Pavillion Field illustrating locations of domestic water wells, production wells, plugged and abandoned (P&A) wells, and EPA monitoring wells (labeled). The entire Field, with labels for production and domestic wells and approximate locations of unlined pits, is illustrated in Figure SI A5. The geographic area in which the Field is located is illustrated in Figure SI A1.

of the Wind River Basin (WRB) (Figure SI A1). The field consists of 181 production wells including plugged and abandoned wells. Conventional and unconventional (tight gas) hydrocarbon production in the Pavillion Field is primarily natural gas from sandstone units in the Paleocene Fort Union and overlying Early Eocene Wind River Formations. However, oil has also been produced from production wells in these formations, primarily in the western portion of the field close to the suspected location of a fault (SI Sections A.1 and A.2).

In response to complaints regarding foul taste and odor in water from domestic wells within the Pavillion Field, EPA initiated a groundwater investigation in September 2008 under the Comprehensive Environmental Response and Liability Act (CERCLA).[6] This investigation remains the only one in which CERCLA has been invoked to investigate potential groundwater contamination due to hydraulic fracturing.[7] Under CERCLA, impact to both groundwater resources and domestic wells is evaluated, in contrast to limiting evaluation to impact to domestic wells as is common in oil- and gas-field-based investigations.

EPA conducted two domestic well sampling events in March 2009 (Phase I)[6] and January 2010 (Phase II).[8] Between June and September 2010, EPA installed two monitoring wells, MW01 and MW02, using mud rotary drilling with screened intervals at 233−239 m and 296−302 m below ground surface (bgs), respectively. These monitoring wells were installed to evaluate potential upward solute transport of compounds associated with well stimulation to maximum depths of current groundwater use (~322 m).[9] EPA sampled MW01 and MW02 during the Phase III (October 2010) and Phase IV (April 2011) sampling events.

In December 2011, EPA[9] released a draft report summarizing results of the Phase I−IV sampling events. EPA documented groundwater contamination in surficial Quaternary unconsolidated alluvium attributable to numerous unlined pits used for disposal of diesel-oil-based (invert) drilling mud and production fluids including flowback, condensate, and produced water prior to the mid-1990s. EPA[9] also documented injection of stimulation fluids into USDWs and concluded that inorganic and organic geochemical anomalies at MW01 and MW02 appeared to be attributable to production well stimulation. EPA received numerous comments both challenging and supporting its findings in the draft EPA report.[10−37] We reviewed and considered these comments when preparing this manuscript.

A substantial amount of data has been collected since publication of the 2011 draft EPA report, adding to an already extensive data set. In April 2012 (Phase V) the EPA[38,39] split samples with the U.S. Geological Survey at MW01[40,41] and MW02.[42] In 2014, the Wyoming Oil and Gas Conservation Commission (WOGCC) released a report on production well integrity[43] and in 2015 released a report on surface pits.[44] In December 2015, the Wyoming Department of Environmental Quality (WDEQ) released a report on sample results of a subset of domestic wells previously sampled by EPA.[45]

We conducted a comprehensive analysis of all publicly available online data and reports, to evaluate impact to USDWs and usable water as a result of acid stimulation and hydraulic fracturing. Although injection of stimulation fluids into USDWs in the Pavillion Field was previously documented by EPA,[9] the potential impact to USDWs at depths of stimulation was not assessed. We evaluate potential upward migration of contaminants to depths of current groundwater use using data from MW01 and MW02. We also evaluate potential impact to domestic wells as a result of legacy disposal of production and drilling fluids in unlined pits.

■ MATERIALS AND METHODS

Sources of EPA reports, versions of the Quality Assurance Project Plan (QAPP), and Audits of Data Quality (ADQs) are provided in Table SI H1. Sources of analytical data and associated information on quality assurance and control are summarized in Table SI H2. ADQs were conducted by EPA for Phase I−IV investigations to verify the quality of analytical data and consistency with requirements specified in the QAPP.

In response to a comprehensive information request by EPA regarding oil and gas production and disposal activities in the Pavillion Field, the field operator, Encana Oil & Gas (U.S.) Inc., provided Material Safety and Data Sheets (MSDSs) of products used for well stimulation to EPA[46] (Table SI C3). During the Phase V sampling event, EPA developed a gas chromatography-

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Table 1. Summary of Major Ion Concentrations of Domestic Wells in the Wind River Indian Reservation (WRIR), Fremont County, WY, and within and around the Pavillion Field

	WRIR[a]			Fremont County[b]			within and around Pavillion Field[c]		
parameter (mg/L)	n	median	range	n	median	range	n	median	range
TDS	154	490	211–5110	77	1030	248–5100	65	925[†]	229[†]–4901[†]
Ca	149	10	1–486	77	45	1.7–380	48	50.8	3.32–452
Mg	128	2.2	0.1–195	77	8.2	0.095–99	45	5.32	0.024–147
Na	153	150	5–1500	77	285	4.5–1500	72	260	38.0–1290
K	149	2.0	0.2–30	77	2.45	0.1–30	43	1.36	0.179–10.5
SO_4	154	201	2–3250	77	510	12–3300	88	590	29.0–3640
Cl	154	14	2–466	77	20	3–420	48	21.1	2.60–77.6
F	154	0.7	0.1–8.8	76	0.9	0.2–4.9	46	0.88	0.20–4.1

[a]With the exception of potassium, from Daddow.[48] Information on potassium extracted from Daddow.[53] [b]From Plafcan et al.[51] There is overlap of 19 sample results with Daddow.[48,53] [c]Major ion concentrations in domestic wells[6,8,9,39,45,52] summarized in Table SI B2. Mean values used for domestic wells sampled more than once. [n]Number of sample results. [†]TDS for EPA data estimated using linear regression equation from Daddow[48] TDS (mg/L) = 0.785 × specific conductance (μs/cm) − 130 (n = 151, r^2 = 0.979)

flame ionization-based approach to obtain a lower reporting limit (50 μg/L) for methanol compared to commercial laboratory analysis (5000 μg/L). We obtained this data set as the result of a Freedom of Information Act request to EPA.[47]

We reviewed over 1000 publicly available well completion reports, sundry notices, drilling reports, and cement bond and variable density logs accessed from the WOGCC Internet site using API search numbers to determine dates of well completion, depths of surface casing, top of original or primary cement, and numbers and depths of cement squeeze jobs (injection of cement through perforated production casing to remediate or extend existing primary cement). Similarly, we reviewed online information to document well stimulation practices summarized in Tables SI C1 and SI C2.

The field operator analyzed major ions in produced water samples at 42 production wells in 2007 (Table SI D1). EPA collected produced water samples at four production wells in 2010 and analyzed them for organic compounds (Table SI D3).[8] The field operator also conducted mechanical integrity and bradenhead (annular space between production and surface casing) testing between November 2011 and December 2012. In addition to sustained casing pressure at many production wells during that period (Table SI D2), water flowed through the bradenhead valve to the surface at four production wells (SI Section D.3). Aqueous analysis of bradenhead water samples by the field operator was limited to major ions (Table SI D1). Production well string and brandenhead gas samples were collected for benzene, toluene, ethylbenzene, xylenes (BTEX) and light hydrocarbons (Table SI D2).

To evaluate the effect of purging volume on water quality, EPA collected ten samples through time (Table SI 3a) during the Phase V sampling event at MW01. Based on EPA's purging procedure, we developed a model incorporating plug flow in casing and mixing in the screened interval (SI Section E.3, Figure SI E4). Our simulations indicated that virtually all (99.997%) of water entering the sampling train at the surface at the time of the first sample collection at MW01 originated directly from the surrounding formation (i.e., no stagnant casing water) (Figure SI E6). MW02 was a low flow monitoring well. The cause of low flow is unknown but could be due to several factors, including low relative aqueous permeability due to gas flow or insufficient removal of drilling mud during well development. During the Phase V sampling event, MW02 was repeatedly purged over a 6-day period to ensure that sampled water originated from the surrounding formation (SI Section E.2, Figure SI E5). A discussion of monitoring well construction, including schematics for MW01 (Figure SI E1) and MW02 (Figure SI E2), is provided in SI Section E.1.

■ RESULTS AND DISCUSSION

Groundwater Resources in the Pavillion Area. The Wind River and Fort Union Formations are variably saturated fluvial depositional systems characterized by shale and fine-, medium-, and coarse-grained sandstone sequences. Lithology is highly variable and difficult to correlate from borehole data. No laterally continuous confining layers of shale exist below the maximum depth of groundwater use to retard upward solute migration. A comprehensive review of regional and local geology, including a lithologic cross-section in the vicinity of MW01 and MW02 (Figure SI A4), is provided in SI Sections A.1–A.6.

Domestic wells in the Pavillion area draw water from the Wind River Formation—a major aquifer system in the WRB.[48,49] From the surface to approximately 30 m bgs, groundwater exists under unconfined conditions.[50] Below this depth, groundwater is present in lenticular, discontinuous, confined sandstone units with water levels above hydrostatic pressure, and in some instances flowing to the surface,[48,50,51] indicating the presence of strong localized upward gradients. The majority of documented domestic well completions in Fremont County[51] and five municipal wells in the Town of Pavillion[52] west of the Field are completed in the Wind River Formation.

Flow to the surface was observed in a domestic well during the Phase II sampling event,[6] and as mentioned, at four production wells during bradenhead testing in 2012. While the overall vertical groundwater gradient in the Pavillion Field is downward, these observations indicate that localized upward hydraulic gradients exist in the Field, which is relevant to potential upward solute migration from depths of production well stimulation. The deepest domestic wells in the Pavillion Field and immediate surrounding area are 229 and 322 m bgs, respectively (Table SI B1). Two municipal wells were proposed, but not drilled, in the Pavillion Field as replacement water for domestic wells at depths of 305 m bgs,[52] similar to the depth of MW02 installed by EPA.

Major ion concentrations of domestic wells in the Pavillion field (summarized in Table SI B2) are typical of the Wind River Indian Reservation (WRIR),[48] west of the Pavillion Field, and

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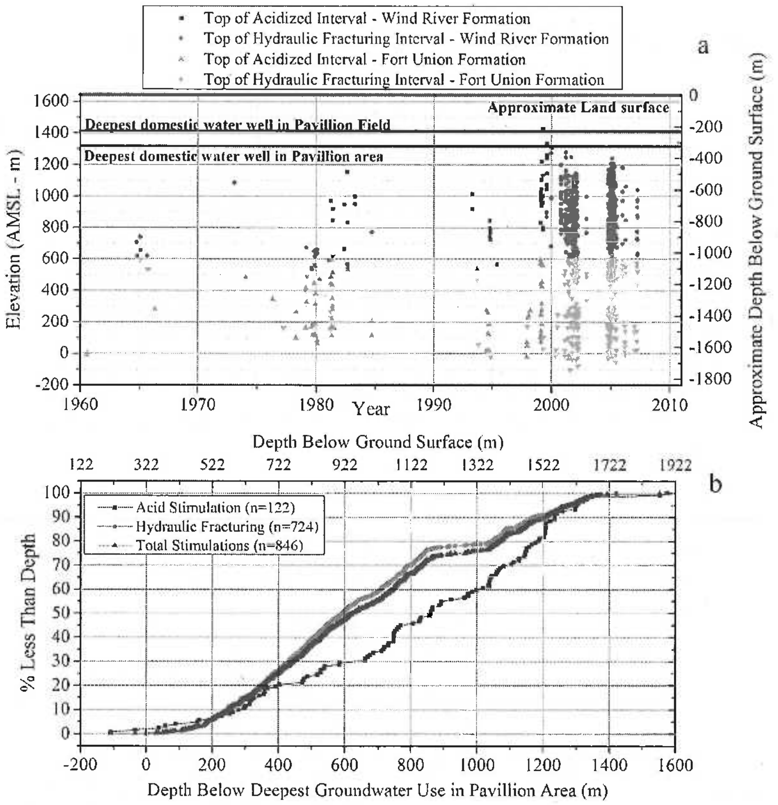

Figure 2. (a) Elevation in absolute mean seal level (AMSL) and approximate depth below ground surface of documented acid and hydraulic fracturing stimulation stages. (b) Cumulative distribution of stimulation stages as a function of depth below deepest groundwater use in the Pavillion Field. Documentation of stimulation stages is absent at a number of production wells so that numbers presented here are a lower bound.

in Fremont County,[51] where the Pavillion Field lies, (Table 1) with TDS levels <5000 mg/L. TDS concentrations in the Wind River Formation appear to vary with lithology rather than depth (white coarse sandstone associated with lower TDS values).[52] There are no apparent trends in TDS levels with depth from data sets from the WRIR,[53] Fremont County,[51] and domestic wells in and around the Pavillion Field.

The Fort Union Formation is not used for water supply in the Pavillion area. However, the formation is highly productive and permeable where fractured[49] with TDS values from 1000 to 5000 mg/L.[54] An aquifer exemption was obtained to enable disposal of produced water in a disposal well perforated in the Fort Union Formation[55] at a location 5.6 km northwest of the Pavillion Field. Use of this well was suspended due to failure of well casing. Thus, the Wind River and Fort Union Formations in the Pavillion Field meet the regulatory definition of USDWs, as explicitly stated by EPA,[9,55] and of usable water as defined by the BLM.

Well Stimulation Depths, Treatments, and Chemical Additives. Exploration of oil and gas in the Pavillion Field commenced in August 1953 with increasingly shallow stimulations through time (Figure 2). The first acid stimulation and hydraulic fracturing stages (injection over one or more discrete intervals) occurred in June 1960 and October 1964, respectively. Acid stimulation ceased in 2001. To date, the last stimulation stage (hydraulic fracturing) occurred in April 2007. Most production wells were completed and stimulated during several periods of increased activity, especially after 1997 (Figure 2a). Acid stimulation and hydraulic fracturing occurred as shallowly as 213 and 322 m bgs, respectively, at depths comparable to deepest domestic groundwater use in the area (Figure 2a). Approximately 10% of stimulation stages were <250 m of deepest domestic groundwater use whereas approximately 50% of stimulation stages were <600 m and 80% were <1 km of deepest domestic groundwater use (Figure 2b).

