National assessment of chemicals associated with coal seam gas extraction in Australia

Technical report number 7

Identification of chemicals associated with coal seam gas extraction in Australia

This report was prepared by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS)

Australian Government
Department of the Environment and Energy
Department of Health
National Industrial Chemicals Notification and Assessment Scheme

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The report's authors gratefully acknowledge input from the Project Steering Committee, which comprised representatives from the National Industrial Chemicals Notification and Assessment Scheme (NICNAS), the Department of the Environment and Energy, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Geoscience Australia (GA), and an independent scientific member, Dr. David Jones of DR Jones Environmental Excellence.

This report was subject to internal review during its development.

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The full set of technical reports in this series and the partner agency responsible for each is listed below.

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13	Human health risks associated with surface handling of chemicals used in coal seam gas extraction in Australia	NICNAS
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14	Environmental risks associated with surface handling of chemicals used in coal seam gas extraction in Australia	Department of the Environment and Energy

Foreword

Purpose of the Assessment

This report is one in a series of technical reports that make up the *National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia* (the Assessment).

Many chemicals used in the extraction of coal seam gas are also used in other industries. The Assessment was commissioned by the Australian Government in June 2012 in recognition of increased scientific and community interest in understanding the risks of chemical use in this industry. The Assessment aimed to develop an improved understanding of the occupational, public health and environmental risks associated with chemicals used in drilling and hydraulic fracturing for coal seam gas in an Australian context.

This research assessed and characterised the risks to human health and the environment from surface handling of chemicals used in coal seam gas extraction during the period 2010 to 2012. This included the transport, storage and mixing of chemicals, and the storage and handling of water pumped out of coal seam gas wells (flowback or produced water) that can contain chemicals. International evidence[1] showed the risks of chemical use were likely to be greatest during surface handling because the chemicals were undiluted and in the largest volumes. The Assessment did not consider the effects of chemical mixtures that are used in coal seam gas extraction, geogenic chemicals, or potential risks to deeper groundwater.

The Assessment findings significantly strengthen the evidence base and increase the level of knowledge about chemicals used in coal seam gas extraction in Australia. This information directly informs our understanding of which chemicals can continue to be used safely, and which chemicals are likely to require extra monitoring, industry management and regulatory consideration.

Australia’s regulatory framework

Australia has a strong framework of regulations and industrial practices which protects people and the environment from adverse effects of industrial chemical use. For coal seam gas extraction, there is existing legislation, regulations, standards and industry codes of practice that cover chemical use, including workplace and public health and safety, environmental protection, and the transport, handling, storage and disposal of chemicals. Coal seam gas projects must be assessed and approved under relevant Commonwealth, state and territory environmental laws, and are subject to conditions including how the companies manage chemical risk.

Approach

Technical experts from the National Industrial Chemicals Notification and Assessment Scheme (NICNAS), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Department of the Environment and Energy conducted the Assessment. The Assessment drew on technical expertise in chemistry, hydrogeology, hydrology, geology, toxicology, ecotoxicology, natural resource management and risk assessment. The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining

[1] See Mallants et al. 2017; Jeffrey et al. 2017; Adgate et al. 2014; Flewelling and Sharma 2014; DEHP 2014a; Stringfellow et al. 2014; Groat and Grimshaw 2012; Vidic et al. 2013; Myers 2012; Rozell and Reaven 2012; The Royal Society and The Royal Academy of Engineering 2012; Rutovitz et al. 2011.

Development (IESC) provided advice on the Assessment. Experts from the United States Environmental Protection Authority, Health Canada and Australia reviewed the Assessment and found the Assessment and its methods to be robust and fit-for-purpose.

The Assessment was a very large and complex scientific undertaking. No comparable studies had been done in Australia or overseas and new models and methodologies were developed and tested in order to complete the Assessment. The Assessment was conducted in a number of iterative steps and inter-related processes, many of which needed to be done in sequence (Figure F.1). There were two separate streams of analysis - one for human health and one for the environment. The steps included for each were: literature reviews; identifying chemicals used in drilling and hydraulic fracturing for coal seam gas extraction; developing conceptual models of exposure pathways; models to predict soil, surface and shallow groundwater concentrations of identified chemicals; reviewing information on human health hazards; and identifying existing Australian work practices, to assess risks to human health and the environment.

The risk assessments did not take into account the full range of safety and handling precautions that are designed to protect people and the environment from the use of chemicals in coal seam gas extraction. This approach is standard practice for this type of assessment. In practice, safety and handling precautions are required, which means the likelihood of a risk occurring would actually be reduced for those chemicals that were identified as a potential risk to humans or the environment.

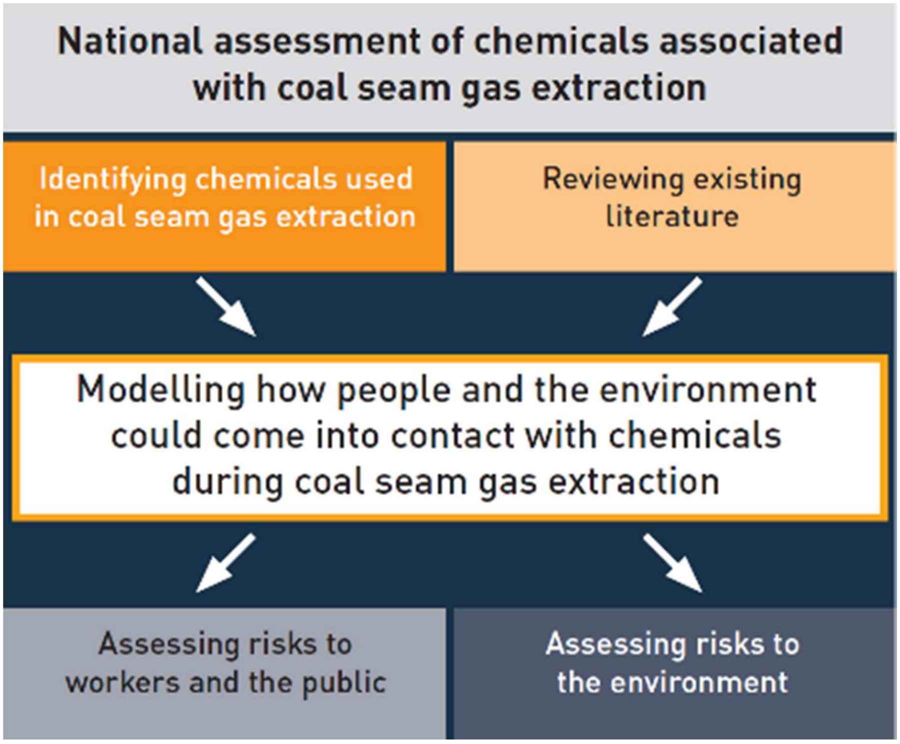

Figure F.1 Steps in the Assessment

Collaborators

The Australian Government Department of the Environment and Energy designs and implements policies and programs, and administers national laws, to protect and conserve the environment and heritage, promote action on climate change, advance Australia's interests in the Antarctic, and improve our water use efficiency and the health of Australia's river systems.

Within the Department, the Office of Water Science is leading the Australian Government's efforts to improve understanding of the water-related impacts of coal seam gas and large coal mining. This includes managing the Australian Government's program of bioregional assessments and other priority research, and providing support to the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC). The IESC provides independent, expert scientific advice on coal seam gas and large coal mining proposals as requested by the Australian Government and state government regulators, and advice to the Australian Government on bioregional assessments and research priorities and projects.

The National Industrial Chemicals Notification and Assessment Scheme (NICNAS) is a statutory scheme administered by the Australian Government Department of Health. NICNAS aids in the protection of the Australian people and the environment by assessing the risks of industrial chemicals and providing information to promote their safe use.

CSIRO, the Commonwealth Scientific and Industrial Research Organisation, is Australia's national science agency and one of the largest and most diverse research agencies in the world. The agency's research is focused on building prosperity, growth, health and sustainability for Australia and the world. CSIRO delivers solutions for agribusiness, energy and transport, environment and natural resources, health, information technology, telecommunications, manufacturing and mineral resources.

This report: *Identification of chemicals associated with coal seam gas extraction in Australia*

This report describes the second stage of the Assessment – the identification of chemicals associated with coal seam gas extraction in Australia. It identifies chemicals that were used for drilling and hydraulic fracturing for coal seam gas extraction in Australia during the period 2010 to 2012. Information on the transportation and storage, use, release, recovery, and disposal of these chemicals was also collected.

Chemicals were identified through an industry survey, direct requests for information made to companies involved in the Australian coal seam gas industry, and by reviewing publicly available information. Information to inform the Assessment was collected through to June 2015.

The report identifies 113 chemicals used for coal seam gas extraction in Australia during the period 2010 to 2012 (see Table 3.1). These comprise:

- 47 chemicals used for drilling
- 84 chemicals used for hydraulic fracturing
- 18 chemicals used for both drilling and hydraulic fracturing

The findings documented in this report were used in subsequent parts of the Assessment. For example, information about how and in what quantities chemicals were used contributed to the development of release scenarios and conceptual models (Stage 3). The identified chemicals formed the basis for the project's subsequent human health and environmental risk assessments (Stage 4).

The Assessment was commissioned by the Australian Government Department of the Environment. The Assessment assessed the risks to human health and the surface and near-surface environment (comprising surface water, soils, and shallow groundwater) from chemicals being used in drilling and hydraulic fracturing for coal seam gas extraction in Australia during the period 2010 to 2012.