Surface casing of production wells—the primary line of defense to protect groundwater during conventional and unconventional oil and gas extraction—is relatively shallow in the Pavillion field with a median depth of 185 m bgs (i.e., shallower than the deepest groundwater use) and range of 100–706 m bgs (Figure SI C1). There is no primary cement below surface casing, often for hundreds of meters, for 55 of 106 (~52%) production wells for which cement bond logs are available (Table SI C1, Figure SI CI). There is currently no requirement in Wyoming for placement of primary cement to surface casing or to ground surface.[45]

Instantaneous shut in pressures (ISIP) (wellhead gauge pressure immediately following fracture treatment) were similar for acid stimulation and hydraulic fracturing (Figure SI C2) suggesting that both matrix acidizing and acid fracturing (no proppants used[56]) occurred in the Pavillion Field. Acidizing solutions used in the Pavillion Field typically consisted of a 7.5% or 15% hydrochloric acid solution plus additives described in well completion reports as inhibitors, surfactants, diverters, iron sequestration agents, mutual solvents, and clay stabilizers.

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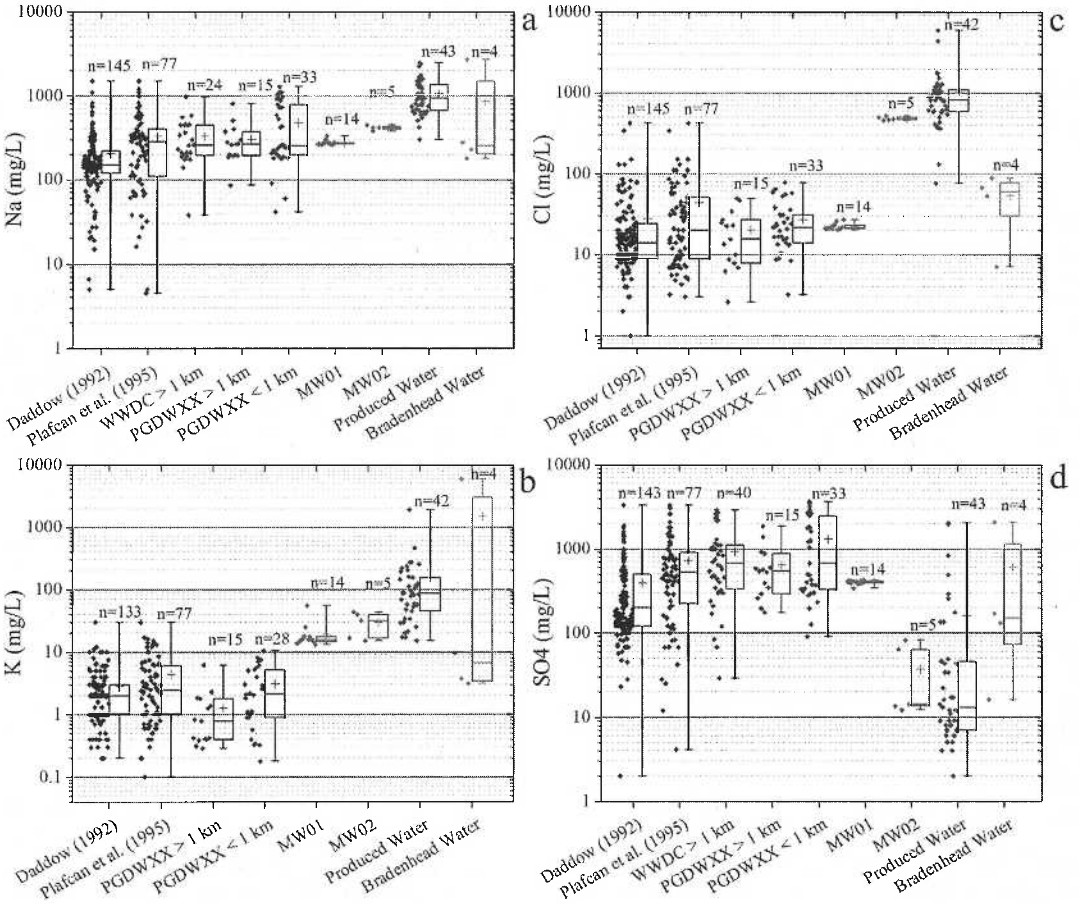

Figure 3. Box and whisker plots of minimum and maximum, quartiles, median (line in boxes), mean (crosses in boxes) of (a) Na, (b) K, (c) Cl, (d) SO_4 for domestic wells inventoried by Daddow[48,53] and Plafcan[51] in the Wind River Indian Reservation and Fremont County, respectively, sampled by EPA[6,8,9,39] and WDEQ[45] (PGDWXX series) greater than and less than 1 km from a production well, Wyoming Water Development Commission[52] (WWDC series) greater than 1 km from a production well, EPA monitoring wells[9,39] (Tables SI E2b, SI E3b), and produced water and bradenhead water samples (Table SI D1). Domestic wells sampled more than once, including data from Daddow,[53] are represented with a mean value. Fourteen measurements in Daddow[53] < 1 mg/L for potassium are not illustrated. Data points at MW01 and MW02 are samples collected during Phase III, IV, and V sample events.

Acidizing solutions were often flushed with a 2, 4, or 6% potassium chloride (KCl) solution. Pad acid, to initiate fractures, contained 10−50% heavy aromatic petroleum naptha. Corrosion inhibitors contained isopropanol and propargyl alcohol. Clay stabilizers contained methanol. Musol solvents used for acid stimulation consisted of 60−100% 2-butoxyethanol and 10−30% oxylated alcohol (Table SI C3).

Prior to 1999, "salt solutions" were commonly used for hydraulic fracturing. After 1999, a 6% KCl solution was used extensively for hydraulic fracturing often combined with CO_2 foam, with subsequent flushing using a 6% KCl solution. There were reported losses of KCl solutions during stimulation (e.g., at Tribal Pavillion 12−13 "lost thousands of bbls KCl"). Undiluted diesel fuel was used for hydraulic fracturing at three production wells before 1985. From the mid-1970s through 2007, there was widespread use of gelled fracture fluids (gelled water, linear gel, and cross-linked gel). Diesel fuel #2 was used for liquid gel concentrates (Table SI C3). Ammonium chloride, potassium hydroxide, potassium metaborate, and a zirconium complex were used as cross-linkers.

Gelled fracture fluids were used extensively with CO_2 foam (Table SI C4). Between 2001 and 2005, "WF-125" was used with CO_2 foam (often with a 6% KCl solution) for hydraulic fracturing (Table SI C5). A stimulation report (one of only three publicly available throughout the operating history of the Field) and MSDSs indicate that WF-125 contained diesel fuel #2, 2-butoxyethanol, isopropanol, ethoxylated linear alcohols, ethanol, and methanol. During 2001, WF-125 and unidentified product mixtures were used with a 6% KCl and a 10% methanol solution and CO_2 foam for hydraulic fracturing followed with a 6% KCl and 10% methanol solution flush. Other WF-series compound mixtures of unknown composition were also used with CO_2 foam and in some cases with N_2 gas. Methanol, isopropanol, glycols, and 2-butoxyethanol were used in foaming agents (Table SI C3). Ethoxylated linear alcohols, isopropanol, methanol, 2-butoxyethanol, heavy aromatic petroleum naptha, naphthalene, and 1,2,4-trimethylbenzene were used in surfactants (Table SI C3). Slickwater (commonly with a 6% KCl solution) was used for hydraulic fracturing with and without CO_2 foam in 2004 and 2005, respectively (Table SI C6).

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At least 41.5 million liters (or ~11 million gallons) of fluid was used for well stimulation in the Pavillion Field (calculated from Table SI C2). Given lack of information at numerous production wells, this is an underestimate of actual cumulative stimulation volume. The cumulative volume of well stimulation in closely spaced vertical wells in the Pavillion Field is characteristic of high volume hydraulic fracturing in shale units.[57] In evaluating solute attenuation in USDWs, EPA[4] did not consider cumulative volumes of injection of well stimulation fluids in closely spaced vertical production wells common to CBM and tight gas production.

Evaluation of Impact to USDWs and Usable Water. In the Pavillion Field, impact to USDWs and usable waters depends upon the advective-dispersive solute transport of compounds (or their degradation products) used for well stimulation to water-bearing units (sandstone units at or near water saturation). Water-bearing units exist throughout the Wind River and Fort Union Formations in the Pavillion Field. For instance, production well Unit 41X-10 was recommended for plugging and abandonment in 1980 because of "problems with water production and casing failure." In 1980, drilling logs at Tribal Pavillion 14–2 stated "Hit water flow while drilling at 4105–4109 ft" bgs. The magnitude of produced water production in the Pavillion Field is variable with some wells having high produced water production (e.g., 17.9 million liters ~4.7 million gallons at Tribal Pavillion 23–10 from July 2000 to present) (Table SI C2). In some cases, stimulation fluids were injected directly into water bearing units. For instance, at Tribal Pavillion 14–1, a cast iron bridge plug was used to stop water production in 1993 from an interval where hydraulic fracturing occurred using undiluted diesel fuel in 1964 (Table SI C2).

The migration of stimulation fluid to water-bearing sandstone units in the Pavillion Field also likely occurred during fracture propagation and subsequent leakoff (loss of fluid into a formation in or near the target stratum). Leakoff increases in complex fracture networks as a result of lithologic variation over short distances and contact of stimulation fluid with permeable strata[58–61] expected during hydraulic fracturing in fluvial depositional environments of the Wind River and Fort Union Formations. Leakoff can remove much or most of the fracturing fluid even for moderate sized induced fractures.[58,59] Maximum ISIP values for acid stimulation and hydraulic fracturing were 19.5 and 40.1 MPa (Figure SI C2), respectively, equivalent to ~2000 and ~4100 m of hydraulic head. Pressure buildup during hydraulic fracturing far in excess of drawdown expected during produced water extraction makes full recovery of stimulation fluids unlikely.[4,62]

The migration of stimulation fluids to water-bearing units also likely occurred as a result of loss of zonal isolation during well stimulation (SI Section D.1). Casing failure occurred at five production wells following well stimulation. Cement squeezes were performed above primary cement often days after hydraulic fracturing without explanation[63] at six production wells, potentially because of migration of stimulation fluid above primary cement. At one production well, stimulation fluid was injected just 4 m below an interval lacking cement outside of the production casing with a stimulation pressure of only 1.3 MPa indicating potential entry into the annular space.

Major ion concentrations in produced water sampled after stimulation (Table SI D1) were distinct from values expected in the Wind River Formation as evidenced by sample data from the WRIR,[48,53] Fremont County,[51] and domestic wells in and around the Pavillion Field which were representative of the Wind River Formation regardless of distance from production wells (Table 1, Figure 3). Using combined data sets in and around the Pavillion Field, and the nonparametric Mann–Whitney test (null hypothesis that two sample sets come from the same population), sodium, potassium, and chloride concentrations were higher and sulfate concentrations lower in produced water compared to concentrations expected in the Wind River Formation ($p = 6.6 \times 10^{-19}$, 2.1×10^{-15}, 2.6×10^{-16}, and 4.4×10^{-19}, respectively), providing direct evidence of impact to USDWs at depths of stimulation. Also, potassium increased with calcium concentrations and sulfate increased with TDS concentrations, respectively, in domestic wells but not in production wells (Figures SI D1). Chloride is a major component of TDS concentrations in production wells. Potassium/calcium and chloride/sulfate concentration ratios were higher in production wells than in domestic wells (Figures SI D2), further indicating anomalous potassium, chloride, and sulfate concentrations in production wells.

Produced water samples were collected from gas–water separators at four production wells and analyzed for organic compounds (Table SI D3, Figure SI D3) during the Phase II sampling event.[6] Samples from one production well appeared to be from both an aqueous and an apparent nonaqueous phase liquid with the latter exhibiting thousands of mg/L of benzene, toluene, ethylbenzene, xylenes (BTEX). Synthetic organic compounds methylene chloride and triethylene glycol (TEG) were detected in produced water samples at 0.51 and 17.8 mg/L, respectively indicating anthropogenic origin. Methylene chloride has been detected in flowback water in other systems,[64] including 122 domestic wells above the Barnett Shale TX,[65] and in air sampled near well sites.[66]

Sample Results at MW01 and MW02. Concentrations of potassium in MW01 and MW02 were higher than expected values in the Wind River Formation (Figure 3) at *p*-values of 2.6×10^{-13} and 1.2×10^{-06}, respectively. High pH values (>11 standard units) were observed during purging at both monitoring wells (Tables SI E3b, SI E4b, Figures SI E5, SI E6, SI E7), indicating that elevated potassium concentrations may have been attributable to release of potassium from potassium oxides and sulfates during curing of cement[67–71] used for monitoring well construction. However, a number of observations were inconsistent with cement interaction as a causative factor for elevated pH, and there was extensive use of compounds containing potassium including potassium hydroxide during stimulation (Table SI C3). Water in contact with hydrating cement is saturated or oversaturated to portlandite ($Ca(OH_2)$)[72–74] and remains oversaturated prior to degradation or carbonation.[75–78] In contrast, water from monitoring wells was highly undersaturated to portlandite. Elevated pH in monitoring wells was not observed during monitoring well development until natural gas intrusion occurred in the wells, suggesting degassing as a possible cause of elevated pH (SI Section E.5). Also, potassium was detected at a concentration of 6000 mg/L in a bradenhead water sample having a pH of 10.86 standard units from Tribal Pavillion 13–1 (Table SI D1). This may indicate either high potassium concentration at depths below EPA monitoring wells due to well stimulation (water from bradenhead samples originated at some unknown distance above cement outside production casing at each production well) or interaction of bradenhead water with wellbore cement.

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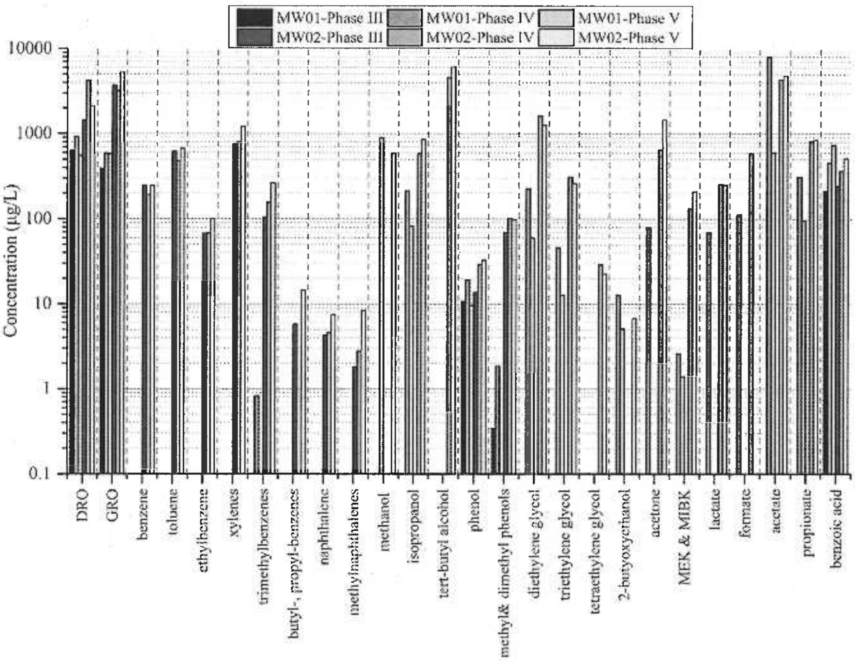

Figure 4. Summary of organic compounds detected by EPA in MW01 and MW02 during Phase III, IV, and V sampling events. Glycols, alcohols, and low molecular weight organic acids were not analyzed in Phase III. Alkylphenols and methanol (GC-FID method) were only analyzed in Phase V. Organic compounds detections for MW01 and MW02 are summarized in Table SI E3a and Table SI E4a, respectively.

The median chloride concentration at MW02 was 469 mg/L (Figure 3), well above expected values in the Wind River Formation ($p = 7.0 \times 10^{-07}$). Compounds containing chlorides (e.g., KCl solutions) were used extensively for stimulation in the Pavillion Field. Sulfate concentrations in MW02 were below expected values in the Wind River Formation ($p = 2.7 \times 10^{-07}$) and not dissimilar ($p = 0.40$) to produced water concentrations. The Cl/SO_4 concentration ratio was similar to produced water (Figure SI D2) at MW02. Chloride and sulfate concentrations in MW01 were more typical of the Wind River Formation which may be due variation in well stimulation practices both spatially and over time.

Concentrations of organic compounds detected in MW01 and MW02 are summarized in Tables SI E3a, SI E4a and Figure 4. Diesel range organics (DRO) and gasoline range organics (GRO) were detected in MW01 and MW02 with maximum DRO concentrations of 924 and 4200 μg/L, respectively and GRO concentrations of 760 and 5290 μg/L, respectively. Benzene, toluene, ethylbenzene, *m,p*-xylenes, and *o*-xylene were detected in MW02 at maximum concentrations of 247, 677, 101, 973, and 253 μg/L, respectively, but were not detected at MW01. The maximum contaminant level (MCL) of benzene is 5 μg/L, so the observed maximum value was 50 times higher than the MCL. Nondetection of BTEX at MW01 is surprising given that the well was gas-charged (foaming during sampling, Figure SI E9) with similar light hydrocarbon composition to MW02 (Table SI E5). Nondetection of BTEX may be due to increased dispersion and biodegradation of these compounds at the shallower depth of this well. We could find no published information on BTEX compounds in groundwater at concentrations detected in MW02 occurring above a gas field in the absence of well stimulation. However, further testing, such as compound specific isotope analysis of BTEX components present in natural gas from the Pavillion Field (Table SI D2) and water from MW02, is necessary to attribute detection of BTEX to well stimulation.

1,3,5-, 1,2,4-, and 1,2,3-Trimethylbenzene were detected at maximum concentrations of 71.4, 148, and 45.8 μg/L, respectively in MW02 and at an order of magnitude lower concentrations in MW01. Naphthalene, methylnaphthalenes, and alkylbenzenes were also detected in MW02 at concentrations up to 7.9, 10.2, and 21.2 μg/L, respectively. Similar to BTEX compounds, detection of trimethylbenzenes, alkylbenzenes, and naphthalenes could in principle reflect non-anthropogenic origin but natural gas from the Pavillion Field and in EPA monitoring wells is "dry" (ratio of methane to methane through pentane concentration >0.95) (SI Section A.2, Table SI E5). Also, oil production in the vicinity of monitoring wells is very low or zero especially in the vicinity of MW02 (Table SI C2, Figure SI A5). Thus, the detection of higher molecular weight hydrocarbons in groundwater is unexpected. Trimethylbenzenes and naphthalenes were present in mixtures used for well stimulation (Table SI C3).

Other organic compounds used extensively for well stimulation were detected in MW01 and MW02 (Figure 4). Methanol, ethanol, and isopropanol were detected in monitoring wells at up to 863, 28.4, and 862 μg/L, respectively (Figure 4). *Tert*-butyl alcohol (TBA) was detected at 6120 μg/L in MW02. Detection of TBA in groundwater has been associated with degradation of *tert*-butyl hydroperoxide used for hydraulic fracturing.[79] Another potential source of TBA is degradation of methyl *tert*-butyl ether (MTBE) associated with diesel fuel.[80−84]

Diethylene glycol (DEG) and TEG were detected in both monitoring wells at maximum concentrations of 226 and 12.7 μg/L, respectively, in MW01, and at 1570 and 310 μg/L respectively, in MW02 (Figure 4). Tetraethylene glycol was detected only in MW02 at 27.2 μg/L. MSDSs indicate that

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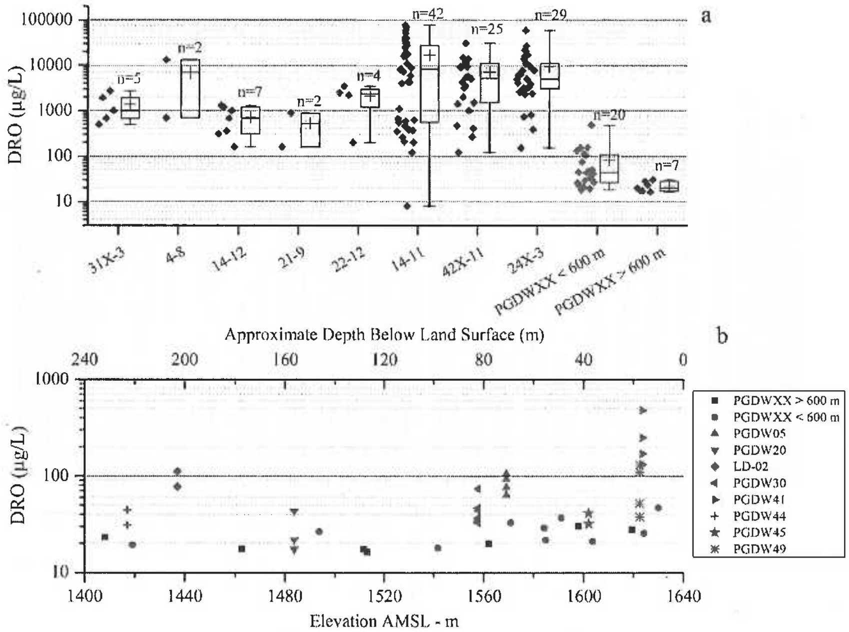

Figure 5. (a) Box and whisker plots of minimum and maximum, quartiles, median (line in boxes), mean (crosses in boxes) of diesel range organics (DRO) in shallow monitoring wells near unlined pits potentially receiving production fluids (abbreviations of production wells in Table SI C1) and domestic wells[6,8,9,39,45] (LD-20 and PGDWXX series) less than and greater than 600 m from pits. Mean values are used for domestic well sampled more than once. (b) DRO as a function of elevation and approximate depth below surface for domestic wells with results of multiple sample events illustrated.

DEG was used for well stimulation. Use of TEG was not specified. Polar organic compounds, including DEG, are commonly used as cement grinding agents.[85−88] DEG and TEG have been detected in leachate from cured cement samples under static (no flow) conditions.[89] Similar to elevated potassium detection, it is possible that detection of glycols could be attributable to cement used for monitoring well construction. However, mass flux scenario modeling, commonly used to evaluate potential concentrations of exposure of compounds released from materials in contact with drinking water under dynamic (flowing) conditions,[90] was conducted on MW01 (SI Section E.7) indicating unlikely impact. The relevance of dynamic testing is corroborated by the observation that detection of DEG and TEG was limited to a water sample from a gas production well[91] with nondetection in water samples from 83 domestic wells at five retrospective study sites[79,91−94] using high performance liquid chromatography with dual mass spectrometry at a reporting limit 5 μg/L in EPA's national study on hydraulic fracturing. 2-Butoxyethanol, a glycol ether used extensively for well stimulation in the Pavillion Field (Table SI C3), was detected in both monitoring wells at a maximum concentration of 12.7 μg/L. 2-Butoxyethanol was not detected in leachate from cured cement.[89].

The low molecular weight organic acids (LMWOAs) lactate, formate, acetate, and propionate were detected in both monitoring wells at maximum concentrations of 253, 584, 8050, and 844 μg/L, respectively (Figure 4). LMWOAs are anaerobic degradation products associated with hydrocarbon contamination in groundwater.[95,96] Acetate has been detected in produced water,[97−99] in impoundments used to hold flowback water from the Marcellus Shale,[100] and in produced water from the Denver-Julesburg Basin, CO.[101] Acetate and formate were detected in flowback water from two different fracturing sites in Germany with investigators concluding that these compounds were likely of anthropogenic origin resulting from degradation of polymers used in the fracturing fluid.[102] Formate and acetate are also degradation products of methylene chloride.[103] Benzoic acid, a degradation product of aromatics, was also detected in both monitoring wells at a maximum concentration of 513 μg/L.

Phenols were detected in both monitoring wells with maximum concentrations of phenol, 2-methylphenol, 3&4-methylphenol, and 2,4-dimethylphenol at MW02 at 32.7, 22.2, 39.8, and 46.3 μg/L, respectively. Ketones were also detected in both monitoring wells with maximum concentrations of acetone, 2-butanone (MEK), and 4-methyl-2-pentanone (MIBK) at MW02 at 1460, 208, and 12.5 μg/L, respectively. Acetone, MEK, phenol, 2-methylphenol, 3&4 methylphenol, and 2,4-dimethylphenol were detected in produced water from the Denver-Julesburg Basin.[101] MIBK, MEK, and acetone may result from microbial degradation of biopolymers used for hydraulic fracturing.[101] Nonylphenol and octylphenol, commonly present in mixtures of ethoxlyated alcohols, were detected in both monitoring wells with maximum concentrations at MW02 at 28 and 2.9 μg/L, respectively. Ethoxlyated alcohols were used for well stimulation in the Pavillion Field.

Detection of organic compounds, especially those that cannot be attributed to cement, and degradation products of compounds known to have been used for production well stimulation in both MW01 and MW02 provide additional evidence of impact to USDWs and indicate upward solute migration to depths of current groundwater use. Installation of additional monitoring wells at depths similar to MW02, with sample analysis supplemented by state-of-the-art analytical methods better suited to detection of compounds present in

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stimulation fluids (e.g., liquid chromatography coupled with quadrupole time-of-flight mass spectrometry[104−106]), is necessary to evaluate long-term risk to domestic well users in the Pavillion Field.

Assessment of Potential Impact of Unlined Pits to Domestic Wells. EPA[7] previously reported disposal of diesel fuel-based (invert) drilling mud and production fluids (flowback, condensate, produced water) in unlined pits in the Pavillion Field and resultant groundwater contamination in surficial Quaternary deposits in shallow monitoring wells sampled by EPA in the vicinity of three unlined pits but did not document the extent of these disposal practices. At least 64 unlined pits were used for disposal of drilling fluids of which invert mud was disposed in 57 pits consisting of up to 79% diesel fuel (Tables SI F1, SI F2). As many as 44 of 64 unlined pits were used or likely used for disposal of production fluids. Unlined pits were emptied and closed in 1995.[107,108]

A summary of information available on disposal of drilling and production fluids in pits is provided in Table SI F2. This summary includes results of soil and groundwater sampling, excavation volumes and associated criteria (1000−8500 mg/kg total petroleum hydrocarbons), proximity and direction of unlined pits to domestic wells, and recommendations by WOGCC[44] for further investigation (or no investigation).

The field operator has collected groundwater samples in surficial Quaternary deposits at 12 unlined pit locations.[44] The highest reported concentrations of GRO and DRO were 91 000 and 78 000 μg/L, respectively (Figure 5, Table SI F2). Benzene, toluene, ethylbenzene, and xylenes were detected at five locations at concentrations up to 1960, 250, 240, and 1200 μg/l, respectively (Table SI F2). Thus, sample results indicate impact to surficial groundwater in Quaternary deposits.

There may be as many as 48 domestic wells within 600 m of unlined pits of which 22 domestic wells were sampled by EPA[6,8,9,39] and 11 were resampled by WDEQ[45] (Table SI F3). DRO concentrations in domestic wells <600 m from unlined pits likely receiving production fluids were elevated ($p = 0.003$) compared to domestic wells >600 m from unlined pits (Figure 5a). DRO was detected at 752 mg/kg in a reverse osmosis filter sample from a domestic well (PGDW20) during the Phase II sampling event[8] (Table SI F3). Concentrations of DRO in domestic wells generally decreased with depth (Figure 5b). Another potential source of DRO in some domestic wells (Table SI G1) is invert mud remaining in boreholes. However, differentiation from other source terms (unlined pits and stimulation) is not possible with currently available data (SI Section G.1).

At two domestic wells (PGDW05 and PGDW30), chromatograms for DRO analysis suggest a diesel fuel source (Figure SI F1a, b). Chromatograms of aqueous (Figure SI F2a) and carbon trap samples (Figure SI F2b) for DRO at another domestic well (PGDW20) indicated the presence of heavy hydrocarbons in water. All three domestic wells are located near unlined pits likely used for disposal of production fluids.

Adamantanes were detected at low aqueous concentrations (<5 μg/L) at four domestic wells (PGDW05, PGDW20, PGDW30, and PGDW32) (Table SI F3). Admantane, 2-methyl adamantane, and 1,3-dimethyladamantane were detected in a reverse osmosis filter sample at PGDW20 at concentrations of 420, 9400, and 2960 μg/kg, respectively. Adamantanes were detected in produced water up to 74 mg/L (Table SI D3) indicating disposal in unlined pits as a potential source term. The inherent molecular stability of admantanes and other diamondoid compounds imparts thermal stability resulting in enrichment in manufactured petroleum distillates.[109] Diamondoids are resistant to biodegradation[110,111] resulting in their use as a fingerprinting tool to characterize petroleum and condensate induced groundwater contamination.[112]

2-Butoxyethanol was detected at 3300 μg/L in a domestic well (PGDW33)[45] (Table SI F3). The depth of this domestic well is only 9.1 m bgs and is located within 134 m of an unlined pit used for disposal of production fluids. Other compounds, including BTEX, associated with production well stimulation (e.g., isopropanol) were detected at lower concentrations (<10 μg/L) in other domestic wells (Table SI F3). Sample results at domestic wells suggest impact from unlined pits and the immediate need for further investigation including installation of monitoring wells in the Wind River Formation. Since flood irrigation is common in the vicinity of unlined pit areas, the lateral extent of groundwater contamination is potentially greater in the Wind River Formation than in overlying surficial Quaternary deposits due to "plume diving" (i.e., uncontaminated water overlies portions of a contaminant plume).[113−115]

Our investigation highlights several important issues related to impact to groundwater from unconventional oil and gas extraction. We have, for the first time, demonstrated impact to USDWs as a result of hydraulic fracturing. Given the high frequency of injection of stimulation fluids into USDWs to support CBM extraction and unknown frequency in tight gas formations, it is unlikely that impact to USDWs is limited to the Pavillion Field requiring investigation elsewhere.