Abbreviations

General abbreviations	Description
APPEA	Australian Petroleum Production and Exploration Association
BTEX	Benzene, Toluene, Ethyl benzene, Xylenes
CAS	Chemical Abstract Service
CAS RN	Chemical Abstract Service Registration Number
CBI	Confidential business information
CSG	Coal seam gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EQL	Estimated Quantitation Limit
G	Gram
g/kg	Gram per kilogram
g/L	Gram per litre
Kg	Kilogram
L	Litre
mg/L	Milligram per litre
ML	Megalitre
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
n.s.	Not specified
PAH	Polycyclic Aromatic Hydrocarbon
QLD DEHP	Queensland Government Department of Environment and Heritage Protection
TRH	Total Recoverable Hydrocarbon
US EPA	United States Environmental Protection Agency
UV	Ultraviolet

Glossary

Term	Description
Adsorption	The binding of molecules to a particle surface. For example, this process can bind methane and carbon dioxide to coal particles
Amended water	Water to which a surfactant has been added
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation, which is saturated and sufficiently permeable to transmit quantities of water to wells and springs
Bactericide	A substance which kills bacteria
Biocide	An additive intended to destroy, deter, render harmless, prevent the action or otherwise exert a controlling effect on microorganisms. Commonly used in drilling and hydraulic fracturing fluids
Buffer	A solution that resists pH change
Breaker	Reduces the viscosity of fluids by 'breaking' the gel; assists in releasing the proppants into the fractures
Casing	Steel or fibreglass pipe used to line a well and support the rock. Casing extends to the surface and is sealed by a cement sheath between the casing and the rock
Coal seam	Coal seams or coal deposits are layers containing coal (sedimentary rock). Coal seams store both water and gas. Coal seams generally contain more salty groundwater than aquifers that are used for drinking water or agriculture
Coal seam gas	A form of natural gas (generally 95 to 97% pure methane, CH_4) typically extracted from permeable coal seams at depths of 300 to 1 000 m. Also called coal seam methane (CSM) or coal bed methane (CBM)
Crosslinker	Chemical compounds used to maintain the viscosity of fluids at higher temperatures
Defoamer	A chemical additive that reduces and hinders the formation of foam
Dispersant	A liquid or gas used to disperse small particles in a medium
Drilling fluids	Fluids that are pumped down the wellbore to lubricate the drill bit, carry rock cuttings back up to the surface, control pressure and for other specific purposes. Also known as drilling muds
Drilling / fracturing products	Proprietary mixtures of chemicals – often with a trade name – used by companies to assist in the drilling and / or hydraulic fracturing processes
Emulsion	A fine dispersion of minute droplets of one liquid in another in which it is not soluble or miscible
Estimated Quantitation Limit (EQL)	Lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. Generally, EQLs are 5-10 times the method detection limit (MDL)
Flowback water	The initial flow of water returned to a well after fracture stimulation and prior to production
Foaming agent	A material that facilitates formation of foam such as a surfactant or a blowing

Term	Description
	agent
Geogenic chemical	A naturally-occurring chemical originating, for example, from geological formations
Groundwater	Water occurring naturally below ground level (whether in an aquifer or other low-permeability material), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage. This does not include water held in underground tanks, pipes or other works
Hazard	Inherent property of an agent or situation having the potential to cause adverse effects when an organism, system, or sub(population) is exposed to that agent
Hydraulic fracturing	Also known as 'fracking', 'fraccing' or 'fracture stimulation', is one process by which hydrocarbon (oil and gas) bearing geological formations are 'stimulated' to enhance the flow of hydrocarbons and other fluids towards the well. In most cases is only undertaken where the permeability of the formation is initially insufficient to support sustained flow of gas. The hydraulic fracturing process involves the injection of fluids, gas, proppant and other additives under high pressure into a geological formation to create a conductive fracture. The fracture extends from the well into the coal reservoir, creating a large surface area through which gas and water are produced and then transported to the well via the conductive propped fracture channel
Hydraulic fracturing fluid	A fluid injected into a well under pressure to create or expand fractures in a target geological formation (to enhance production of natural gas and / or oil). It consists of a primary carrier fluid (usually water or gel based), a proppant and one or more additional chemicals to modify the fluid properties
Loss circulation material	Substances added to drilling fluids to prevent these fluids being lost to formations downhole during drilling or cementing operations
pH	A measure of the acidity / alkalinity of a solution – a logarithmic scale from 1 (most acidic) to 14 (most alkaline); 7 is neutral
Photodegradation	Alteration of materials by light, usually through oxidation and hydrolysis
Produced water	Water that is pumped out of coal seams to release the natural gas during the production phase. Some of this water is returned fracturing fluid and some is natural 'formation water' (often salty water that is naturally present in the coal seam). This produced water moves through the coal formation to the well along with the gas, and is pumped out via the wellhead
Proppant	A component of the hydraulic fracturing fluid system comprised of sand, ceramics or other granular material that 'prop' open fractures to prevent them from closing when the injection pressure is stopped
Radionuclide	An unstable form of a chemical element that decays radioactively, resulting in the emission of nuclear radiation. Also called a radioisotope
Risk	The probability of an adverse effect in an organism, system, or (sub)population caused under specified circumstances by exposure to an agent
Separator	A vessel used to separate gas and water from the total fluid stream produced by a well
Shale Inhibitor	Drilling fluid additives that inhibit the interaction between shale and water, helping prevent the swelling of shale formations and dispersion of shale into the drilling fluid

Term	Description
Shear slippage	Slippage of rock along pre-existing fractures or joints resulting from the high-pressure injection of fluids inducing shearing stresses parallel to the joint
Shallow groundwater	Groundwater that occurs in the shallowest aquifer bounded by a water table and an unsaturated zone of variable thickness (sometimes absent) above, and by deeper aquifer or aquitard systems below. Also generally referred to as the water table aquifer
Surfactant	Used during the hydraulic fracturing process to decrease liquid surface tension and improve fluid movements
Tote	A reusable industrial container, also known as an intermediate bulk container (IBC)
Tubing	Steel pipe that is hung inside the casing. The tubing string may have a pump installed at its lower end and, for pumped wells, is a primary path for producing water from coal seam gas wells
Viscosifier	Substance added to a fluid to change the thickness or resistance of the fluid
Weight additive	Low specific gravity additives used to modify the density of drilling fluids and cement slurries used in the drilled borehole
Well	A human-made hole in the ground, generally created by drilling, to obtain water. As used in this report: a coal seam gas well including the wellhead and all subsurface components (such as the drilled borehole, annulus, and casings)
Wellbore	The hole in the rock produced by drilling, with the final intended purpose being for production of oil, gas, or water
Wellhead	The above-ground part of a well placed on top of the wellbore. Wellheads manage the movement of gas and water to the surface

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1 Methodology to identify chemicals

1.1 Industry survey

Between August and October 2012, survey forms were sent to 29 companies (listed at Appendix A) involved in coal seam gas extraction, identified from Australian state and territory government information, industry websites and media reports. These included well drilling service providers, hydraulic fracturing service providers and coal seam gas site operators or companies responsible for site monitoring and storage and treatment of flowback and / or produced waters. The Australian Petroleum Production and Exploration Association (APPEA) assisted in forwarding the survey to members associated with coal seam gas-related activities.

Information was requested via three different survey forms shown at Appendix B with each company requested to complete the survey form(s) most relevant to the activity in which they were or had been involved.

Information requested included:

- chemical identity information (including individual components of formulations), that is the chemical name, Chemical Abstract Service (CAS) registry number, concentrations and functions, intended use, annual volumes or mass imported / manufactured / bought locally, physical state as delivered to site and container sizes
- trends in substitution of chemicals in drilling or hydraulic fracturing fluids
- data on chemicals identified in flowback and co-produced waters, including estimated or monitored levels of geogenic chemical contaminants mobilised as a result of hydraulic fracturing (for example, naturally occurring or newly formed trace metals, organics, salts and radionuclides)
- details of company operating procedures, practices and / or policies covering drilling or hydraulic fracturing activities, including procedures employed to ensure that drilling or hydraulic fracturing activities do not cause new connections, or exacerbate existing connections, between target formations and another aquifer
- data for chemicals released to the environment due to accidents, including recovery details and remedial measures
- lists of published and unpublished studies on human health and environmental impacts of drilling or hydraulic fracturing fluid chemicals.

Consistent with the *Industrial Chemicals (Notification and Assessment) Act 1989*, companies were requested to highlight information claimed as confidential business information (CBI). Where this confidentiality was accepted, chemicals have been identified by their generic name in the Assessment and their use reported with less specificity. However, full details of the chemicals and their use as provided by companies were used for the Assessment.

From the industry survey, 103 chemicals were identified. A summary of the survey responses is at Appendix A. Twenty of the 29 companies contacted responded to the survey with a response rate of 69 per cent.

Respondents also provided details of 39 published and unpublished studies on human health and / or environmental impacts of chemicals used in drilling or hydraulic fracturing or found in flowback and / or produced waters. A list of these studies is at Appendix C.

1.2 Review of publicly available Australian information

The chemicals reported through the survey were compared with publicly available information on the websites of the following:

- Queensland Government Department of Environment and Heritage Protection (DEHP 2014b) – identified 55 chemicals
- Australian Petroleum Production and Exploration Association (APPEA 2012) – identified 55 chemicals
- National Toxics Network (Lloyd-Smith and Senjen 2011) – identified 23 chemicals
- various companies involved in the coal seam gas sector in Australia – identified 52 chemicals.

A further 10 chemicals not reported in the survey were identified through this review.

1.3 Additional information provided by industry

Additional information on the use of 23 of the 113 chemicals was provided by companies in May and June 2015 to better inform the assessment of the environmental risks. This included:

- volumes and concentrations transported
- handling procedures including packaging, transport, distribution and quantities and concentrations stored and used, and concentrations of chemicals in fracturing fluids
- drilling and hydraulic fracturing operations, and the locations of chemical stores and operational sites.

1.4 Possible limitation of the methodology

Completion of the survey was voluntary and it is possible that not all companies involved in coal seam gas activities in Australia responded or responded in full.

However, chemicals reported through the survey were compared with publicly available Australian sources ensuring a comprehensive list of chemicals to be considered by the Assessment. Further, survey responses were received from the hydraulic fracturing service providers that conducted the majority, if not all, of the hydraulic fracturing activities in Australia. Also, the coal seam gas site operators that provided information are considered to be the major companies involved in coal seam gas extraction and production in Australia during the survey period 2010 to 2012.

2 Findings

Chemical additives are used in drilling and hydraulic fracturing fluids for a variety of functions. These include to control pH, inhibit bacterial growth, adjust viscosity, prevent scale formation and reduce friction. Water and sand (or other types of engineered ceramics) are typically reported to comprise 97 to 99 per cent with other chemicals comprising 1 to 3 per cent of the hydraulic fracturing fluid (CSIRO 2012).

A number of chemicals are common to both drilling and hydraulic fracturing.

2.1 Drilling fluids

Forty-seven chemicals were identified as being used in drilling for coal seam gas extraction in Australia during the period 2010 to 2012. Eighteen of these chemicals were identified as also being used for hydraulic fracturing.

2.1.1 Drilling fluid products

Twenty-nine drilling fluid products were identified. These are listed in Table 2.1.

Products were reported packaged in 2 to 25 kg containers (for solids) or 20 L containers (for liquids). Large quantities were introduced in bulk bags of up to 10 000 kg (for solids), and 206 L drums or 500 to 1 000 L totes (for liquids).