Second, well stimulation in the Pavillion Field occurred many times less than 500 m from ground surface and, in some cases, at or very close to depths of deepest domestic groundwater use in the area. Shallow hydraulic fracturing poses greater risks than deeper fracturing does,[57,116] especially in the presence of well integrity issues[117,118] as documented here in the Pavillion Field. Additional investigations elsewhere are needed.

Finally, while disposal of production fluids in unlined pits is a legacy issue in Wyoming, this practice has nevertheless caused enduring groundwater contamination in the Pavillion Field. Impact to groundwater from unlined pits is unlikely to have occurred only in the Pavillion Field, necessitating investigation elsewhere.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.5b04970.

Supplemental discussion and tables summarizing data sets are provided in the Supporting Information (SI) portion of the paper (PDF)

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Notes

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THE WILDERNESS SOCIETY

How much 'Water for Food'?

New Fitzroy River study warns of need for more information and better processes

"Water Resources of the Mardoowarra (Fitzroy River) Catchment"

AUTHOR: Associate Professor Ryan Vogwill, University of Western Australia.

FOREWORD by Dr Anne Poelina.

A new report by Associate Professor Ryan Vogwill from UWA has highlighted concerns over the WA government's plans for large scale water extraction from the Kimberley's iconic Fitzroy River (Mardoowarra). The report was commissioned by the Wilderness Society in response to the government's **Water for Food** program which is promoting large scale irrigated cropping projects across the Fitzroy River valley in coming years.

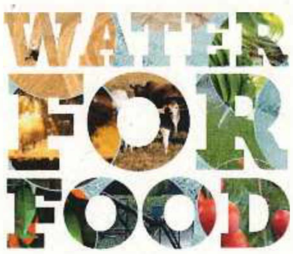
Mardoowarra (Fitzroy River) was placed on Australia's National Heritage list in 2011 due to its outstanding Indigenous cultural values. It is home to many rare, threatened and endemic species, including some 18 fish species that are found nowhere else. Mardoowarra truly is a Living River requiring careful protection. Development in the river system should only proceed based on detailed studies, wide consultation and fully informed Indigenous consent.

Download the report at wilderness.org.au/fitzroyriverreport

Email peter.robertson@wilderness.org.au

- "Estimated additional 200 gigalitres (200 BILLION litres) taken per year from Fitzroy River (surface and groundwater)."
- "50,000+ hectares of landclearing in Fitzroy valley for irrigated cropping."

SOURCE: WA Department of Water presentation, July 2015.



GOVERNMENT OF WESTERN AUSTRALIA

Department of **Water**
Department of **Regional Development**
Department of **Lands**
Department of **Agriculture and Food**

ROYALTIES FOR REGIONS

IMAGES: Mardoowarra | Magali McDuffie; Endangered Purple-crowned fairy wren | Hans and Judy Beste/Lochman Transparencies

AUTHOR: Associate Professor Ryan Vogwill, University of Western Australia

Executive Summary

Based on the literature, it is clear that our understanding of the biota and other culturally significant natural assets of the Fitzroy River is not complete. We have yet to comprehensively map and describe the biota, link them to Indigenous heritage values and predict the impact of increased water use. The work that has been completed highlights the high value people place on this relatively undisturbed system. Our understanding of the hydrology of the Fitzroy River is limited by a low gauging density, almost no information on salinity concentrations/loads and inadequate groundwater monitoring. Some environmental water requirements have been developed for the aquatic fauna of the lower Fitzroy, but these can be considered preliminary and do not cover the range of species already identified. No environmental water requirements information exists in the public domain for flora, the terrestrial fauna or the King Sound Estuary.

The prospect of large-scale development of irrigated agriculture represents a significant potential increase in consumptive water use in the lower Fitzroy valley (currently 2GL/year). The collection and storage of large quantities of surface water has also been proposed – requiring dams, diversions, and off-stream storage facilities. Agriculture typically requires application of fertilisers and agricultural chemicals such as herbicides and pesticides. Nutrients and agricultural chemicals are known to cause significant impacts to aquatic ecosystems in particular. Altered flow regimes affect the extent of flooding and water temperatures, which can impact both aquatic and terrestrial ecosystems. Increased erosion, altered sediment loads, and subsequent increased sediment deposition has the potential to impact critical dry season and drought refugia habitat.

The volumes of water that would be needed for proposed developments (200GL/year) require a specific level of hydrological and hydrogeological understanding, including the linkages between water use and subsequent impact. This does not yet exist in the public domain. A sound understanding of the impact of surface or groundwater allocation must be developed before any substantial allocations should be granted, particularly in such an important biogeographic region. There are several examples of environmental and economic damage in Australia and overseas caused by improper allocation of water resources, owing to a failure to apply a rigorous planning process. Impacts to the biota will impact upon Indigenous heritage values, in addition to commercially relevant activities and occupations such as tourism and both commercial and recreational fisheries.

The recommendation of this report is that a more rigorous assessment is required prior to any significant water allocation in the Fitzroy Basin. If the process of developing the water resource of this catchment is conducted in the correct order, with an appropriate level of understanding acquired first, the existing environment, cultural, and other water users can be protected while supporting responsible long-term agricultural development. This will, however, take 10 years or more if the resources to conduct comprehensive investigations are available immediately.

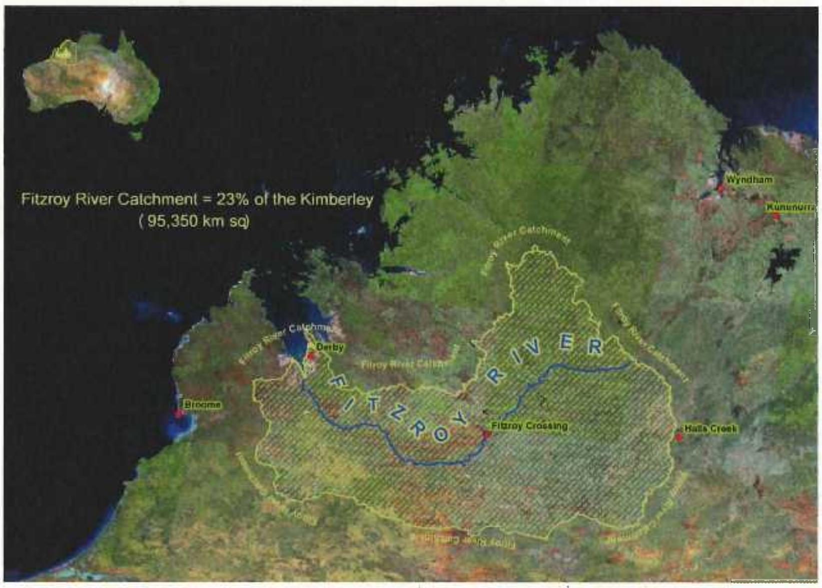


IMAGE: Fitzroy River catchment | ©EcoMap 2006

massive volumes flowback +

It's not safe	Air pollution from methane flaring, polycyclic aromatic hydrocarbons and other chemicals	Water contamination when flooding	Waste water inc radioactive materials	Well integrity and safety storage ponds
health	air pollutants	Gas in water faucets, bath water	Need MDS of chemical interactions not just individual chemicals	Premature births, high risk pregnancies, asthma, migraines, fatigue, rhinosinusitis, neurology, cardiology, rashes, muscular, vomiting, nosebleeds, skin irritations, insomnia, mental health
Social issues	aesthetics	public safety	industrialisation	community
water	Amount of water required	Loss of water for others who use it and need it	contamination	70% of fluid stays underground
farming	Potable water at risk, bores running dry	Stock losses, Break up of stock movement, Fencing damage, not shutting gates, dust,	Loss of property values and lifestyle; Interruptions to farming operations, Loss of revenue	Can't get insured, can't get credit, liable for contamination of neighbouring properties
animals /stock	Water contamination	Failure to breed	death	
bushland	Clearing and fragmentation, failure to rehabilitate	Tracks, roads, weeds/biosecurity	Increase feral animal movement	Lights and wildlife
Communities	don't want it voices need to be heard - there is an enormous opposition - not small	It would industrialise regions	Loss of tourism	FIFO – damages local community structures, increases rent, damage to local business – except the pub
	Intimidation, coercion, bullying by companies	Noise and light pollution	Traffic & infrastructure	
regulations aren't going to protect our health and	When the damage is	Baseline data must be	Seismic activity	

caused by fracking + re-injection of wastewater

land and water	done it's too late	done first including community health, employee health, fauna, waterways		
Climate change	Methane more powerful than carbon dioxide	More polluting than coal when used to generate electricity		
Democratic	No Rights to veto	Democratic right to say no	No consultation or right to object	Don't have to be vnotified
Studies to be done	Cradle to grave	Lifespan of a well – could be like mine shaft across the country.	Scientific	
Government responsibilities	If things go wrong government should be responsible	If they fail , there should be a fund to 'rescue' property owners and custodians	Precautionary principle	
We want renewable energy instead and a push to head towards cleaner energy				
We want a ban on simulated hydraulic fracturing immediately	protected by an act of parliament			
We want to see exploration for unconventional gas banned immediately				
What recommendations have taken place since the 2015 inquiry?	re 'trade secrets'			

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	Further information
	www.dontfrackwa.com.au
	www.frackfreewa.org.au
	www.lockthegate.org.au

<u>AUSTRALIA'S PRICELESS WATER RESERVES</u>

1 We are incredibly lucky to be living in this marvellous land.
2 We have enormous space.
3 We have incredible food production capabilities - way beyond our immediate needs.
4 We have abundant sunshine energy.
5 We have most of the minerals in the periodic table.
6 We could manufacture any thing that humans need (or even want).

BUT:

WE do not have enough water to endlessly unlock these riches. Right now surface water supplies are being fought over in Queensland / New South Wales border regions as big Chinese/Japanese cotton producers in Queensland dam rivers thereby starving New South Wales farmers as an example.

One thing we ought not to allow is having mining giants from around the world to somehow cajole our politicians into letting them use gigantic volumes of our precious surface waters to extract oil and gas. It is becoming less and less acceptable around the planet to burn these carbon-rich fuels just to produce electricity.

Apart from the criminal use of fresh water, my greatest worry at this time is that the techniques being planned to release the underground gas reserves are far more risky in terms of disruption and destruction of the aquifers than the investors, engineers and their political backers care to admit.

Aquifers are not like surface water supplies. They are 3-dimensional, so when punctures are made through them the water flows into and out from them are far from predictable. To allow the fracturing of various gas-bearing strata above and below such aquifers is, in my opinion,grossly irresponsible. Based on the data, pictures and abundant anecdotal evidence so far published, we as responsible Australians must not tolerate this fracking technology to release the carbon-rich energy products to be burnt/oxidised simply to produce electricity.

Solar energy is abundant, endless and non-polluting.

ALAN IVEMY

[redacted]

WA Scientific Inquiry into Hydraulic Fracture Stimulation in WA
Information for Public meeting – Perth 28 February 2018

Margaret Whan

My name is Margaret Whan. I am a resident of The Vines, a suburb north east of Perth in the Swan Valley.

I became aware of the issues of fracking because our daughter owns a 15 acre property in the Swan Valley. The area was and is still covered by a gas licence. This licence is over land which is a major tourist area with restaurants, tourist accommodation, vineyards, equestrian properties and on the edge of densely populated suburbs.

I became involved with local concerned citizens learning more about unconventional gasfields and their impacts through meetings, films and research.

Our local group undertook a door to door survey of over 500 residences in the original area of The Vines. Our survey showed 98.8% of residents were opposed to unconventional gasfields in the surrounding areas. I personally spoke to at least 5 people employed in the gas industry who stated their opposition to fracking, considering it unsafe. Other areas surveyed in WA have all had at least 80% of residents opposed to the development of unconventional gasfields.

Our newly elected local Labor member of parliament stated that she left the mining industry because she could not accept their methods. Since the Labor government was elected (with many people changing their vote because of a promise to ban fracking in the Swan valley, Peel and South West) it has been stated that exploration can still happen, and the licences will not be cancelled. In fact new licences have been granted in the south west.

I would like to speak to 3 areas.

Firstly, this inquiry is stated as being an Independent Scientific Inquiry. Apart from the fact that questions have been raised as to the neutrality of some panel members this is not my major concern.

A genuine Scientific Inquiry, by definition, must begin from a base of no bias with no preconceived factors already limiting and skewing the findings. However, and I quote 2 of the 5 points from the published Terms of Reference:

'The inquiry will describe regulatory mechanisms that may be employed to mitigate or minimise risks to an acceptable level, where appropriate.'
Also 'recommend a scientific approach to regulating hydraulic fracture stimulation.'
This is not the basis for an unbiased inquiry. Is it any wonder people are sceptical about the legitimacy of this Independent Scientific Inquiry?

Secondly, my husband Bryan has spent a great deal of time researching, collecting and collating information from scientific reports from international and Australian sources. As an experienced scientist himself he initially began the process to gauge the accuracy of information being distributed through the media.
I have a copy of the summary of this research which I can leave with you, with the number of references noted. The longer documentation from which this summary was compiled is much more in-depth and specifically referenced. This will be in his submission to the inquiry. I believe the evidence from this in-depth study needs to be taken seriously by the panel. * list no. of ref.

Thirdly. I have lived in Toowoomba, on the fringe of the Darling Downs, a very fertile area of Australia. I wish to speak about the documented evidence which relates to the impacts on the environment, individuals and their health and livelihood, and communities on the Darling Downs.
Many impacts felt in Queensland as this younger industry develops, are already similar to those documented from international unconventional gasfields.

Evidence from tests on venting, river water, bore levels and rainwater tanks, and the soil itself show the detrimental and in many cases irreversible damage done to areas that were the fertile agricultural lands of the Darling Downs.
Data from darling Downs Health show an alarming increase in admissions from respiratory and cardiovascular illnesses from those living in and near the gasfields. A psychologist and a minister of religion report on the stress and emotional impact experienced by people living in and near unconventional gasfields. The stress relates to the processes used in gas extraction, constant noise at the sites and with transport etc., 24 hour operations, increased degradation of property as well as the mining companies lack of honesty and transparency about the extent of the invasiveness of their operations.