Table 2.1 Drilling fluid products

	Product name	Intended use	Physical state as delivered to site	Total volume or mass imported, manufactured or acquired locally
1	Aldacide G	Biocide	Liquid	19 480 L
2	Aquagel Goldseal	Viscosifier	Powder	153 775 kg
3	Barascav D	Oxygen scavenger	Solid	6 275 kg
4	Barazan D	Viscosifier	Powder	64 200 kg
5	Barite	Weight additive	Solid	1 587 400 kg
6	Barofibre F/M/C	Loss circulation material	Powder	127 414 kg
7	Baro-Seal	Loss circulation material	Solid	276 210 kg
8	Bentonite	Weight additive	Solid - beige	Variable
9	Bicarbonate of Soda	Buffer	Solid	20 000 kg
10	Caustic Soda	pH control	Solid	27 975 kg
11	Citric Acid	pH control	Crystalline powder	15 000 kg
12	Defoam W300/Foam Zapper	Defoamer	Liquid	6 000 L
13	Diamond Seal	Loss circulation material	Solid granules	2 966 kg

	Product name	Intended use	Physical state as delivered to site	Total volume or mass imported, manufactured or acquired locally
14	EZ-Mud DP	Shale inhibitor	Solid	34 325 kg
15	Lime	pH control	Solid	12 000 kg
16	N-Plex/N-Seal N-Squeeze	Loss circulation material	Liquid / fibre / solid	5 000 kg
17	Omyacarb 10/CaCO3 F	Weighting agent / Control fluid loss	Powder	6 250 kg
18	Omyacarb 20/CaCO3 M	Weighting agent / Control fluid loss	Powder	6 250 kg
19	Omyacarb 40/CaCO3 C	Weighting agent / Control fluid loss	Powder	6 250 kg
20	PAC L/LE	Fluid loss additive	Powder	71 375 kg
21	Pac R/RE	Fluid loss additive	Solid powder	59 525 kg
22	PHPA	Shale inhibitor	Liquid	8 650 kg
23	Potassium Chloride	Shale inhibitor	Solid	15 000 kg
24	Potassium Sulfate	Shale inhibitor	Granules or powder	1 183 725 kg
25	Quik Foam	Foaming agent	Liquid	44 650 kg
26	SAPP	Dispersant	Solid	27 600 kg
27	Sawdust	Loss circulation material	Granular flake	10 000 kg
28	Soda Ash	Buffer	Powder	15 000 kg
29	Walnut / Barofibre F/M/C	Loss circulation material	Solid granules or fibre	11 748 kg

2.1.2 Constituent chemicals

The 47 constituent chemicals identified as ingredients of drilling fluid products are listed in Table 2.2. Where available, information on the concentration after final dilution prior to injection is also reported.

Table 2.2 Chemicals used in drilling products

	CAS RN	CAS Chemical Name	Concentration in formulation delivered to site (g/kg or g/L)	Concentration after final dilution prior to injection (g/kg or g/L)
1	107-22-2	Ethanedial	CBI	n.s.
2	111-30-8	Pentanedial	100 – 300	0.503 – 6.54
3	11138-66-2	Xanthan gum	600 – 1 000	0–3.8
4	1302-78-9	Bentonite	0 – 1 000	n.s.
5	1303-96-4	Borax ($B_4Na_2O_7.10H_2O$)	10 – 24	n.s.
6	1305-62-0	Calcium hydroxide ($Ca(OH)_2$)	600 – 1 000	n.s.
7	1310-73-2	Sodium hydroxide (Na(OH))	10 – 1 000	>0.76
8	1317-65-3	Limestone	>990	n.s.
9	144-55-8	Carbonic acid sodium salt (1:1)	600 – 1 000	0 – 2.156
10	14464-46-1	Cristobalite (SiO_2)	0 – 10	n.s.
11	14808-60-7	Quartz (SiO_2)	10 – 50	n.s.
12	15468-32-3	Tridymite (SiO_2) (9CI)	0 – 10	n.s.
13	497-19-8	Carbonic acid sodium salt (1:2)	600 – 2 532	0.17 – CBI
14	55566-30-8	Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1)	180 - 250	0 – 0.357
15	64-17-5	Ethanol	50 – 100	n.s.
16	64742-47-8	Distillates (petroleum), hydrotreated light	100 – 600	n.s.
17	67-56-1	Methanol	CBI	n.s.
18	67-63-0	2-Propanol	50 – 100	n.s.
19	7447-40-7	Potassium chloride (KCl)	500 – 1 000	0.04 – 160
20	7647-14-5	Sodium chloride (NaCl)	990	28 – 127
21	7727-43-7	Sulfuric acid, barium salt (1:1)	600 – 1 000	n.s.
22	7732-18-5	Water	CBI	n.s.
23	7757-83-7	Sulfurous acid, sodium salt (1:2)	600 – 1 000	n.s.
24	7758-16-9	Diphosphoric acid, sodium salt (1:2)	600 – 1 000	n.s.
25	7778-80-5	Sulfuric acid potassium salt (1:2)	600 – 1 000	3.5
26	77-92-9	1,2,3-Propanetricarboxylic acid, 2-hydroxy-	600 – 1 000	0 – 4.194
27	9000-30-0	Guar gum	CBI	n.s.

	CAS RN	CAS Chemical Name	Concentration in formulation delivered to site (g/kg or g/L)	Concentration after final dilution prior to injection (g/kg or g/L)
28	9003-06-9	2-Propenoic acid, polymer with 2-propenamide	CBI	n.s.
29	CBI	2-Ethylhexanol heavies	CBI	n.s.
30	CBI	Ester alcohol	CBI	n.s.
31	CBI	Fatty acids ester	600 – 1 000	n.s.
32	n.s.	Natural fibres I	CBI	n.s.
33	n.s.	Natural fibres II	CBI	n.s.
34	CBI	Natural fibres III	CBI	n.s.
35	n.s.	Nut hulls	600 – 1 000	n.s.
36	CBI	Organic acid salt	CBI	n.s.
37	CBI	Organic sulfate	CBI	n.s.
38	CBI	Polyacrylamide/polyacrylate copolymer	900 – 950	n.s.
39	n.s.	Polyanionic cellulose PAC	n.s.	n.s.
40	n.s.	Polyesters	CBI	n.s.
41	CBI	Polymer I	CBI	n.s.
42	CBI	Polymer II	CBI	n.s.
43	CBI	Polymer with substituted alkylacrylamide salt	CBI	n.s.
44	CBI	Polysaccharide	600 – 1 000	n.s.
45	n.s.	Walnut hulls	600 – 1 000	n.s.
46	n.s.	Wood dust	CBI	n.s.
47	n.s.	Wood fibre	CBI	n.s.

n.s. = not specified; CBI = confidential business information

2.1.3 Drilling operations

No specific details were provided on operating procedures to ensure isolation between target formations and other aquifers. Zonal isolation between the producing zone and all other subsurface formations is important, as it prevents any other geologic horizon in the well from being affected by the hydraulic fracturing fluids introduced from the surface into the producing formation. One company stated that the most critical factors in zonal isolation techniques during well construction were casing and cement seals. Another company reported that each candidate well undergoes a rigorous procedure to ensure that all the conditions of the relevant Australian state environmental authority are satisfied.

2.1.4 Introduction, handling and disposal of chemicals

Most of the chemicals in drilling fluids are imported as end-use products which are not reformulated or sold to retailers in Australia.

The products are transported and temporarily stored at holding warehouses close to the job sites. Products are then blended with other chemicals to make the formulation to be used in drilling operations. These blended formulations are brought to the well site and transferred to a chemical trailer.

For a typical application, the blended formulation is incorporated into a specific treatment application (an emulsion) consisting of base oil, water and other products. The emulsion is then dissolved within the drilling fluid system, typically 159 000 to 318 000 L.

No information was provided for typical or maximum volumes of drilling fluid formulations used for a complete coal seam gas drilling operation.

At the completion of well drilling, the drilling fluid is reused if it is synthetic or oil-based. Disposal of water-based drilling fluid is conducted in accordance with local waste disposal requirements.

2.1.5 Substitution of chemicals

No specific information was received on substitutions of chemicals in drilling fluids (that is, replacement or use of alternative chemicals) other than that chemicals used are reviewed continually and evaluated for performance to ensure product improvement. One company stated that chemical substitution is not a normal occurrence.

2.2 Hydraulic fracturing fluids

Eighty-four chemicals were identified as being used in hydraulic fracturing for coal seam gas extraction in Australia during the period 2010 to 2012. Eighteen of these chemicals were identified as also being used for drilling.

Water and sand (or other types of engineered ceramics) are widely accepted in the coal seam gas industry to comprise approximately 97 to 99 per cent of the injected hydraulic fracturing fluid. However, responses to the survey indicate the value as approximately 90.5 per cent.

2.2.1 Hydraulic fracturing fluid products

Fifty-nine hydraulic fracturing fluid products or fracturing pre-treatment formulations (mixture of products and / or chemicals) were identified. These are listed in Table 2.3.

The majority of products were reported to be packaged in 25 kg containers (for solids) or 20 L containers (for liquids). Large quantities are introduced in bulk bags of up to 10 000 kg (for solids), and 206 L drums or 500 to 1 000 L totes (for liquids).

Table 2.3 Hydraulic fracturing fluid products or fracturing pre-treatment formulations

	Product / Formulation name	Intended use	Physical state as delivered to site	Total volume or mass imported, manufactured or acquired locally
1	Acetic Acid 60%	Buffer / Solvent	Liquid	79 073.4 L
2	BC-140 C X-linker	Crosslinker	Liquid	47 851.4 L
3	BE-09	Biocide	Liquid	n.s.
4	BE-6 Bactericide	Bactericide	Powder	5.4 kg
5	BE-7	Biocide	Liquid	44 919.6 L
6	BF-3	pH buffer	Solid	n.s.
7	BF-7L	pH buffer	Liquid	n.s.
8	BF10L, L401	pH buffer	Liquid	n.s.
9	Boric Acid 3.6%	Crosslinker	Liquid	8 000 L
10	Caustic Soda, 50% solution	Buffer	Liquid	2 646 L
11	Citric Acid	Chelating	Solid - crystalline	25 kg
12	CL-28M Crosslinker	Crosslinker	Liquid	n.s.
13	Clatrol	Clay control	Liquid	400 L
14	Clayfix II Plus	Clay stabiliser	Liquid	10 601 L
15	ClayTreat-3C	Clay control	Liquid	400 L
16	FE-2	Iron control agent	Solid granular	174.6 kg
17	FE-300	pH buffer	Powder / granules	n.s.
18	FR-46	Friction reducer	Liquid	n.s.
19	GasPerm 1000	Surfactant	Liquid	104.1 L
20	GasPerm 1100	Non-ionic surfactant	Liquid	10 595.4 L
21	GBW-12CD	Breaker	Liquid	69 L
22	GBW-18	Breaker	Powder	n.s.
23	GBW-30	Breaker	Powder	n.s.
24	Gelatine	Corrosion inhibitor	Solid - crystalline	50 kg
25	Gel-Sta L	Gel stabiliser	Liquid	15 879.8 L
26	GLFC-5	Slurry guar gum	Liquid	3 000 L
27	GS-1L	Chlorine neutraliser	Liquid	200 L
28	GW-3	Guar gum	Powder	5 000 kg
29	HC-2	Foaming agent	Liquid	749.5 L

	Product / Formulation name	Intended use	Physical state as delivered to site	Total volume or mass imported, manufactured or acquired locally
30	HC-2A	Foaming agent	Liquid	1 203.8 L
31	HCl 32-35%	pH control	Liquid	400 L
32	HpH Breaker	Breaker	Liquid	2 386.7 L
33	Hydrochloric acid, 22 baume	Acid/Solvent	Liquid	10 031.3 L
34	J218, GBW-5, EB-CLEAN, J479 LT Encapsulated Breaker	Breaker	Granules	n.s.
35	J494	pH buffer	Granules	n.s.
36	J580, GW-3, GW-4, GW-38, WG-36, WG-11	Gelling agent	Powder	n.s.
37	K-34	Buffer	Solid	1 696.4 kg
38	K-35, Sodium Carbonate	Buffer	Powder	1 733.9 kg
39	K-38	Biocide, crosslinker	Solid	n.s.
40	L010	Crosslinker	Liquid	n.s.
41	M003, Soda Ash	pH buffer	Solid	n.s.
42	Magnacide-575	Bactericide	Liquid	832 L
43	Magnacide 575 Microbiocide	Biocide	Liquid	n.s.
44	M275, Biocide BPA68915	Biocide	Liquid	n.s.
45	Optiflo HTE	Breaker	Solid	179.2 kg
46	Oxygon	Oxygen scavenger	Powder	n.s.
47	Potassium Chloride	Additive	Solid or liquid	n.s.
48	ScaleChek LP-55	Scale inhibitor	Liquid	n.s.
49	Sodium Hypochlorite 12.5%	Bactericide	Liquid	12 000 L
50	Sodium Hydroxide 10%	pH buffer	Liquid	4 000 L
51	SuperFlo 2000	Surfactant	Liquid	n.s.
52	Temporary Clay Stabiliser L64, ClayTreat-3C	Clay control	Liquid	n.s.
53	Tolcide PS75	Biocide	Liquid	77.6 L
54	Vicoon NF Breaker	Breaker	Liquid	n.s.
55	WG-19	Gelling agent	Powder	687.2 kg
56	WG-21, WG-17	Gelling agent	Solid	n.s.

	Product / Formulation name	Intended use	Physical state as delivered to site	Total volume or mass imported, manufactured or acquired locally
57	WG-36	Gelling agent	Powder	93 628 kg
58	XLW-10A	Crosslinker	Liquid	2 288 L
59	YF-120LG	Crosslinked gel prop frac	Fluid system	n.s.

n.s. = not specified

2.2.2 Constituent chemicals

The 84 constituent chemicals reported as ingredients of hydraulic fracturing fluid products or fracturing pre-treatment formulations are listed in Table 2.4. Where available, information on the concentration after final dilution prior to injection is also reported.

Table 2.4 Chemicals present in hydraulic fracturing products or fracturing pre-treatment formulations

	CAS RN	CAS Chemical Name	Concentration in formulation delivered to site (g/kg or g/L)	Concentration after final dilution prior to injection (g/kg or g/L)
1	10043-35-3	Boric acid (H_3BO_3)	36 - 800	0.1532 – 0.216[a]
2	10043-52-4	Calcium chloride ($CaCl_2$)	CBI	CBI
3	102-71-6	Ethanol, 2,2',2''-nitrilotris -	n.s	n.s
4	10377-60-3	Nitric acid, magnesium salt (2:1)	10 - 50	0.0069
5	107-21-1	1,2-Ethanediol	150 – 496	0.08 – 0.496
6	108-10-1	2-Pentanone, 4-methyl-	CBI	CBI
7	111-76-2	Ethanol, 2-butoxy-	300 – 600	0.04
8	111-90-0	Ethanol, 2-(2-ethoxyethoxy)-	CBI	CBI
9	11138-66-2	Xanthan gum	CBI	0.01
10	112926-00-8	Silica gel, pptd., cryst.-free	n.s	n.s
11	12008-41-2	Boron sodium oxide ($B_8Na_2O_{13}$)	600 – 1 000	n.s.
12	124-38-9	Carbon dioxide	1 000	n.s.
13	127-09-3	Acetic acid, sodium salt (1:1)	n.s	n.s
14	1303-96-4	Borax ($B_4Na_2O_7.10H_2O$)	100 – 372	0.372
15	1305-78-8	Calcium oxide (CaO)	CBI	CBI
16	1310-73-2	Sodium hydroxide (Na(OH))	0 – 1 000	0.019 – 0.1375[a]

	CAS RN	CAS Chemical Name	Concentration in formulation delivered to site (g/kg or g/L)	Concentration after final dilution prior to injection (g/kg or g/L)
17	141-43-5	Ethanol, 2-amino-	<15	CBI
18	144-55-8	Carbonic acid sodium salt (1:1)	600 – 1 000	CBI
19	144588-68-1	Bauxite ($Al_2O_3.xH_2O$), sintered	CBI	CBI
20	14464-46-1	Cristobalite (SiO_2)	n.s.	0.0007[a]
21	14807-96-6	Talc ($Mg_3H_2(SiO_3)_4$)	n.s.	0.0006
22	14808-60-7	Quartz (SiO_2)	100 – 2 650	89.3494 – 119.8263[a]
23	25038-72-6	2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene	n.s.	0.0152
24	26038-87-9	Boric acid (H_3BO_3), compd. with 2-aminoethanol (1:?)	300 – 600	CBI
25	26062-79-3	2-Propen-1-aminium, N,N-dimethyl-N-2-propen-1-yl-, chloride (1:1), homopolymer	651	1.302
26	26172-55-4	3(2H)-Isothiazolone, 5-chloro-2-methyl-	100	0.003 - 0.01
27	2634-33-5	1,2-Benzisothiazol-3(2H)-one	CBI	CBI
28	2682-20-4	3(2H)-Isothiazolone, 2-methyl-	50	0.001 - 0.0014
29	463-79-6	Carbonic acid	n.s	n.s
30	497-19-8	Carbonic acid sodium salt (1:2)	600 – 2 532	0.316 – CBI
31	52-51-7	1,3-Propanediol, 2-bromo-2-nitro-	600 – 1 000	CBI
32	533-96-0	Carbonic acid, sodium salt (2:3)	600 – 1 000	0.8317
33	55566-30-8	Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1)	300 - 750	0.04125[a]
34	56-81-5	1,2,3-Propanetriol	CBI	CBI
35	584-08-7	Carbonic acid, potassium salt (1:2)	400 – 500	n.s.
36	6381-77-7	D-erythro-Hex-2-enonic acid, γ-lactone, sodium salt (1:1)	600 – 1 000	n.s.
37	64-02-8	Glycine, N,N'-1,2-ethanediylbis[N-(carboxymethyl)-, sodium salt (1:4)	n.s	n.s
38	6410-41-9	2-Naphthalenecarboxamide,	CBI	CBI

	CAS RN	CAS Chemical Name	Concentration in formulation delivered to site (g/kg or g/L)	Concentration after final dilution prior to injection (g/kg or g/L)
		N-(5-chloro-2,4-dimethoxyphenyl)-4-[2-[5-[(diethylamino)sulfonyl]-2-methoxyphenyl]diazenyl]-3-hydroxy-methoxyphenyl]azo]-3-hydroxy-		
39	64-17-5	Ethanol	100 – 300	CBI
40	64-19-7	Acetic acid	300 – 1 050	0.0005 – 0.525
41	67-48-1	Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, chloride (1:1)	n.s.	n.s.
42	67-56-1	Methanol	50 – 100	CBI
43	67-63-0	2-Propanol	50 – 300	0.0134[a]
44	68130-15-4	Guar gum, carboxymethyl 2-hydroxypropyl ether, sodium salt	450 – 1 000	n.s.
45	68187-17-7	Sulfuric acid, mono-C_{6-10}-alkyl esters, ammonium salts	n.s.	n.s.
46	68439-45-2	Alcohols, C_{6-12}, ethoxylated	n.s.	n.s.
47	68647-72-3	Terpenes and Terpenoids, sweet orange-oil	10 – 300	CBI
48	7447-40-7	Potassium chloride (KCl)	10 – 1 987	0.0028 - 22.9629
49	75-57-0	Methanaminium, N,N,N-trimethyl-, chloride (1:1)	300 – 612	0.612 – 1.2733[a]
50	7631-86-9	Silica	CBI	0.0059[a]
51	7647-01-0	Hydrochloric acid	300 – 600	<1[a]
52	7647-14-5	Sodium chloride (NaCl)	100 – 1 000	0.0002 – 0.4[a]
53	7681-52-9	Hypochlorous acid, sodium salt (1:1)	100 – 300	0.05775[a]
54	7722-84-1	Hydrogen peroxide (H_2O_2)	n.s.	n.s.
55	7727-37-9	Nitrogen	1 000	n.s.
56	7727-54-0	Peroxydisulfuric acid ($[(HO)S(O)_2]_2O_2$), ammonium salt (1:2)	600 – 1 000	0.4521 - <1
57	7732-18-5	Water	100 – 1 000	905.298
58	7757-82-6	Sulfuric acid sodium salt (1:2)	CBI	CBI
59	7757-83-7	Sulfurous acid, sodium salt (1:2)	CBI	CBI

	CAS RN	CAS Chemical Name	Concentration in formulation delivered to site (g/kg or g/L)	Concentration after final dilution prior to injection (g/kg or g/L)
60	7758-19-2	Chlorous acid, sodium salt (1:1)	80 – 100	n.s.
61	7772-98-7	Thiosulfuric acid ($H_2S_2O_3$), sodium salt (1:2)	300 – 600	0.175[a]
62	7775-27-1	Peroxydisulfuric acid ($[(HO)S(O)_2]2O_2$), sodium salt (1:2)	990 – 1 000	n.s.
63	7783-20-2	Sulfuric acid ammonium salt (1:2)	100–300	n.s.
64	7786-30-3	Magnesium chloride ($MgCl_2$)	100	0.0028 – 0.01
65	77-92-9	1,2,3-Propanetricarboxylic acid, 2-hydroxy-	600 – 1 000	0.0001 - 1.76504[a]
66	81741-28-8	Phosphonium, tributyltetradecyl-, chloride (1:1)	50 – 100	n.s.
67	9000-30-0	Guar gum	450 – 1 050	0.001–2.6
68	9000-70-8	Gelatins	1 000	2.99566
69	9003-05-8	2-Propenamide, homopolymer	300 – 600	n.s.
70	9004-62-0	Cellulose, 2-hydroxyethyl ether	600 – 1 000	n.s.
71	9012-54-8	Cellulase	50 – 150	n.s.
72	9025-56-3	Hemicellulase	1 000 – 1 200	0.03636[a]
73	90622-53-0	Alkanes, C_{12-26} -branched and linear	520	2.6
74	91053-39-3	Diatomite, calcined	n.s.	0.0344
75	CBI	Amine salt	CBI	CBI
76	CBI	Enzyme	CBI	CBI
77	CBI	Ethoxylated fatty acid I	CBI	CBI
78	CBI	Ethoxylated fatty acid II	CBI	CBI
79	CBI	Ethoxylated fatty acid III	CBI	CBI
80	CBI	Inner salt of alkyl amines	300 – 1 000	CBI
81	CBI	Polyamine	CBI	CBI
82	CBI	Quaternary amine	CBI	CBI
83	CBI	Terpenes and terpenoids	CBI	CBI
84	n.s.	Walnut hulls	600 – 1 000	CBI

[a] *Concentrations claimed as CBI may be lower or higher than the values reported. n.s. = not specified. CBI = confidential business information*

2.2.3 Hydraulic fracturing operations

The number of hydraulic fracturing operations per well, where required, were reported to vary between 1 and 9. Across the responses provided, estimates for typical operations were 1 to 5 operations per well, with a maximum of 6 to 9 operations per well. Site operators were reported to be responsible for developing a well construction program in accordance with regulatory requirements. According to the service providers, zonal isolation techniques (for example, casing and cement sealing) ensure proper wellbore isolation of the lower zones from the upper zones, preventing the upward migration of hydraulic fracturing treatments.