People living in rural areas, making a living producing agricultural products from fertile land find themselves living in an industrial estate.
A Queensland doctor studying the impacts on community and land also documents many instances where reported problems are disregarded by the

government agencies set up to protect the wellbeing of citizens and communities.

You may argue that that is Queensland. I acknowledge that it is coal seam gas in Queensland. However chief scientists have stated that the impact from fracking could be at least as bad. Evidence from the Northern Territory shows failure of companies to act responsibly. Existing wells in WA have failed.
The same or similar companies will operate in WA if allowed.
Already there are examples of misleading and false information being distributed by mining companies in WA. Stand over and bullying tactics have led to people being afraid to speak out.

Lastly I want to say it seems that communities and individuals have to be the ones to prove that methods used in unconventional gas mining are unsafe. As with the registration of pharmaceutical products, the mining companies should be compelled, through legitimate data, to prove their claims that fracking is safe are true. Evidence from vast data sources prove that this is not the case, even though companies claim otherwise.

You will be hearing that the people of WA say no to fracking. Communities do not trust that any regulations would be successful in eliminating risks. Reducing risks is not enough. Companies do not have a social licence to destroy this beautiful state. It is important that the panel acknowledge the extent of this opposition and it is reflected in the findings.

The risks are too high, and the community says no the fracking in WA.

Panel Member: Dr Jackie Wright
Table number: ? [redacted]

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia [redacted]

Public Meeting [redacted]

Purpose: The purpose of this meeting is to record factual information and evidence that informs an analysis of potential impacts of hydraulic fracture stimulation, or how risk might be managed or mitigated through regulation, if possible.

Process: Working in small groups with a panel member recording your information. We will be mindful that the panel members are here to listen and record your information and evidence only, and it is not to be used as an opportunity to try to convince other or debate your perspective.

Agenda:

Activity	**By Whom**
Introduction purpose and process	Facilitator
Background	Dr Tom Hatton
Group Session Providing information, ideas and perspectives	All
Wrap up any other items	Facilitator
What Next	Dr Tom Hatton
Close and thanks	Dr Tom Hatton

In order to get the best out of the meeting please:

- State your information clearly and confirm that the table scribe has it recorded as you want it.
- Respect the other members of your table and allow them time to speak.
- Speak one at a time so that the table scribe can hear clearly.
- Use the personal comment form for additional information or evidence you want to be considered.
- Avoid debating or arguing as this will not be recorded so just wastes time.
- Do not try to bully or intimidate other participants.
- Make new friends and network.
- Enjoy this opportunity to share.

(1)

Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

Perth Public Meeting – Additional Comments

Table: Panel Member - Dr Jackie Wright

Table number: ? Name: [redacted]

Email Address: [redacted]

Well-Pipework and Casing deteriation/Rusting etc with Age
Water table Levels and Rising Salt Issues
This could accelerate Casing rust issues (Some cases 25 years) or Less
Rural WA has suffered The Salinity Degradation Problem Previously
Fracking Water usage in areas of WA that rely on Good water (ground & Artesian)
for Agriculture and Food Production "WA being one of the Driest States on the Continent"
* The Attached Public Notice on Airborne Geophysical Survey {most driest}
on Behalf of Empire Oil clearly illustrates Agricultural/Food production Areas
Since this (2015) Article/Airborne Surveys complete, Oil & Gas exploration Licenses were
submitted, some granted. No Proper Enviromental Assessments carried out.
No or Not much Public consultation carried out.

The evidence of Methane & other Toxic gases leaking
from Compressors, Flanges and pipework but also the
stages of Process / Flaring of Gas is frequenlty permitted
This has been in the vicinity of animals, crops & even close to
peoples homes and businesses. Causing Health Issues

How and Who will be responsible for the Monitoring of (Plant, ponds
Dams & well head areas? An Independent Body or the
Industries Self Monitoring Regime? If Independent, How can
they gain Access. To this Day Land owners cannot gain Information
about Toxicity Levels/Emmisions Data etc. Where Drilling/Fracking
occurs on there Land.

- How and Who will Issue Fines for Enviromental damage to - Air Land & Water?
- Damage to Highways - main roads & Local Roads (The Cost of Repairs?
- The Cost to the Land Owner for Property De-valuation (Fracked Land etc)

P10 ↓

Additional Comments "continued"

Plant, Drillsite and Compressor Stations will create Light &

- Noise Pollution to Farming areas ie Livestock etc
  " " " The wildlife that live or frequent area:

- Employement Opportunities: From my experience of 10 years in the Offshore Oil & Gas. Most personell are just transfered from one Job to another. Mostly everybody is experienced in the different Processes of Exploration through to Production.
  This Industry does not Bring Long Term Employement to Gas Fields in or Near Rural Towns. Drill crews move on Then when Production kicks in. Its usually very few operators on site. Just leaving a small scale Refinery/ Gas Plant on site.

- With the amount of Water and Chemicals used in Fracturing each well, Holding ponds and dams are filled with the waste water, This will eventually have to be transfered or Treated (Costly) Where is the Best Waste disposal Site when these areas are Farming or Food Production areas
  The State Controlled Waste Regulations 2004; Requires Licensing of carriers, drivers and vehicles involved in transporting controlled waste to an Approved Waste facility for disposal
  This toxic waste water should never be dumped/pumped or injected back into the ground, where it could leach back into our ground or artesian water supply let alone the contamination of the Soil that can occur.

- The Waste Water holding ponds/dam's etc are also Subject to overflowing due to heavy rains or blocked pipework or Pump failure. This would then release the waste water back into the enviroment.

* See example of what can happen No matter how Big or Small Santos CSG Plant

See Attached media Release

With so much of WA being very flat and vast. With heavy rainfall ie Tropical Low Pressure Systems. These waste storage areas would/could overflow. The Kimberley, Pilbara Gascoyne, Mid West are all subject to Tropical Low's Working their way down, dumping huge amounts of Rain. Broome only just Recently Recorded its highest Ever amount of Rainfall. The Gas Exploration Licenses of The Canning Basin are all Within this Kimberley Region

Additional Comments "continued"

- I have included some printed media articles, some photo's past and present. high lighting Halliburton Oilfield Services.

I have worked alongside Halliburton service hands from my Offshore days as a Roughneck in Timor Gap, Timor Sea & N/West Shelf. My knowledge of the Halliburton's Global Domination goes way back to the Nineties.
Many Safeguards, Acts and Regulations have been rewritten to Exempt The Oil & Gas Hydraulic Fracturing Industry. in the USA across several States, By The Bush Administration with Vice President Dick Cheney who also sat as a Director on the Halliburton Board for many years, & served as a Great Asset to the Company. Halliburton became the most Powerfull Oil Services Company in the World. They now have many Subsidaries in different fields from Drilling, Testing, Siesmic, Production, Chemical Supply, Servicing to Security. They own different Companies under different Names. Halliburton are Australia wide and have had offices and service yards in WA for many years and helped to establish the Oil & Gas Industry in WA.
In 2014 Halliburton Bought out "Mintec". A mining, oil & gas Chemical supply Company. Mintec have a Large plant Located on Ward Road, just between Rockingham and The Kwinana Strip On the Announcement of ownership Takeover, Halliburton's Management Spokesperson stated that, Plans to Expand the Business to Allow for the Production of Chemicals and Addatives for the Gas Fracturing Industry. *I can't find Press Release"
At around this period of Time, Minister for Water, Minister of Enviroment Mr Bill Marmion was questioned many times about Proposed Hydraulic Fracturing in WA. Minister Marmion stated. There is not enough Interest put Forward. Minister Marmion then Became Mines & Petroluem Minister. Since then Oil & Gas Licenses were laid out over much of WA's North & South

Additional Comments continued

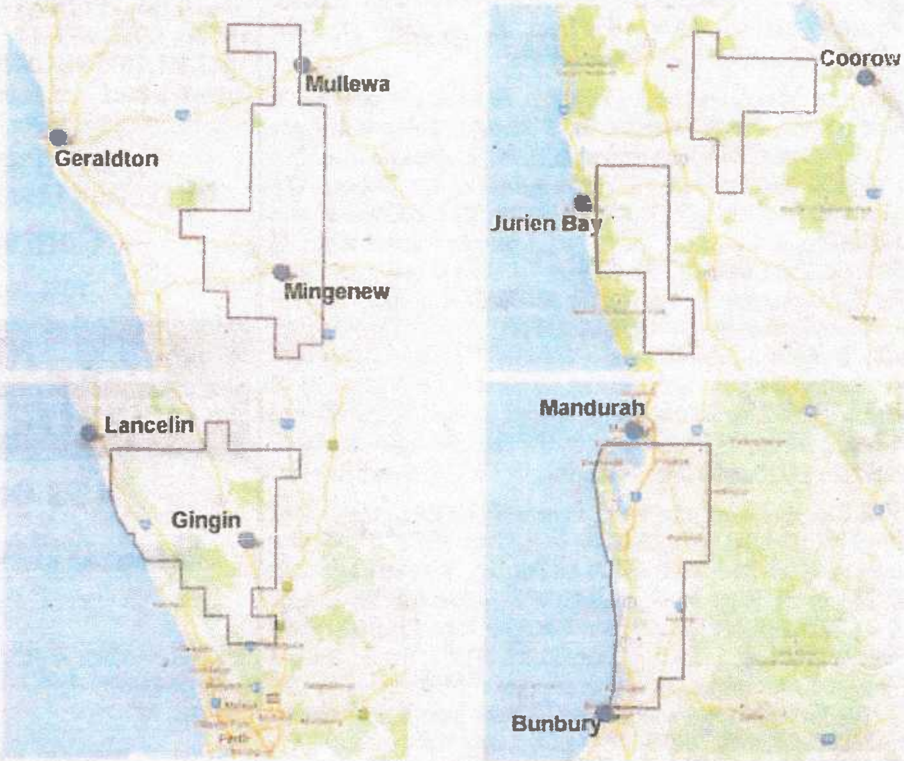
with alot of the exploration licenses issued over the states Farmland, Food production land, nature reserves, Native Title and Indigenous land. But then over the Top of WA's most precious Water Sources Mounds and Aquifer's. Licenses issued without the Science, Enviromental Assesments or Public Conseltation One can only suggest that there is Industry Cohersion/ Industry Influence. Personally with Halliburton's Powerfull Lobby Force, I do not trust that Transparency can be obtained. The Fracking Industry has had a clear path laid across The USA and parts of Australia.
I have also just completed 10 years working at Alcoa World Alumina Kwinana Refinery. I terminated my employement as a Serviceman in August 2016 Alcoa has also been one of the Powerfull Lobbyists behind pushing The Gas Fracking Industry forward in WA. They need to secure a cheaper, easier supply of Gas for their 3 Refineries, Kwinana, Pinjarra and Wagerup. They originally Invested in the Canning Basin then pulled out in 2016. but have Investments in the Mid West Gas Fields. My concern's are many, If the Gas Fracturing Industry can be allowed to progress. The Farming Communities around these Refineries will be affected by the many Risks this Industry can pose on the Health and Enviroment of Plant, Animal and Human. Alcoa World Alumina and Halliburton are Both Giant American Companies, that have Huge Political Clout and have a very strong Legal Arm. I am deeply worried about how much Influence they can have on Governments, Party Leaders, Departments and the General Public. I wish that the Panel can Follow up on the Many Questions, Quireys and Concerns. Regards
Glenn

Original Article 10x12cm

Published in Saturday's West 18/4/15

PUBLIC NOTICE

Notice of Commencement of Airborne Geophysical Survey



Notice is hereby given that **CGG AVIATION (Australia) Pty Ltd** will be conducting a low-level-fixed wing Airborne Gravity Gradiometry (AGG) and Magnetic geophysical survey on behalf of **Empire Oil Company (WA) Ltd**, in the areas shown above.

The survey is entirely passive. Flight lines will be no less than 1000m apart and at a minimum flying height of 100m. Flight lines over built-up areas will be over 300m in altitude, as per standard aviation requirements.

Flying is due to commence late April 2015 and finish in early June 2015.

For queries of an operational nature please contact **Richard Butterfield** at CGG by telephone **(08) 9214 6200** or email **richard.butterfield@CGG.com**

For enquiries regarding the general nature of the survey please contact **Pierre Achour** at Empire Oil & Gas by telephone (08) 9286 4600 or by email **pachour@empireoil.com.au**

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#15W2837394-18/4

Waste-water spill at Santos CSG plant

March 26, 2014

Saffron Howden

Reporter

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The Environment Protection Authority is investigating a 500-litre waste-water spill from a coal seam gas operation at the Pilliga forest in north-w NSW.

The waste water was spilled during a transfer from an assessment well to a holding pond at the Santos gas field near Narrabri on Tuesday, the NSW said in a statement.

"Immediately following the release, the diversion drain was blocked to prevent the produced water leaving the site," it said.

"The produced water was captured and returned to the pond."

An EPA spokeswoman said the spill involved Bibblewindi 2 pond, not the No. 3 pond that is leaking wastewater into the aquifer layer beneath.

The Greens described the waste water as "toxic" and said it contained high levels of salt, as well as dangerous heavy metals such as arsenic, le uranium.

Greens MP Jeremy Buckingham called for Santos's operations to be halted.

"Santos promised that their 'new' management would ensure that the pollution incidents stopped," he said in a statement.

"This latest spill of toxic coal seam gas water is proof that this industry is unsafe no matter who runs it," Greens MP Jeremy Buckingham said.

"We've had multiple spills and contamination incidents with only a dozen pilot wells.

"The risk will be multiplied with 850 gas wells planned for their Narrabri operations."

"Santos's coal seam gas operations continue to threaten our water resources with yet another spill in its trouble-plagued operations in the Pilliga in north-west NSW," said Wilderness Society Newcastle Campaign Centre Manager Naomi Hogan.

"It's also difficult to believe that the contaminated waste water has been contained when the Pilliga has been drenched with rain this week, with millimetres falling on Tuesday, the reported day of the spill, and 80 millimetres on Wednesday."

"Santos has a long tragic history of failure in the Pilliga forest, with at least 20 toxic coal seam gas waste water spills including uranium contamir and continuing leaks from evaporation ponds," she said.

"These spills were from just 56 exploration wells, and Santos has plans to drill 850 wells throughout the Pilliga and productive Narrabri farmland: Hogan said.