One company reported that microseismic monitoring or mapping is conducted for hydraulic fracturing activities to obtain images of the fractures and to detect microseismic events triggered by shear slippage on bedding planes adjacent to the hydraulic fracture. According to the company, microseismic mapping assists in ensuring that the fracture stays in the intended zone, minimises the number of wells and fractures required and aids in preventing under- or over-treatment of a well.

In addition, fracture analysis is conducted to determine where and when the fractures propagate, revealing the complexity of the fracture network in a specific formation. The results of microseismic monitoring and fracture analysis are utilised to improve the design of subsequent stimulations.

Table 2.5 and Table 2.6 summarise responses on the volumes of formulations and individual chemicals injected into wells after final dilution for pre-treatment or hydraulic fracturing operations.

Table 2.5 Volumes of injected product or formulation per operations

Formulation	Typical total volume of injected fluid per operation (L, unless specified otherwise)	Maximum total volume of injected fluid per operation (L)
20# Crosslink gel	50 000	120 000
20# Linear gel	80 000	140 000
Acetic acid	75.7	n.s.
BC-140C	757	n.s.
BE-7	189.3	n.s.
Caustic Soda	75.7	n.s.
GasPerm 1100	757	n.s.
Gel-Sta L	113.6	n.s.
HpH Breaker	56.8	n.s.
Potassium chloride	3 883.8	n.s.
Proppant	6 825.7 kg	n.s.
Treated Water	150 000	400 000
Water	378 541	n.s.

Formulation	Typical total volume of injected fluid per operation (L, unless specified otherwise)	Maximum total volume of injected fluid per operation (L)
WG-36	73.9 kg	n.s.

n.s. = not specified

Table 2.6 Volumes of individual chemicals injected per operation

CAS RN	CAS Chemical Name	Total volume of injected fluid per operation (L)
10043-35-3	Boric acid (H_3BO_3)	72.42
10377-60-3	Nitric acid, magnesium salt (2:1)	5.25
14464-46-1	Cristobalite (SiO_2)	0.18
14807-96-6	Talc ($Mg_3H_2(SiO_3)_4$)	0.15
14808-60-7	Quartz (SiO_2)	23 229.35
25038-72-6	2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene	5.77
26172-55-4	3(2H)-Isothiazolone, 5-chloro-2-methyl-	2.00
2682-20-4	3(2H)-Isothiazolone, 2-methyl-	0.59
497-19-8	Carbonic acid sodium salt (1:2)	84.43
533-96-0	Carbonic acid, sodium salt (2:3)	265.19
64-19-7	Acetic acid	45.69
67-63-0	2-Propanol	11.52
75-57-0	Methanaminium, N,N,N-trimethyl-, chloride (1:1)	735.64
7631-86-9	Silica	1.66
7727-54-0	Peroxydisulfuric acid ($[(HO)S(O)_2]2O_2$), ammonium salt (1:2)	154.34
7732-18-5	Water	612 279.11
7786-30-3	Magnesium chloride ($MgCl_2$)	0.99
9000-30-0	Guar gum	2 096.43
91053-39-3	Diatomite, calcined	49.47

2.2.4 Introduction, handling and disposal of fluids

Most of the chemicals in hydraulic fracturing fluids and pre-treatment formulations are imported from chemical suppliers packaged in bulk containers (that is, in totes, drums or bags).

The individual chemicals and / or formulations are transported to the job sites and stored temporarily at holding warehouses.

Individual chemicals and / or formulations are blended using one of two methods:

- batch mixing where chemicals are circulated into tanks or above ground lined pits using a mixing hopper and fluid transfer pumps
- continuous mixing where chemicals are added to the main hydraulic fracturing fluid by utilising specialised liquid additive system pumps and mixers.

For a typical hydraulic fracturing process, the mixed products are brought to the well site and transferred to a chemical trailer for use. At the completion of hydraulic fracturing, the unused product from a job site is transported back to the holding warehouse. Small amounts of unused chemicals are sometimes disposed of at the site in accordance with approved management plans.

2.2.5 Substitution of chemicals and / or fluids

Companies reported ongoing development of new products to improve the performance of the formulations. Some examples of substitution practices are:

- polymer blend using a dry polymer instead of hydrocarbon based liquid gel concentrates
- treating hydraulic fracturing fluids with ultraviolet (UV) light as a bactericide, instead of using chemical biocides
- use of potassium chloride as a clay control agent instead of chemically blended clay control agents
- use of boric acid based and / or borate based crosslinkers instead of other blended chemicals
- reduction of proppant and water requirements by utilising either:
  - nitrogen to provide better flowback properties and reduce water content
  - fracturing placement technologies.

2.3 Chemicals in flowback or produced waters

Data were provided on the monitoring and estimation of flowback and / or produced waters for drilling and hydraulic fracturing chemicals. In addition to injected chemicals, information was provided on the identities and concentrations of geogenic contaminants mobilised into flowback and / or produced waters as a result of fracturing or pre-treatment activities.

Of the three companies that provided data, one company estimated that 40 to 60 per cent of the chemical mass injected during a fracture could be recovered in flowback water, with the remaining proportion most likely biodegraded, complexed (that is, chelated) or adsorbed to the coal and considered immobile. The company's estimates were derived from preliminary assessments that utilised groundwater fate and transport modelling.

Monitoring data were provided for samples collected at the well heads of seven wells within one company's project area. The concentrations recorded for each chemical could be aggregated concentrations of geogenic, drilling and hydraulic fracturing chemicals. The concentrations were provided to NICNAS as commercial business information.

Another company provided monitoring data from 64 hydraulically fractured and non-hydraulically fractured wells from a commercial coal seam gas development in Queensland. The concentrations of the analytes monitored for these wells are summarised in Table 2.7. Important points to note are:

- The readings spanned approximately 10 years with the most recent data being up to the end of June 2013
- The ratio of the number of analytes detected from hydraulically fractured wells to non-hydraulically fractured wells ranged from 7:1 to 20:1 depending on the analyte tested
- The monitoring data for the hydraulically fractured wells related to analytes in flowback and / or produced waters. The majority (92 per cent) of the samples were taken from volumes up to 400 per cent of the hydraulic fracturing fluid used, with the remaining 8 per cent of samples taken from 400 to 900 per cent of the hydraulic fracturing fluid used.
- It was reported that the hydraulic fracturing fluid volume of 900 per cent is statistically representative of the fluid most likely to flow from the well over its lifetime. Current regulatory requirements in some Australian jurisdictions involve the monitoring and reporting of analytes in flowback and/or produced waters for 1.5 times the hydraulic fracturing fluid used.
- Limited data were available from non-hydraulically fractured wells and do not include initial production data in the earlier life of the wells. A greater number of analyte samples (up to 30 times more) were reported to be taken from hydraulically fractured wells than the non-hydraulically fractured ones.
- Samples from hydraulically fractured wells were taken from the tubing / wellhead. Some samples from non-hydraulically fractured wells were taken from the separator due to operational constraints and safety issues. The company noted that the monitoring values may reduce or change significantly if sampling was not conducted at the tubing / wellhead.
- The median, mean and maximum concentrations of the analytes were calculated by the company using the Spotfire statistical software from the individual data points. In addition, the proportion of concentration values at or below the estimated quantitation limit (EQL), and the proportion of outliers, were also provided. The proportion of concentration values at or below the EQLs were calculated as a percentage based on the number of analyte samples that were equal to or below the EQL divided by the total number of analyte samples.
- The concentration values that fell outside the upper and lower thresholds were considered as outliers (upper threshold was at the 75^{th} percentile plus three times the difference of the 75^{th} and 25^{th} percentile concentration values; lower threshold was at the 25^{th} percentile minus three times the difference of the 75^{th} and 25^{th} percentile concentration values). The outliers were also calculated as a percentage based on: the number of concentration values that fall outside the upper and lower thresholds divided by the total number of concentration values.

Table 2.7 Monitoring data from samples collected at the well heads for hydraulically fractured (HF) and non-hydraulically fractured (NHF) wells

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
BTEX – Benzene, Toluene, Ethylbenzene, Xylenes						
Benzene	NHF	0.0010	0.0010	0.0010	55	0
Benzene	HF	0.0020	0.0123	0.1100	55	15
Ethylbenzene	NHF	0.0010	0.0010	0.0010	61	0
Ethylbenzene	HF	0.0010	0.0019	0.0110	61	12
Toluene	NHF	0.0010	0.0010	0.0010	43	0
Toluene	HF	0.0080	0.0274	0.1900	43	14
Xylene (m- and p-)	NHF	0.0020	0.0020	0.0020	54	0
Xylene (m- and p-)	HF	0.0030	0.0080	0.0550	54	13
Xylene (o-)	NHF	0.0010	0.0010	0.0010	52	0
Xylene (o-)	HF	0.0020	0.0041	0.0270	52	16
Xylene (total)	NHF	0.0030	0.0030	0.0030	53	0
Xylene (total)	HF	0.0040	0.0124	0.0820	53	14
Metals						
Aluminium	NHF	0.0500	0.1300	1.9000	72	19
Aluminium	HF	0.1000	0.1530	2.0000	72	42
Aluminium (filtered)	NHF	0.0500	0.0500	0.0500	100	0
Aluminium (filtered)	HF	0.0500	0.0650	0.1000	100	0
Antimony	NHF	0.0200	0.0184	0.0200	97	11
Antimony	HF	0.0050	0.0075	0.0480	97	5
Antimony (filtered)	NHF	0.0050	0.0050	0.0050	36	0
Antimony (filtered)	HF	0.0050	0.0065	0.0100	36	0
Arsenic	NHF	0.0100	0.0101	0.0180	34	36
Arsenic	HF	0.0040	0.0065	0.0370	34	8
Arsenic (filtered)	NHF	0.0090	0.0085	0.0150	36	0
Arsenic (filtered)	HF	0.0020	0.0033	0.0190	36	11
Barium	NHF	3.2000	3.6000	7.4000	0	15
Barium	HF	5.0000	4.9000	7.8000	0	0
Barium (filtered)	NHF	5.2000	5.2000	7.4000	0	0
Barium (filtered)	HF	4.8000	4.6000	6.9000	0	0

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
Beryllium	NHF	0.0050	0.0050	0.0050	100	0
Beryllium	HF	0.0050	0.0050	0.0050	100	0
Boron	NHF	2.2000	2.4000	4.1000	0	0
Boron	HF	1.3000	1.6000	5.7000	0	8
Boron (filtered)	NHF	2.2000	2.2000	3.1000	0	0
Boron (filtered)	HF	1.1000	1.3000	5.7000	0	12
Cadmium	NHF	0.0010	0.0009	0.0010	96	8
Cadmium	HF	0.0002	0.0004	0.0010	96	14
Cadmium (filtered)	NHF	0.0002	0.0002	0.0002	100	0
Cadmium (filtered)	HF	0.0002	0.0003	0.0005	100	0
Chromium	NHF	0.0370	0.0370	0.0690	7	0
Chromium	HF	0.0120	0.0425	0.8300	7	6
Chromium (filtered)	NHF	0.0370	0.0370	0.0690	25	0
Chromium (filtered)	HF	0.0020	0.0047	0.0440	25	15
Chromium (III and VI)	NHF	0.0010	0.0081	0.0810	61	22
Chromium (III and VI)	HF	0.0010	0.0032	0.0230	61	23
Cobalt	NHF	0.0020	0.0018	0.0040	80	4
Cobalt	HF	0.0010	0.0026	0.0330	80	10
Cobalt (filtered)	NHF	0.0010	0.0010	0.0010	96	0
Cobalt (filtered)	HF	0.0010	0.0013	0.0020	96	0
Copper	NHF	0.0030	0.0188	0.1700	11	24
Copper	HF	0.0080	0.2872	23.0000	11	14
Copper (filtered)	NHF	0.0010	0.0010	0.0010	72	0
Copper (filtered)	HF	0.0020	0.0036	0.1300	72	8
Iron	NHF	1.2000	2.8000	29.0000	0	17
Iron	HF	14.5000	35.8000	390.0000	0	10
Iron (filtered)	NHF	0.0600	0.0600	0.0600	4	0
Iron (filtered)	HF	1.1000	4.2000	21.0000	4	9
Lead	NHF	0.0050	0.0118	0.1500	56	32
Lead	HF	0.0020	0.0286	1.8000	56	14
Lead (filtered)	NHF	0.0010	0.0010	0.0010	95	0

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
Lead (filtered)	HF	0.0010	0.0015	0.0120	95	1
Lithium	NHF	1.1000	0.9457	1.890	44	0
Lithium	HF	0.1000	0.3777	2.0800	44	23
Manganese	NHF	0.0180	0.0417	0.1400	17	0
Manganese	HF	0.1450	0.4411	5.2000	17	10
Manganese (filtered)	NHF	0.0110	0.0105	0.0160	4	0
Manganese (filtered)	HF	0.0770	0.1048	0.3500	4	0
Mercury	NHF	0.0001	0.0001	0.0001	100	0
Mercury	HF	0.0001	0.0001	0.0001	100	0
Molybdenum	NHF	0.0050	0.0063	0.0200	56	12
Molybdenum	HF	0.0100	0.0200	0.4200	56	3
Molybdenum (filtered)	NHF	0.0050	0.0050	0.0050	52	0
Molybdenum (filtered)	HF	0.0100	0.0121	0.0360	52	18
Nickel	NHF	0.0020	0.0120	0.1500	35	20
Nickel	HF	0.0020	0.0070	0.0810	35	14
Nickel (filtered)	NHF	0.0010	0.0010	0.0010	62	0
Nickel (filtered)	HF	0.0020	0.0015	0.0030	62	0
Phosphorus	NHF	0.2500	0.2500	0.3000	34	0
Phosphorus	HF	0.3500	0.6370	10.0000	34	5
Selenium	NHF	0.0050	0.0070	0.0110	32	0
Selenium	HF	0.0100	0.0090	0.0210	32	4
Selenium (filtered)	NHF	0.0090	0.0090	0.0100	5	0
Selenium (filtered)	HF	0.0080	0.0080	0.0210	5	15
Silver	NHF	0.0050	0.0050	0.0050	100	0
Silver	HF	0.0050	0.0050	0.0050	100	0
Strontium	NHF	4.0000	3.9400	6.2000	0	0
Strontium	HF	4.7000	4.6600	8.1000	0	2
Strontium (filtered)	NHF	4.9000	4.9000	5.9000	0	0
Strontium (filtered)	HF	4.6000	4.6200	7.1000	0	3
Thallium	NHF	0.0100	0.0100	0.0100	100	0
Thallium	HF	0.0100	0.0100	0.0100	100	0

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
Tin	NHF	0.0200	0.0200	0.0200	100	0
Tin	HF	0.0200	0.0200	0.0200	100	0
Vanadium	NHF	0.0050	0.0059	0.0190	85	16
Vanadium	HF	0.0050	0.0073	0.0270	86	2
Vanadium (filtered)	NHF	0.0130	0.0130	0.0190	86	0
Vanadium (filtered)	HF	0.0050	0.0072	0.0270	85	3
Zinc	NHF	0.0050	0.0221	0.3700	35	8
Zinc	HF	0.0110	0.0792	1.6000	35	12
Zinc (filtered)	NHF	0.0040	0.0035	0.0040	51	0
Zinc (filtered)	HF	0.0020	0.0030	0.0290	51	15
PAH – Polycyclic Aromatic Hydrocarbons						
Acenaphthene	NHF	0.0010	0.0010	0.0010	100	0
Acenaphthene	HF	0.0010	0.0010	0.0010	100	0
Acenaphthylene	NHF	0.0010	0.0010	0.0010	100	0
Acenaphthylene	HF	0.0010	0.0010	0.0010	100	0
Anthracene	NHF	0.0010	0.0010	0.0010	100	0
Anthracene	HF	0.0010	0.0010	0.0010	100	0
Benz(a)anthracene	NHF	0.0010	0.0010	0.0010	98	0
Benz(a)anthracene	HF	0.0010	0.0010	0.0020	98	2
Benzo(a)pyrene	NHF	0.0010	0.0010	0.0010	98	0
Benzo(a)pyrene	HF	0.0010	0.0010	0.0010	98	0
Benzo(b&j)fluoranthene	NHF	0.0010	0.0010	0.0010	100	0
Benzo(b&j)fluoranthene	HF	0.0010	0.0010	0.0010	100	0
Benzo(g.h.i)perylene	NHF	0.0010	0.0010	0.0010	100	0
Benzo(g.h.i)perylene	HF	0.0010	0.0010	0.0010	100	0
Benzo(k)fluoranthene	NHF	0.0010	0.0010	0.0010	100	0
Benzo(k)fluoranthene	HF	0.0010	0.0010	0.0010	100	0
Chrysene	NHF	0.0010	0.0010	0.0010	94	0
Chrysene	HF	0.0010	0.0011	0.0070	94	4
Dibenz(a.h)anthracene	NHF	0.0010	0.0010	0.0010	100	0

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
Dibenz(a.h)anthracene	HF	0.0010	0.0010	0.0010	100	0
Fluoranthene	NHF	0.0010	0.0010	0.0010	100	0
Fluoranthene	HF	0.0010	0.0010	0.0010	100	0
Fluorene	NHF	0.0010	0.0010	0.0010	100	0
Fluorene	HF	0.0010	0.0010	0.0010	100	0
Indeno(1.2.3.cd)pyrene	NHF	0.0010	0.0010	0.0010	100	0
Indeno(1.2.3.cd)pyrene	HF	0.0010	0.0010	0.0010	100	0
Naphthalene	NHF	0.0010	0.0010	0.0010	70	0
Naphthalene	HF	0.0010	0.0017	0.0100	70	22
Phenanthrene	NHF	0.0010	0.0010	0.0010	98	0
Phenanthrene	HF	0.0010	0.0010	0.0010	98	0
Phenol	NHF	0.0010	0.0010	0.0010	100	0
Phenol	HF	0.0010	0.0010	0.0010	100	0
Pyrene	NHF	0.0010	0.0010	0.0010	97	0
Pyrene	HF	0.0010	0.0010	0.0030	97	3
Total PAH	NHF	0.0010	0.0010	0.0010	63	0
Total PAH	HF	0.0010	0.0023	0.0120	63	14
TRH – Total Recoverable Hydrocarbons						
C_6-C_{10}	NHF	0.0200	0.0200	0.0200	48	0
C_6-C_{10}	HF	0.0300	0.1666	7.0000	48	19
C_6-C_{10} less BTEX	NHF	0.0200	0.0200	0.0200	83	0
C_6-C_{10} less BTEX	HF	0.0200	0.1161	6.9000	83	20
> C_{10}-C_{16}	NHF	0.0500	0.0500	0.0500	73	0
> C_{10}-C_{16}	HF	0.0500	0.0948	0.7200	73	23
> C_{10}-C_{16} less Naphthalene	NHF	0.0500	0.0500	0.0500	73	0
> C_{10}-C_{16} less Naphthalene	HF	0.0500	0.0948	0.7200	73	23
> C_{16}-C_{34}	NHF	0.1000	0.1000	0.1000	58	0
> C_{16}-C_{34}	HF	0.1000	0.9101	9.9000	58	18
> C_{34}-C_{40}	NHF	0.1000	0.1000	0.1000	83	0