Santos described the amount of wastewater spilled as "very small".

"There was no impact to any nearby water source and no risk to the environment," the energy company said.

NSW Premier Barry O'Farrell this week announced a six-month freeze on processing new coal seam gas exploration licences.

Concerned Health Professionals of NY

PSR PHYSICIANS FOR SOCIAL RESPONSIBILITY

Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction)

Fifth Edition Please Reference.

March 2018 This 266 Page Report

Fracking industry site near Greers Ferry Lake in Quitman, Arkansas in the Fayetteville Shale region. ©2014 Julie Dermansky

Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction)

About this Report

The *Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (*the Compendium*)* is a fully referenced compilation of the evidence outlining the risks and harms of fracking.

The Compendium is organized to be accessible to public officials, researchers, journalists, and the public at large. In addition, the Compendium is complemented by a fully searchable, near-exhaustive citation database of peer-reviewed journal articles pertaining to shale gas and oil extraction, the Repository for Oil and Gas Energy Research, that was developed by PSE Healthy Energy and which is housed on its website (https://www.psehealthyenergy.org/our-work/shale-gas-research-library/).

For this fifth edition of the Compendium, as prior ones, we collected and compiled findings from three sources: articles from peer-reviewed medical or scientific journals; investigative reports by journalists; and reports from, or commissioned by, government agencies. Peer-reviewed articles were identified through databases such as PubMed and Web of Science, and from within the PSE Healthy Energy database. Our entries briefly describe studies that document harm, or risk of harm, associated with fracking and summarize the principal findings.

The studies and investigations referenced in the dated entries catalogued in Compilation of Studies & Findings are current through December 2017.

In our review of the data, seventeen compelling themes emerged; these serve as the organizational structure of the Compendium. Readers will notice the ongoing upsurge in reported problems and health impacts, making each section top-heavy with recent data.

The Compendium focuses on topics most closely related to the public health and safety impacts of unconventional gas and oil drilling and fracking. We also include in this edition a section on risks from fracking infrastructure that focuses on compressor stations, pipelines, silica sand mining operations, natural gas storage facilities, and, for the first time, the manufacture and transportation of liquefied natural gas (LNG).

Given the rapidly expanding body of evidence related to the harms and risks of unconventional oil and gas extraction, we plan to continue revising and updating the Compendium approximately every year. It is a living document, housed on the websites of Concerned Health Professionals of New York and Physicians for Social Responsibility. Read more about the process and scope of our work in the "About this Report" and the "Foreword to the Fifth Edition" sections of the Compendium.

Download the full 5th Edition of the Compendium

The Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (the Compendium) is a fully referenced compilation of the evidence outlining the risks and harms of fracking. It is a public, open-access document that is housed on the websites of Concerned Health Professionals of New York (www.concernedhealthny.org) and Physicians for Social Responsibility (www.psr.org).

The four earlier editions of the Compendium have been used and referenced all over the world. The Compendium has been twice translated into Spanish: independently in 2014 by a Madrid-based environmental coalition, followed by an official translation of the third edition, which was funded by the Heinrich Böll Foundation and launched in Mexico City in May 2016. The Compendium has been used in the European Union, South Africa, the United Kingdom, Australia, Mexico, and Argentina.

About Concerned Health Professionals of New York

Concerned Health Professionals of New York (CHPNY) is an initiative by health professionals, scientists, and medical organizations for raising science-based concerns about the impacts of fracking on public health and safety. CHPNY provides educational resources and works to ensure that careful consideration of science and health impacts are at the forefront of the fracking debate.

About Physicians for Social Responsibility

Working for more than 50 years to create a healthy, just, and peaceful world for both present and future generations, Physicians for Social Responsibility (PSR) uses medical and public health expertise to educate and advocate on urgent issues that threaten human health and survival, with the goals of reversing the trajectory towards climate change, protecting the public and the environment from toxic chemicals, and addressing the health consequences of fossil fuels. PSR was founded by physicians concerned about nuclear weapons, and the abolition of nuclear weapons remains central to its mission.

Contents

Full Report can be Accessed by concernedhealthny.org/compendium/.

CBS/AP | *May 24, 2010, 9:01 AM*

Bad Cement Jobs Plague Offshore Oil Rigs

In this Monday, May 3, 2010 file photo provided by Transocean, the ultra-deepwater semisubmersible rig Development Drill III begins operations for drilling a relief well in the Gulf of Mexico. A relief well is designed to drill down and intersect the existing well bore and pump heavy fluids and cement in to stop the leaking oil. (AP Photo/Transocean, File / **AP PHOTO**

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The tricky process of sealing an offshore oil well with cement - suspected as a major contributor to the Gulf of Mexico oil spill disaster - has failed dozens of times in the past, according to an Associated Press investigation.
Yet federal regulators give drillers a free hand in this crucial safety step - another example of lax regulation regarding events leading up to the April 20 explosion on the Deepwater Horizon oil rig.

Federal regulators don't regulate what type of cement is used, leaving it up to oil and gas companies. The drillers are urged to simply follow guidelines of the American Petroleum Institute, an industry trade group.

Special Section: Disaster in the Gulf

Far more stringent federal and state standards and controls exist on cement work for roads, bridges and buildings.

think they need all the ingredients in the cement, he said. Cement is often squeezed in later to try to fill gaps, but Beck said the success rate of this remedial work is low.

And if cement was part of the cause of the Deepwater Horizon catastrophe, it also could be part of the remedy. Two relief wells are being drilled to intersect the leaking well and plug it with cement.

Halliburton was completing the final cement work on the exploratory well beneath Deepwater Horizon in the wee hours of April 20. It added an initial cement plug to the well to act as a cap until a later production phase.

Workers started running a series of tests to check if the cement and casing could stand up to sufficient pressure. The first tests of outward, positive pressure showed no problems.

In the first sign of trouble, though, the well then failed a negative pressure test, where internal fluid pressure is reduced, according to congressional testimony from a BP PLC executive. It showed different pressures in two areas, indicating an unseen leak somewhere in the well.

Despite the test, managers eventually decided to replace drilling fluid with seawater and set a final cement plug so the well could be mothballed pending a decision to possibly begin production drilling.

And while it is not yet clear what sections of the casing or cement may have failed - or why - it is known that the blowout ignited and exploded before the last plug was set.

In the aftermath of the blowout, questions have been raised about the safety of nitrogen-laced cement foam. But several cementing experts told the AP it is a sound technique. Halliburton says it has used such a mix on scores of wells and told a congressional committee that the cementing on the Deepwater Horizon job was successful.

Halliburton did not respond to AP requests for comment.

In the wake of the accident, some experts support mandatory uniform cement standards for underwater wells. "When you change the composition, it should meet a certain standard. Such standards exist for the building construction industry," said Surendra Shah, Northwestern University engineering professor and director of the Center for Advanced Cement-Based Materials at Evanston, Illinois.

Elmer Danenberger, a retired chief of offshore regulatory programs for MMS, told a congressional committee this month: "An industry standard should be developed to address cementing problems, how they can be prevented, and the actions that should be taken when they do occur."

Many construction projects use concrete hardened with sand and gravel aggregate, but cement is the glue that holds it together. On federal projects, "just about everything is regulated, from the thickness of the concrete, to the strength of the concrete, to the type of aggregate that's used," said Brian Turmail, spokesman for the Associated General Contractors of America.

Oil companies test the thickness and strength of cement in wells by shooting sound waves into the cement. This kind of test, called a sonic logging test, wasn't run on April 20 at Deepwater Horizon. A Halliburton manager said it's the most realistic way of testing the quality of the cement bond, but a BP manager said pressure tests are better and log tests are used only if there's already a sign of a problem.

Either way, these tests are not 100 percent reliable. Sometimes, oil companies don't discover a bad cementing job until it fails.

There can be early warning signs, though. Federal regulators have known for years that a condition called sustained casing pressure - usually gas caught between the casing and well wall - is a major problem that typically signals bad cement work.

In the August 2007 blowout, investigators cited tests showing high casing

NEWS SHOWS VIDEO CBSN MORE

blowout, the report said.

More than 8,000 of the 22,000 offshore wells on federal leases, most of them in the Gulf, show sustained pressure, according to government reports.

While the chain of failures on Deepwater Horizon is under investigation, rig owner Transocean has singled out cement work as one likely fundamental cause of the blowout.

Even before Transocean pointed to cementing, independent experts suspected it partly because faulty cement work - either badly mixed or poorly placed against well walls - is so prevalent at offshore wells.

An AP review of federal accident and incident reports on offshore wells shows that the cementing process has been implicated at least 34 times since 1978. Many of the reports, available from the U.S. Minerals Management Service that regulates offshore wells, identify the cause simply as "poor cement job."

In a November 2005 accident where the Deepwater Horizon was positioned above another well in the Gulf, faulty cement work allowed wall-supporting steel casing to come apart. Almost 15,000 gallons (56,800 liters) of drilling fluid spilled into the Gulf.

Just a week later in a nearby well at another platform, cement improperly seeped through drilling fluid. As a result of an additive meant to quicken setting time, the cement then failed to block a gas influx into the well. When the crew finally replaced heavy drilling fluid with lighter seawater, as they also did last month before the blowout at Deepwater Horizon, the well flowed out of control and much of the crew had to be evacuated.

Cementing was identified by federal investigators as a glaring cause of an August 2007 blowout, also off Louisiana. They said, "The cement quality is very poor, showing what looks like large areas of no cement."

Reports by MMS, a branch of the Interior Department, also provide evidence of the role bad cement work has played in accidents. One study named cementing as a factor in 18 of 39 well blowouts at Gulf rigs from 1992 to 2006. Another attributed five of nine out-of-control wells in the year 2000 to cementing problems.

Cementing in the oil rig business is a sensitive, involved process. Well cement constitutes an essential barrier that is difficult to install and control, said Gene Beck, a petroleum engineer at Texas A&M University at College Station, Texas.

Deepwater wells pose special challenges: severe pressures and temperatures, as well as the need for specialized equipment and lots of cement. The wellhead of the Deepwater Horizon operation sat on the ocean floor, nearly a mile (1.6 kilometers) from the surface. The drill hole itself went another 13,000 feet (3,960 meters) into rock.

All cement begins as a slurry with cement flakes and water. Contractors then add ingredients to make the cement set at the right time and to keep out gas and oil.

There are three major U.S. cementing companies: Halliburton, Schlumberger and BJ Services. Cementing is typically performed by such rig contractors as part of a broad range of drilling services that they supply.

Halliburton, which had the Deepwater Horizon job, mixes in nitrogen to make its slurry more elastic. The nitrogen also helps create a lightweight cement that resembles a gray foamy mousse and bonds better to the casing.

But the recipe also depends on the job, because cement must respond to varying pressures and temperatures. Cement contractors work closely with oil and gas companies on the formulas for individual wells. The oil and gas companies have the final say on what is used.

Once the consistency of the mix is decided on, it is pumped deep into the well, where it first sinks to the bottom and then oozes upward to fill the narrow spaces between the steel casing pipe and rock walls. When the cement sets, the casing and cement are supposed to form an impenetrable wall to keep gas or oil from pushing into the hole anywhere but the bottom, where its flow up the pipe can be controlled.

But if gas bubbles invade the setting cement, they can form a channel for pressurized gas and oil to surge uncontrollably up the well, usually around the casing. The cement must be strong enough to withstand up to 5,000 pounds (2,270 kilograms) of pressure per square inch (6.45 square centimeters), to keep the well walls from collapsing.

"Cement is cheap, and it fixes a lot of problems, but it's not a good place to cut corners," Beck said. Many oil and gas companies will scrimp, though, if they don't

This month, in a move in the works long before the Deepwater Horizon explosion, regulators wrote in the Federal Register that the oil and gas industry in the Gulf has "suffered serious accidents as a result of high sustained casing pressure, and the lack of proper control and monitoring of these pressures."

New rules take effect June 3. But they take a conservative watch-and-wait approach and demand only routines already carried out around the industry: a management program with monitoring and diagnostic testing. If operators discover sustained pressure, they must notify MMS of plans to fix it.

There are no new record-keeping or reporting requirements in the new rules, which are backed by industry. In the rule-making documents, regulators - long accused of being too cozy with the industry - said the regulations would cost the entire industry only $5 million, compared with the "impracticable and exceedingly costly" $2 billion alternative of fixing the wells outright.

"Unfortunately, this is yet another crisis in a long line of accidents caused by cementing problems in drilling," said U.S. Rep. Diana DeGette of Colorado, a member of the Energy Committee looking into the cause of the blowout.

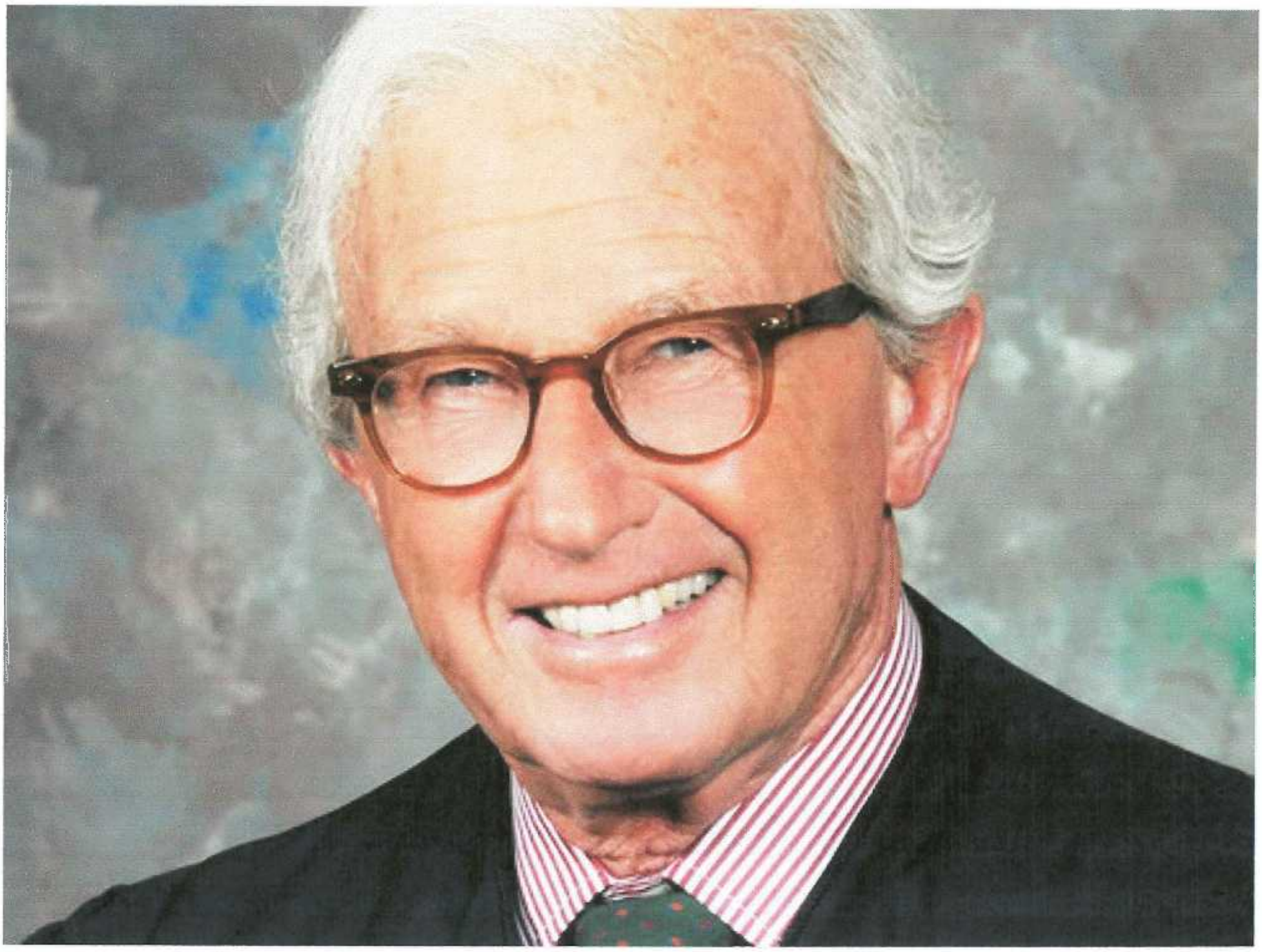
MMS refused to answer specific questions about its cementing policies, including why it took so long to craft the pressure regulations and whether MMS has issued any citations for cement problems.