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
> C_{34}-C_{40}	HF	0.1000	0.2595	2.8000	83	14
C_6-C_9	NHF	0.0100	0.0118	0.0200	54	18
C_6-C_9	HF	0.0200	0.5974	40.0000	54	18
C_{10}-C_{14}	NHF	0.0100	0.0173	0.0500	82	18
C_{10}-C_{14}	HF	0.0500	0.0912	1.2000	82	32
C_{15}-C_{28}	NHF	50.0000	40.9000	50.0000	68	18
C_{15}-C_{28}	HF	0.1000	1.7000	50.0000	68	20
C_{29}-C_{36}	NHF	50.0000	40.9000	50.0000	76	18
C_{29}-C_{36}	HF	0.1000	1.7000	50.0000	76	20
C_{10}-C_{36}	NHF	0.1100	0.1082	0.1100	66	18
C_{10}-C_{36}	HF	0.1000	0.9000	11.0000	66	21
Other water analysis results						
Ammonia (as N)	NHF	2.1000	2.1000	2.6000	0	4
Ammonia (as N)	HF	2.0000	1.9650	9.1000	0	3
Carbonate as ($CaCO_3$)	NHF	1.0000	1.0000	1.0000	92	0
Carbonate as ($CaCO_3$)	HF	1.0000	11.6800	180.0000	92	10
Chloride (as Cl^-)	NHF	2150.0000	2185.0000	3500.0000	0	3
Chloride (as Cl^-)	HF	2500.0000	2496.0000	3900.0000	0	0
Fluoride (as F^-)	NHF	4.1000	3.9400	6.8000	0	0
Fluoride (as F^-)	HF	2.0000	4.1900	32.0000	0	8
Nitrate (as N)	NHF	0.0100	0.0259	0.2800	64	3
Nitrate (as N)	HF	0.0100	0.0233	0.0700	64	4
Nitrate (as NO_3^-)	NHF	0.1000	0.1000	0.1000	93	0
Nitrate (as NO_3^-)	HF	0.1000	0.2870	8.0000	93	7
Sulphate (as SO_4^{2-})	NHF	2.0000	3.8700	10.0000	71	0
Sulphate (as SO_4^{2-})	HF	0.7000	1.9600	10.0000	71	15
Bromide	NHF	7.3000	7.1706	8.7000	0	0
Bromide	HF	7.3500	7.0700	8.3000	0	0
Carbon dioxide (free)	NHF	5.0000	9.2360	33.0000	17	16
Carbon dioxide (free)	HF	18.0000	138.0000	2100.0000	17	10

Analyte	Well	Median conc. (mg/L)	Mean conc. (mg/L)	Maximum conc. (mg/L)	Proportion of conc. values ≤ EQL (%)	Proportion of outliers (%)
Calcium (as Ca^{2+}), dissolved	NHF	12.0000	13.5294	25.0000	0	0
Calcium (as Ca^{2+}), dissolved	HF	17.0000	19.2897	60.0000	0	8
Potassium (as K^{+}), dissolved	NHF	15.0000	17.8059	75.0000	0	9
Potassium (as K^{+}), dissolved	HF	18.0000	17.4200	48.0000	0	6
Magnesium (as Mg^{2+}), dissolved	NHF	2.2500	3.1500	9.5000	0	15
Magnesium (as Mg^{2+}), dissolved	HF	4.0000	3.9833	12.0000	0	4
Sodium (as Na^{+}), dissolved	NHF	2200.0000	2100.0000	3100.0000	0	3
Sodium (as Na^{+}), dissolved	HF	2200.0000	2305.0000	2900.0000	0	0
Chlorine (free)	NHF	0.1000	0.1000	0.1000	97	0
Chlorine (free)	HF	0.1000	0.1007	0.2000	97	1
Ethanol	NHF	5.0000	5.0000	5.0000	100	0
Ethanol	HF	5.0000	5.0000	5.0000	100	0
Formaldehyde	NHF	0.2000	0.2000	0.2000	100	0
Formaldehyde	HF	0.2000	0.2000	0.2000	100	0
Hydrogen sulphide	NHF	0.1000	0.1000	0.1000	96	0
Hydrogen sulphide	HF	0.1000	0.0971	0.1000	96	8
Ortho-phosphorus	NHF	0.0400	0.0700	0.5000	19	4
Ortho-phosphorus	HF	0.0200	0.0400	0.0930	19	0
Phosphorus	NHF	0.4200	0.4600	3.1000	7	4
Phosphorus	HF	0.3900	0.7300	3.0000	7	5
Silica	NHF	26.0000	26.4348	31.0000	0	4
Silica	HF	28.0000	28.0000	34.0000	0	0
Sulphide (soluble)	NHF	0.0500	0.0500	0.0500	100	0
Sulphide (soluble)	HF	0.0500	0.0500	0.0500	100	0
Sulphide	NHF	0.1000	0.0880	0.1000	70	25
Sulphide	HF	0.1000	0.0990	0.1400	70	29

Conc. = concentration; EQL = estimated quantitation limit; NHF = non-hydraulically fractured; HF = hydraulically fractured.

Care should be taken in interpreting the monitoring data shown in Table 2.7. The number of analyte samples from hydraulically fractured wells was substantially higher than the number of analyte samples from non-hydraulically fractured wells. The number of analytes also varied between geographical regions. The company indicated that sample collection and / or laboratory contamination errors may have contributed to some of the differences in concentrations reported for the hydraulically fractured and non-hydraulically fractured wells. More importantly, analyte concentrations are a function of coal seam water quality, flowback and / or produced water flows, sampling times and sampling methods. Limit concentrations for individual analytes are also likely to vary with any additional sampling.

Some general trends, which are not necessarily similar to monitoring results from other coal seam gas extraction areas, are listed below:

- Although present at low levels, BTEX chemicals were detected in samples and the concentrations of all the BTEX chemicals were higher in hydraulically fractured wells than non-hydraulically fractured ones. Reasons for this may include that the chemicals may be naturally occurring (that is, geogenic) in the groundwater within the coal seam; hydraulic fracturing may result in naturally-occurring BTEX chemicals being released from the coal; or the chemicals may be derived from other anthropogenic sources.
- The company reported that the slight increase in BTEX levels only occurred in the early life of the hydraulically fractured wells and was not continuous or ongoing. It is possible that since some analyte samples of non-hydraulically fractured wells were obtained from the water/gas separator, volatile compounds such as BTEX chemicals may have fully or partially vaporised due to the lower pressure environment in the separator compared to tubing/wellhead where analyte samples from hydraulically fractured wells were collected. This could have contributed to the differences in the concentrations between hydraulically and non-hydraulically fractured wells.
- The concentrations of some metals varied between hydraulically fractured wells.
- The concentrations of most of the PAHs were comparable in hydraulically fractured and non-hydraulically fractured wells.
- The concentrations of most of the TRHs were higher in hydraulically fractured wells than non-hydraulically fractured wells, with the exception of C_{15}-C_{28} and C_{29}-C_{36} concentrations. The TRHs containing a lower carbon number range are more volatile than those with a higher carbon number range and the concentration differences were linked to where the samples were collected (that is, in the separator for non-hydraulically fractured wells and in the tubing / wellhead for hydraulically fractured wells).
- The maximum concentrations of carbon dioxide and carbonate (as $CaCO_3$) were higher in hydraulically fractured wells. The company indicated that analyte collection and laboratory errors were specifically identified for these samples and provided additional information, showing that the maximum values were part of the outliers from the datasets.

Another company provided produced water analysis results from a storage pond connected to a single non-hydraulically fractured well. The results are summarised in Table 2.8.

Sampling of flowback and / or produced water from different sources (for example, well head versus storage ponds) is likely to provide different concentrations because of the influence of surface environmental fate processes such as adsorption and photodegradation.

Table 2.8 Chemicals and concentrations monitored from storage pond samples

Analyte	Maximum concentration (µg/L)
Arsenic	15
Benzene, 1,2-dimethyl-	< 2
Benzene, ethyl-	< 2
Benzene, methyl-	8
Benzene	6
Boron	880
Cadmium	< 0.1
Cobalt	< 1
Copper	2
Lead	< 1
Mercury	< 0.1
Naphthalene	< 5
Selenium	< 10
Sum of BTEX	14
Total Petroleum Hydrocarbons C_6-C_9	< 20
Total Petroleum Hydrocarbons C_{10}-C_{14}	< 50
Total Petroleum Hydrocarbons C_{15}-C_{28}	< 100
Total Petroleum Hydrocarbons C_{29}-C_{36}	< 50
Total Petroleum Hydrocarbons C_{10}-C_{36} (sum)	< 50
Total Recoverable Hydrocarbons C_6-C_{10}	< 20
Total Recoverable Hydrocarbons C_6-C_{10} minus BTEX	< 20
Total Recoverable Hydrocarbons C_{10}-C_{16}	< 100
Total Recoverable Hydrocarbons C_{16}-C_{34}	< 100
Total Recoverable Hydrocarbons C_{34}-C_{40}	< 100
Total Recoverable Hydrocarbons C_{10}-C_{40} (sum)	< 100
Xylenes (meta, and para)	< 2
Xylenes (ortho, meta and para)	< 2
Zinc	11

2.4 Chemicals unintentionally released to the environment

2.4.1 Reported Incidents

Ten specific incidents of unintentional chemical releases were reported in the survey (identified in Table 2.9). These include:

- well injection incidents as a result of mechanical failures
- spills during mixing
- transport accidents
- releases from liquid storage ponds following high rainfall events or liner failure.

Table 2.9 Reported unintentional releases to the environment due to specific incidents

Nature of incident		Estimated volume released	Handling and recovery
Well injection incidents			
1.	Mechanical failure of valve on intake line of pumping equipment caused by over pressurisation and the opening of the pressure relief valve	50 L	Contained and handled at the well site
2.	Mechanical failure of valve on blender equipment	70 L	
3.	Single burst disc failed while pumping water with recently certified pump	100 L	
4.	Single burst disc failed while pumping water with recently certified pump	100 L	
Incident during mixing			
5.	Tank overflow on well lease (to land) during mixing hydraulic fracturing fluids	CBI	Approx 1 000 L of hydraulic fracturing fluids were recovered from tank overflow
Transport incident			
6.	Truck rollover (release to land) of drilling mud samples (soil)	CBI	-
Storage pond incidents			
7.	Release of fluids from storage pond (to land) following high rainfall event (post drilling storage)	CBI	Recovery not possible due to health and safety reasons; all necessary steps taken including environmental risk assessment and reporting to regulator
8	Release of fluids from storage pond (to land) following high rainfall event (post drilling storage)	CBI	
9	Release of fluids from storage pond (to land) following high rainfall event (post drilling storage)	CBI	
10	Leak of flowback water from storage pond to land from liner failure of the flowback and / or produced water storage	CBI	Recovery of lost fluids not possible; environmental risk assessment conducted and provided to regulator

CBI = confidential information

Limited data Information on chemicals unintentionally released through six of these incidents, as well as their concentrations, were provided. However, the data were insufficient to confirm the origin of the chemicals or whether the concentrations provided were above detection limits. It was reported that the chemicals detected could be from a combination of drilling, hydraulic fracturing and / or geogenic chemicals, as well as fluids from other sources used in the drilling and hydraulic fracturing process (that is, bore water or amended water).

It was also reported that revisions to operating procedures were implemented to minimise future incidents. These include addressing wet weather preparedness, a review of engineering design of well lease pads and ponds, and additional inspection activities as part of monitoring.

Approximately 30 coal seam gas incidents classified as spills, discharges or overflows (flooding) were reported in a paper by the Institute for Sustainable Futures, University of Technology Sydney (ISF-UTS) (Rutovitz et al. 2011). This report lists the type and number of incidents in the period January to June 2011 as provided by the then Queensland Department of Environment and Resource Management (QLD DERM) to ISF-UTS.