"All of these questions are questions that we are reviewing," said Interior Department spokeswoman Kendra Barkoff.

Judge who rejected Gulf drilling ban lined pockets with big oil

BY SEAN ALFANO

Wednesday, June 23, 2010, 7:18 AM



U.S. District Judge Martin L. C. Feldman (HANDOUT)

The federal judge who overturned the Obama administration's deepwater drilling ban in the Gulf of Mexico reportedly has extensive investments in the energy industry, financial disclosure reports reveal.

U.S. District Judge Martin Feldman owned roughly $15,000 in Transocean Ltd. stock in 2008.

Transocean owned the Deepwater Horizon rig that exploded April 20, killing 11 workers and triggering the worst oil spill disaster in U.S. history, with as much as 127 million gallons of oil leaked into the Gulf of Mexico.

Feldman's other financial investments from the 2008 report include Halliburton, which was also involved with the Deepwater Horizon.

On Tuesday, Feldman ruled that the government overreacted, saying one rig's explosion did not mean others would blow up, too.

"If some drilling equipment parts are flawed, is it rational to say all are? Are all airplanes a danger because one was? All oil tankers like Exxon Valdez? All trains? All mines? That sort of thinking seems heavy-handed, and rather overbearing," Feldman wrote.

Louisiana Gov. Bobby Jindal welcomed the decision, saying the ban could lead to "economic catastrophe" for the Gulf Coast.

Interior Department Secretary Ken Salazar vowed to appeal the decision immediately.

"I will issue a new order in the coming days that eliminates any doubt that a moratorium is needed, appropriate, and within our authorities," Salazar said Tuesday.

Feldman, appointed in 1983 by President Ronald Reagan, also sits on the Foreign Intelligence Surveillance Court, which is devoted to national security cases.

Prior to Feldman's ruling, the ban on deepwater drilling, pertaining to wells 500 feet or more below the surface, suspended drilling in 33 wells for up to six months.

Dick Cheney's Halliburton made billions of dollars from the Iraq war. (photo: Getty Images)

Cheney's Halliburton Made $39.5 Billion on Iraq War

By Angelo Young, International Business Times
20 March 13

The accounting of the financial cost of the nearly decade-long Iraq War will go on for years, but a recent analysis has shed light on the companies that made money off the war by providing support services as the privatization of what were former U.S. military operations rose to unprecedented levels.

Private or publicly listed firms received at least $138 billion of U.S. taxpayer money for government contracts for services that included providing private security, building infrastructure and feeding the troops.

Ten contractors received 52 percent of the funds, according to an analysis by the Financial Times that was published Tuesday.

The No. 1 recipient?

Houston-based energy-focused engineering and construction firm KBR, Inc. (NYSE:KBR), which was spun off from its parent, oilfield services provider Halliburton Co. (NYSE:HAL), in 2007.

The company was given $39.5 billion in Iraq-related contracts over the past decade, with many of the deals given without any bidding from competing firms, such as a $568-million contract renewal in 2010 to provide housing, meals, water and bathroom services to soldiers, a deal that led to a Justice Department lawsuit over alleged kickbacks, as reported by Bloomberg.

Who were Nos. 2 and 3?

Agility Logistics (KSE:AGLTY) of Kuwait and the state-owned Kuwait Petroleum Corp. Together, these firms garnered $13.5 billion of U.S. contracts.

As private enterprise entered the war zone at unprecedented levels, the amount of corruption ballooned, even if most contractors performed their duties as expected.

According to the bipartisan Commission on Wartime Contracting in Iraq and Afghanistan, the level of corruption by defense contractors may be as high as $60 billion. Disciplined soldiers that would traditionally do many of the tasks are commissioned by private and publicly listed companies.

Even without the graft, the costs of paying for these services are higher than paying governement employees or soldiers to do them because of the profit motive involved. No-bid contracting - when companies get to name their price with no competing bid - didn't lower legitimate expenses. (Despite promises by President Barack Obama to reel in this habit, the trend toward granting favored companies federal contracts without considering competing bids continued to grow, by 9 percent last year, according to the Washington Post.)

Even though the military has largely pulled out of Iraq, private contractors remain on the ground and continue to reap U.S. government contracts. For example, the U.S. State Department estimates that taxpayers will dole out $3 billion to private guards for the government's sprawling embassy in Baghdad.

The costs of paying private and publicly listed war profiteers seem miniscule in light of the total bill for the war.

Last week, the Costs of War Project by the Watson Institute for International Studies at Brown University said the war in Iraq cost $1.7 trillion dollars, not including the $490 billion in immediate benefits owed to veterans of the war and the lifetime benefits that will be owed to them or their next of kin.

ECONOMIC POLICY COLUMN APRIL 30, 2001 ISSUE

Cheney Was a Gusher Deal for Halliburton

By Robert Scheer

APRIL 17, 2000

Let's not begrudge Dick Cheney his $36 million income last year. Sure, it dwarfs the puny $744,682 reported by the President, but George W. Bush represents old money, and he knows better than to be too showy, particularly when you're running for office as a Joe Six-Pack kind of guy. Better to roll over the income from inherited money into tax-protected accounts.

Cheney didn't have time for such accounting niceties. Bush caught him right in the middle of a tax year with that Vice President nod, and remember, Cheney was only supposed to be advising Bush on the best choice for Veep. How was Cheney to know he'd be forced to recommend himself as the most qualified?

Still, just because he had become Vice President didn't mean he had to take a vow of poverty. As Cheney told CBS News at the time, "I'd like not to give away all of my assets to serve the public." And why should he, since there's no law limiting the assets of federal office-holders or any

requirement that they give up their acquired wealth? Cheney had only to look as far as Bush, who merely put his in a blind trust, no questions asked.

Huge financial assets are now the norm for leaders of our representative democracy, and it wasn't unexpected that the mostly wealthy members of the Senate recently voted rich people like themselves an enormous tax cut, albeit not as large as the one Bush wanted for himself and his pals.

Cheney's assets are only at risk of taxation if he wants to leave a huge amount to his heirs without paying additional taxes. Soon, even that will no longer be a problem because Bush and Cheney are sensitive to the unfairness of the estate tax to ordinary people like themselves, and they want to eliminate it.

What was at issue during the campaign was not Cheney's assets or his income but his future stock options in Halliburton Co. These being tied to the rise and fall of Halliburton stock, presented a potential conflict of interest because, as Vice President, it was conceivable that he could influence stock prices. Under considerable pressure, Cheney decided to donate those stock options to charity, but he was left with a bit more than a hair-shirt.

Even after taxes, Cheney cleared more than $20 million in 2000. If the Bush tax cut had been in effect last year, Cheney would've saved another couple of million, to which he obviously feels entitled.

Don't forget, Cheney was playing catch-up after years in the public sector, first as a congressman and then as Defense secretary. As it turned out, he only had about five years in the private sector to cash in his chips, and he didn't really know much about the energy business. When

he hired on to serve as the CEO of an oil services firm, he knew he would have to justify the big bucks he was getting paid.

Fortunately for him and Halliburton, it all worked out in the end.

For the Texas-based Halliburton, there initially was some concern. Only two years ago, with the company's stock floundering, the board of directors chastised Cheney for the company's poor performance. But then came the presidential election, and those same directors must have figured they had died and gone to heaven after Cheney got the Veep nod. That's when the board of directors turned around and rewarded him with an incredibly lucrative severance package providing the bulk of his reported $36 million income in 2000.

Can you blame them? Most of Cheney's working hours last year were devoted to seizing the White House for the most avidly pro-Big Oil presidency in US history, and servicing Big Oil is what Halliburton Co. is all about. That and construction projects around the world that an anti-environmental Administration now seems all too eager to facilitate.

Quite an impressive record for an executive who was just learning the business. They knew the guy would be good; after all, as a congressman he had one of most pro-industry voting records. And it was Defense Secretary Cheney who had made the decision to privatize logistical support facilities for the military, which gave Halliburton's subsidiary, Brown & Root, huge construction contracts for the US military at bases throughout the world.

Of course, as the former Defense secretary who'd saved Kuwait, where Halliburton has huge contracts, Cheney was already known to be an effective player. But how could Halliburton have known Cheney would be this good? Not only did he help elect another Texas oil guy as President, but if you look at the short record of the Bush-Cheney Administration, when it comes to opening the environment for energy exploration, even that most pristine area in Alaska, these guys know no limits.

Indeed, they must be guffawing down in Texas to have two good old boys running the White House without a scintilla of shame. It's been oil money well spent.

Robert Scheer Robert Scheer, a contributing editor to *The Nation*, is editor of Truthdig.com and author of *The Great American Stickup: How Reagan Republicans and Clinton Democrats Enriched Wall Street While Mugging Main Street* (Nation Books), *The Pornography of Power: How Defense Hawks Hijacked 9/11 and Weakened America* (Twelve) and Playing President (Akashic Books). He is author, with Christopher Scheer and Lakshmi Chaudhry, of *The Five Biggest Lies Bush Told Us About Iraq* (Akashic Books and Seven Stories Press.) His weekly column, distributed by Creators Syndicate, appears in the *San Francisco Chronicle*.

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Halliburton - Wikipedia
https://en.wikipedia.org/wiki/Halliburton
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Category:Halliburton · Erle P. Halliburton · David J. Lesar · KBR

Dick Cheney - Wikipedia
https://en.wikipedia.org/wiki/Dick_Cheney
During his time in the Department of Defense, **Cheney** oversaw the 1991 Operation Desert Storm, among other actions. Out of office during the Clinton administration, **Cheney** was the Chairman and **CEO** of **Halliburton** Company from 1995 to 2000. In July 2000, **Cheney** was chosen by presumptive Republican Presidential ...
Liz Cheney · Mary Cheney · Halliburton · Lynne Cheney

A Closer Look at Cheney and Halliburton - The New York Times
www.nytimes.com/2004/09/28/us/a-closer-look-at-cheney-and-halliburton.html
Sep 28, 2004 - 17, Mr. Kerry declared: "**Dick Cheney's old** company **Halliburton** has profited from the mess in Iraq at the expense of American troops and taxpayers. While **Halliburton** has been engaging in massive overcharging and wasteful practices under this no-bid contract, **Dick Cheney** has continued to receive ...

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THE TRUTH ABOUT HALLIBURTON - April 18, 2005 - Fortune
archive.fortune.com/magazines/fortune/fortune_archive/2005/04/18/.../index.htm
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May 24, 2010 - The oil-services and infrastructure giant **Halliburton** is a favorite target for critics of **former** Vice President **Dick Cheney**, who used to be the company's **CEO**. During the presidency of George W. Bush, the company's Iraq War-related contracts attracted wide attention. Now, the company's role in the Deepwater ...

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Dick Cheney
Former Vice President of the United States

Richard Bruce "Dick" Cheney is an Ameri and businessman who served as the 46th of the United States from 2001 to 2009. B Nebraska, Cheney was primarily raised in Nebraska, and Casper, Wyoming. Wikipe

Born: 30 January 1941 (age 77), Lincoln, United States

Height: 1.73 m

Spouse: Lynne Cheney (m. 1964)

Previous offices: Vice President of the U (2001–2009), MORE

Did you know: Dick Cheney is the ninth-l United States Secretary of Defense by tin (1,401 days). wikipedia.org

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www.foxnews.com/story/2004/10/07/truth-about-cheney-ties-to-halliburton.html ▾

Oct 7, 2004 - BRIT HUME, HOST: There it was again, the issue that Democrats keep bringing up against **Dick Cheney**, who was the **CEO** of the vast, energy services company, **Halliburton** (search), before running for vice president. It is indeed the focus of one of the Kerry campaign's ads. (BEGIN KERRY-EDWARDS AD ...

FOCUS | Cheney's Halliburton Made $39.5 Billion on Iraq War

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Halliburton defrauded American taxpayers of "hundreds of millions of dollars in Iraq."

— *Arianna Huffington on Sunday, June 6th, 2010 in an interview on "This Week."*

Halliburton, KBR, and Iraq war contracting: A history so far

By Angie Drobnic Holan on Wednesday, June 9th, 2010 at 4:21 p.m.

"The truth is that right now we have precisely the regulatory system that the Bush-Cheney Administration wanted -- full of loopholes, full of cronies and lobbyists filling the very agencies they're supposed to be overseeing," she said, adding a bit later, "Right here, we have the poster child of Bush-Cheney crony capitalism. Halliburton (was) involved in this, and we haven't said (anything) about that. They after all were responsible for cementing the well. Here's Halliburton, after it defrauded the American taxpayer (of) hundreds of millions of dollars is involved again..."

That's when conservative pundit Liz Cheney interrupted.

"Arianna, I don't know what planet you live on ..." she said, starting interruptions and crosstalk that finally ended with this:

Cheney: "Her assertion that Halliburton defrauded the U.S. government --"

Huffington: "It did. It did."

Cheney: "-- that it was Bush-Cheney cronyism -- these are the left's talking points --"

Huffington: "It did -- hundreds of millions of dollars in Iraq."

Cheney: "Arianna, it is absolutely not true. It is absolutely not true."

Huffington: "Okay, I'm so glad PolitiFact is going to be checking this. I'm so glad."

Cheney: "Good, good."

There is no dispute that Halliburton was a contractor on the Deepwater Horizon rig, which is what Huffington was alluding to when she said Halliburton was "involved" in the oil spill. Host Jake Tapper affirmed that, then Cheney indicated she was objecting specifically to the claim of fraud. So we decided to fact-check Huffington's statement that Halliburton defrauded the U.S. government of "hundreds of millions of dollars in Iraq."

We first want to note something not explicitly stated on the show: Former Vice President Dick Cheney was CEO of Halliburton before becoming vice president, and Liz Cheney is his daughter. And we'll also stipulate that there is a mountain of evidence that many American companies profited off of the government's inefficient contracting system during the rebuilding of Iraq.

Dick Cheney was secretary of defense from 1989 to 1993, during the administration of President George H.W. Bush. A few years after leaving office, he became chairman and chief executive officer of Halliburton, a Houston-based oil services company. He led Halliburton until 2000, when he left to run for vice president on a ticket with George W. Bush. The Iraq war began a few years later.

Most of the allegations of waste involving Halliburton focus on a subsidary company that Halliburton acquired in 1962, then known as Brown & Root. A series of mergers under Halliburton's ownership led to its current name, Kellogg, Brown & Root, or KBR.

Halliburton's KBR held one of the largest contracts given during the Iraq war effort, the Logistics Civil Augmentation Program, or LOGCAP, which was part of the trend of government outsourcing traditionally military duties to the private sector. (We're focusing on the LOGCAP contract in this report because it's the contract that has the potential for "hundreds of millions of dollars" in fraud. There have been other isolated allegations of fraud that involved significantly smaller amounts.)

The history of KBR's LOGCAP contracts are documented in *Hard Lessons: The Iraq Reconstruction Experience*, a 2009 report prepared by the Office of the Special Inspector General for Iraq Reconstruction:

"Just as USAID had outsourced much of its work in the years after the Cold War, the military also had turned to the private sector to perform work once done by its own personnel. Under the LOGCAP contract, which KBR held for all but a few years since the program's inception in 1985, contractors provide services ranging from building bases to cooking food and doing laundry. LOGCAP grew out of the post-Vietnam downsizing of the armed services, reflecting the government-wide growth of outsourcing, which would dramatically affect the war and reconstruction efforts in Iraq. In World War II, one contractor was deployed for every seven soldiers. During the 2003 invasion, that number had increased to one for every 2.4. By 2006, contractors outnumbered soldiers in Iraq."

The report noted that some government officials raised the concern of a potential conflict of interest because of Cheney's former position with Halliburton, but that "White House officials said the mission took priority over whatever political fallout might occur" from awarding contracts to KBR. Since winning the latest version of the LOGCAP contract in 2001, the government has ordered work from KBR worth more than $31 billion.

Government officials have raised many questions about KBR's fulfillment of its contracts, everything from billing for meals it didn't serve to charging inflated prices for gas to excessive administrative costs. Government auditors have noted that KBR refused to turn

over electronic data in its native format and stamped documents as proprietary and secret when the documents would normally be considered public records.

Over the course of several years, the Defense Contract Audit Agency found that $553 million in payments should be disallowed to KBR, according to 2009 testimony by agency director April Stephenson before the bipartisan Commission on Wartime Contracting in Iraq and Afghanistan.

Commissioner Charles Tiefer, a professor at the University of Baltimore Law School, said that amount represents a small portion of everything that auditors examined as potentially questionable.

"The DCAA is known for cautious conclusions about contracting," Tiefer said. "The large majority of those auditor findings get actually withheld from the contractor."

KBR itself acknowleges it may not get paid for all of its contract services. In its most recent annual report filed with the Securities Exchange Commission, it acknowledged that the Defense Contract Audit Agency was recommending withholding $289 million in contract costs not yet paid and asking for the return of $121 million already paid. "We continue to work with our administrative contracting officers, the DCAA and our subcontractors to resolve these issues. However, for certain of these matters, we have filed claims with the Armed Services Board of Contract Appeals or the United States Court of Claims," the report states.

But there is one notable allegation where KBR is being accused of fraud, that KBR "knowingly included impermissible costs" in its bills. In April 2010, the U.S. Department of Justice filed a civil fraud case against KBR over the issue of using private security forces in Iraq to protect its workers and subcontractors. Private security wasn't allowed under the LOGCAP contract because the U.S. military was supposed to provide protection.

The lawsuit alleges that internal documents showed KBR executives knew private security wasn't allowed but charged for it anyway. While the lawsuit doesn't put a dollar amount on those billings, the director of the Defense Contract Audit Agency said the total could come to $99 million or higher.

KBR has denied wrongdoing and said in a response to the lawsuit that the government has known for years that KBR was hiring private security, and KBR only did so because its employees were being left unprotected by the military.

"KBR believes the costs incurred and actions taken by the company and its subcontractors to provide support and to protect its employees and subcontractors were reasonable, necessary and appropriate under the contractual arrangement between KBR and the Army. ... The Army breached the contract by repeatedly failing to provide the necessary force protection," the statement said.

"Since 2001, KBR and its employees and subcontractors have worked diligently, and at often times at great sacrifice, to support American troops serving in Iraq," it also said. We should note here that KBR workers have died in Iraq. Company officials said 74 people working on the LOGCAP III contract have died in Iraq between 2003 and 2010.

Halliburton sold KBR in 2007. Halliburton officials said KBR's war contracts weren't adding much to the oil company's profits. The same year, Halliburton opened a "second headquarters" (their words) in Dubai, in the United Arab Emirates, to emphasize its identity as a worldwide oil services company. But Halliburton did own KBR during the height of KBR's activities in Iraq. The Department of Justice fraud lawsuit specifically stipulates that KBR was overcharging between 2003 and 2006, years that Halliburton owned the company.

We asked Halliburton for comment on this report, and they sent us this statement: "Halliburton cannot comment on activity that relates to KBR's work in Iraq and Afghanistan as it would be inappropriate for Halliburton to comment on the merits of a matter affecting only the interest of KBR."

The U.S. government continues to use KBR for contract work in Iraq. In fact, the U.S. Army recently granted additional work worth $568 million to KBR in May. Military officials said it would be too disruptive to change contractors at this point in the process. Indeed, one defense of KBR's work is that they take extra steps -- which some might call excessive -- to keep troops happy with extra amenities at the request of military commanders.

Recently, government officials have warned that KBR is dragging its feet on withdrawing its personnel from Iraq; the company's withdrawal rate significantly lags that of the military itself. If KBR doesn't reduce its employees in Iraq quicker, the U.S. government could be overbilled by as much as $193 million in 2010, officials said during hearings held by the Commission on Wartime Spending in Iraq and Afghanistan.

In evaluating Huffington's statement, we're most bothered by her use of the word "defrauded." Some of the overbilling in Iraq appears to have been done from haste or inefficiency, or even in a desire to please military officials in the field without regard for

cost. Whether the waste in contracting constitutes fraud is still being examined.

"It's a lot money being spent in a region of the world where we don't have a lot of infrastructure for accounting for how the money is being spent. It will take years before we fully determine how we spent the money," said Todd Harrison, a senior fellow for defense budget studies at the nonpartisan Center for Strategic and Budgetary Assessments.

In ruling on Huffington's statement, we find much in the public record to support her statement, most notably the Justice Department lawsuit. Certainly there have been hundreds of millions of dollars that Halliburton's KBR attempted to charge the government that have been denied. Government audits of KBR's work in Iraq will likely continue for some time, and we do not expect a final accounting on these fronts anytime soon. Huffington glossed over some of these points in her back and forth with Liz Cheney. There's also much evidence that makes us believe that hundreds of millions of dollars were lost to waste and inefficiency, not deceitful fraud. So we rate Huffington's statement Half True.

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Halliburton Overseas ltd	DII Industries, LLC	Halliburton Worldwide ltd

Halliburton - Wikipedia
https://en.wikipedia.org/wiki/Halliburton
As of Halliburton's latest form 10-K filings with the SEC, Exhibit 21.1 lists the following as subsidiaries of Halliburton Co.: Baroid International Trading, LLC (United States, Delaware) BITC Holdings (US) LLC (United States, Delaware) Halliburton (Barbados) Investments SRL (Barbados)
Net income: US$ (5.77) billion (2016) Number of employees: 50,000
Industry: Oilfield services & equipment Operating income: US$ (6.78) billion (2016)
Category:Halliburton · KBR · Erle P. Halliburton · David J. Lesar

List of Halliburton subsidiaries - Wikipedia, the free encyclopedia
libertyparkusafd.org/.../List%20of%20Halliburton%20subsidiaries%20-%20Wikipedia...
Apr 26, 2005 - The following is a list of subsidiaries, affiliates, branches, brands and divisions of Halliburton Co. Adute Pty Ltd. (Australia); AOC Services Limited - (Jersey, tax haven); Antilles Dresser-Rand (tax haven); Avalon Financial Services, Ltd. (Cayman Islands, tax haven); Axelson; Baroid Caribbean Limited Brown ...

HALLIBURTON CO - FORM 10-K - EX-21.1 - SUBSIDIARIES OF THE ...
getfilings.com/sec-filings/170207/HALLIBURTON-CO.../hal_12312016-ex211.htm
Dec 31, 2016 - Barbados. Halliburton Affiliates, LLC. United States, Delaware. Halliburton Canada Holdings B.V.. Netherlands. Halliburton Canada ULC. Canada, Alberta. Halliburton de Mexico, S. de R.L. de C.V.. Mexico. Halliburton Energy Cayman Islands Limited II. Cayman Islands. Halliburton Energy Services Limited.

Top 3 Companies Owned by Halliburton (HAL) | Investopedia
https://www.investopedia.com/articles/.../top-3-companies-owned-halliburton-hal.asp
Jan 22, 2018 - Learn about Halliburton's most important subsidiaries from its acquisition of Dresser Industries and other companies.

Halliburton's Affiliates and Subsidiaries: A Global Scope - Google ...
https://groups.google.com/forum/#!msg/misc.activism.progressive/nfsPdNihiog/...
Sep 16, 2003 - The following is A COMPLETE LIST OF HALLIBURTON'S SUBSIDIARIES AND AFFILIATES. The list provides a clear vision of ... Halliburton De Mexico, S De Rl De Cv (Mexico) Halliburton Del Peru Sa (Peru) ... Pt Halliburton Drilling Systems Indonesia (Indonesia) Pt Halliburton Indonesia (Indonesia)

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www.halliburton.com/en-US/search/default.page?k=subsidiaries&page=2...11
Results 11 - 20 of 58 - Halliburton Announces Third Quarter 2016 Results ...Total liabilities 17,029 21,447 Company shareholders' equity 9,682 15,462 Noncontrolling interest in consolidated subsidiaries 44 33 Total shareholders' equity 9,726 15,495 Total liabilities and shareholders' equity $ 26,755 $ 36,942.

CorpWatch : Halliburton
www.corpwatch.org › ... › Company Profiles › Halliburton
Dorgan, who chairs the Senate Democratic Policy Committee, has also noted that Halliburton avoids accountability by hiring employees under its subsidiary in the Cayman Islands, a tax haven country in the Caribbean, which allows for avoidance of U.S. tax, worker safety and other laws. "We've had a report showing a large ...

Halliburton
Corporation

Halliburton is an American multinational c
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CEO: Jeff Miller (1 Jun. 2017–)
Headquarters: Houston, Texas, United S
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[2] Source: United States Geological Survey. https://www2.usgs.gov/faq/node/3824

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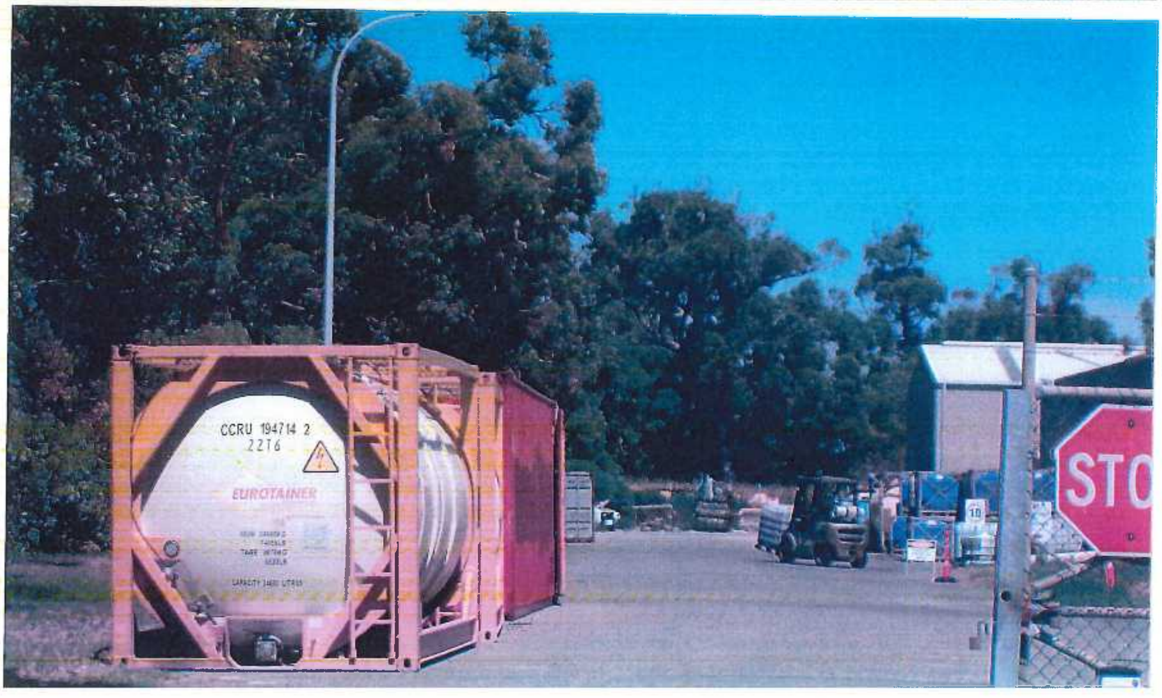
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