3 Conclusion

The chemicals identified as being used in drilling and hydraulic fracturing for coal seam gas extraction in Australia during the period 2010 to 2012 are listed in Table 3.1.

In total, 113 chemicals were identified, including:

- 47 chemicals used for drilling
- 84 chemicals used for hydraulic fracturing
- 18 chemicals used for both drilling and hydraulic fracturing

Table 3.1 Chemicals identified as being used in drilling and hydraulic fracturing for coal seam gas extraction in Australia during the period 2010 to 2012

	CAS RN	Chemical Name	Drilling chemical	Hydraulic fracturing chemical
1	10043-35-3	Boric acid (H_3BO_3)		✓
2	10043-52-4	Calcium chloride ($CaCl_2$)		✓
3	102-71-6	Ethanol, 2,2',2''-nitrilotris -		✓
4	10377-60-3	Nitric acid, magnesium salt (2:1)		✓
5	107-21-1	1,2-Ethanediol		✓
6	107-22-2	Ethanedial	✓	
7	108-10-1	2-Pentanone, 4-methyl-		✓
8	111-30-8	Pentanedial	✓	
9	111-76-2	Ethanol, 2-butoxy-		✓
10	111-90-0	Ethanol, 2-(2-ethoxyethoxy)-		✓
11	11138-66-2	Xanthan gum	✓	✓
12	112926-00-8	Silica gel, pptd., cryst.-free		✓
13	12008-41-2	Boron sodium oxide ($B_8Na_2O_{13}$)		✓
14	124-38-9	Carbon dioxide		✓
15	127-09-3	Acetic acid, sodium salt (1:1)		✓
16	1302-78-9	Bentonite	✓	
17	1303-96-4	Borax ($B_4Na_2O_7.10H_2O$)	✓	✓
18	1305-62-0	Calcium hydroxide ($Ca(OH)_2$)	✓	
19	1305-78-8	Calcium oxide		✓
20	1310-73-2	Sodium hydroxide ($Na(OH)$)	✓	✓
21	1317-65-3	Limestone	✓	

	CAS RN	Chemical Name	Drilling chemical	Hydraulic fracturing chemical
22	141-43-5	Ethanol, 2-amino-		✓
23	144-55-8	Carbonic acid sodium salt (1:1)	✓	✓
24	144588-68-1	Bauxite ($Al_2O_3.xH_2O$), sintered		✓
25	14464-46-1	Cristobalite (SiO_2)	✓	✓
26	14807-96-6	Talc ($Mg_3H_2(SiO_3)_4$)		✓
27	14808-60-7	Quartz (SiO_2)	✓	✓
28	15468-32-3	Tridymite (SiO_2) (9CI)	✓	
29	25038-72-6	2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene		✓
30	26038-87-9	Boric acid (H_3BO_3), compd. with 2-aminoethanol (1:?)		✓
31	26062-79-3	2-Propen-1-aminium, N,N-dimethyl-N-2-propen-1-yl-, chloride (1:1), homopolymer		✓
32	26172-55-4	3(2H)-Isothiazolone, 5-chloro-2-methyl-		✓
33	2634-33-5	1,2-Benzisothiazol-3(2H)-one		✓
34	2682-20-4	3(2H)-Isothiazolone, 2-methyl-		✓
35	463-79-6	Carbonic acid		✓
36	497-19-8	Carbonic acid sodium salt (1:2)	✓	✓
37	52-51-7	1,3-Propanediol, 2-bromo-2-nitro-		✓
38	533-96-0	Carbonic acid, sodium salt (2:3)		✓
39	55566-30-8	Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1)	✓	✓
40	56-81-5	1,2,3-Propanetriol		✓
41	584-08-7	Carbonic acid, potassium salt (1:2)		✓
42	6381-77-7	D-erythro-Hex-2-enonic acid, γ-lactone, sodium salt (1:1)		✓
43	64-02-8	Glycine, N,N'-1,2-ethanediylbis[N-(carboxymethyl)-, sodium salt (1:4)		✓
44	6410-41-9	2-Naphthalenecarboxamide, N-(5-chloro-2,4-dimethoxyphenyl)-4-[2-[5-[(diethylamino)sulfonyl]-2-methoxyphenyl]diazenyl]-3-hydroxy-		✓
45	64-17-5	Ethanol	✓	✓
46	64-19-7	Acetic acid		✓
47	64742-47-8	Distillates (petroleum), hydrotreated light	✓	

	CAS RN	Chemical Name	Drilling chemical	Hydraulic fracturing chemical
48	67-48-1	Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, chloride (1:1)		✓
49	67-56-1	Methanol	✓	✓
50	67-63-0	2-Propanol	✓	✓
51	68130-15-4	Guar gum, carboxymethyl 2-hydroxypropyl ether, sodium salt		✓
52	68187-17-7	Sulfuric acid, mono-C_{6-10}-alkyl esters, ammonium salts		✓
53	68439-45-2	Alcohols, C_{6-12}, ethoxylated		✓
54	68647-72-3	Terpenes and Terpenoids, sweet orange-oil		✓
55	7447-40-7	Potassium chloride (KCl)	✓	✓
56	75-57-0	Methanaminium, N,N,N-trimethyl-, chloride (1:1)		✓
57	7631-86-9	Silica		✓
58	7647-01-0	Hydrochloric acid		✓
59	7647-14-5	Sodium chloride (NaCl)	✓	✓
60	7681-52-9	Hypochlorous acid, sodium salt (1:1)		✓
61	7722-84-1	Hydrogen peroxide (H_2O_2)		✓
62	7727-37-9	Nitrogen		✓
63	7727-43-7	Sulfuric acid, barium salt (1:1)	✓	
64	7727-54-0	Peroxydisulfuric acid ($[(HO)S(O)_2]2O_2$), ammonium salt (1:2)		✓
65	7732-18-5	Water	✓	✓
66	7757-82-6	Sulfuric acid sodium salt (1:2)		✓
67	7757-83-7	Sulfurous acid, sodium salt (1:2)	✓	✓
68	7758-16-9	Diphosphoric acid, sodium salt (1:2)	✓	
69	7758-19-2	Chlorous acid, sodium salt (1:1)		✓
70	7772-98-7	Thiosulfuric acid ($H_2S_2O_3$), sodium salt (1:2)		✓
71	7775-27-1	Peroxydisulfuric acid ($[(HO)S(O)_2]2O_2$), sodium salt (1:2)		✓
72	7778-80-5	Sulfuric acid potassium salt (1:2)	✓	
73	7783-20-2	Sulfuric acid ammonium salt (1:2)		✓
74	7786-30-3	Magnesium chloride ($MgCl_2$)		✓

	CAS RN	Chemical Name	Drilling chemical	Hydraulic fracturing chemical
75	77-92-9	1,2,3-Propanetricarboxylic acid, 2-hydroxy-	✓	✓
76	81741-28-8	Phosphonium, tributyltetradecyl-, chloride (1:1)		✓
77	9000-30-0	Guar gum	✓	✓
78	9000-70-8	Gelatins		✓
79	9003-05-8	2-Propenamide, homopolymer		✓
80	9003-06-9	2-Propenoic acid, polymer with 2-propenamide	✓	
81	9004-62-0	Cellulose, 2-hydroxyethyl ether		✓
82	9012-54-8	Cellulase		✓
83	9025-56-3	Hemicellulase		✓
84	90622-53-0	Alkanes, C_{12-26} branched and linear		✓
85	91053-39-3	Diatomite, calcined		✓
86	CBI	2-Ethylhexanol heavies	✓	
87	CBI	Amine salt		✓
88	CBI	Enzyme		✓
89	CBI	Ester alcohol	✓	
90	CBI	Ethoxylated fatty acid I		✓
91	CBI	Ethoxylated fatty acid II		✓
92	CBI	Ethoxylated fatty acid III		✓
93	CBI	Fatty acids ester	✓	
94	CBI	Inner salt of alkyl amines		✓
95	n.s.	Natural fibres I	✓	
96	n.s.	Natural fibres II	✓	
97	CBI	Natural fibres III	✓	
98	n.s.	Nut hulls	✓	
99	CBI	Organic acid salt	✓	
100	CBI	Organic sulphate	✓	
101	CBI	Polyamine		✓
102	CBI	Polyacrylamide/polyacrylate copolymer	✓	
103	n.s.	Polyanionic cellulose PAC	✓	
104	n.s.	Polyesters	✓	
105	CBI	Polymer I	✓	

	CAS RN	Chemical Name	Drilling chemical	Hydraulic fracturing chemical
106	CBI	Polymer II	✓	
107	CBI	Polymer with substituted alkylacrylamide salt	✓	
108	CBI	Polysaccharide	✓	
109	CBI	Quaternary amine		✓
110	CBI	Terpenes and terpenoids		✓
111	n.s.	Walnut hulls	✓	✓
112	n.s.	Wood dust	✓	
113	n.s.	Wood fibre	✓	

CBI = confidential business information; n.s. = not specified.

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Appendix A – Companies surveyed

Table A 1 identifies the list of companies who were sent the survey in 2012 and a summary of their response.

Table A 1 Companies surveyed in 2012 and their responses

Company name	Response
Well drilling service providers	
AJ Hickey Contractors	Does not drill for CSG extraction
AJ Lucas Group	Drills for CSG extraction but does not use chemicals in drilling activities
AMC Imdex	Did not respond
Asahi Diamond Industrial Australia Pty Ltd	Does not drill for CSG extraction
Calidad Drilling	Not involved in CSG extraction drilling but was previously contracted for exploration drilling of coal seam resource definition drilling for mining operations
EastCore Drilling Services	Survey not applicable to the company
Geoaxiom Pty Ltd	Does not drill for CSG extraction
Integrated Directional Services Pty Ltd	Does not own/operate drilling rigs and does not use chemicals
Macquarie Drilling Pty Ltd	Did not respond
Mongolian National Diamond Drilling LLC	Did not respond
Spaulding Drillers Pty Ltd	Chose not to provide information on chemical use stating that the drilling fluids were supplied by clients. The company provided the client list
Techdrill Mining Services	Does not drill for CSG extraction
Wallis Drilling Pty Ltd	Did not respond
Hydraulic fracturing service providers	
Baker Hughes Australia Pty Ltd	Provided information
Halliburton Australia Pty Ltd	Provided information
Schlumberger Australia Pty Ltd	Provided information
Site operators / Gas companies	
AGL Upstream Investments Pty Ltd	Provided information
Arrow Energy[†]	Did not respond
Beach Energy	Conducted CSG exploration activities and provided the name of a drilling service provider it employed in the exploration

Company name	Response
Dart Energy	Explored for CSG in three core holes and gave the well drilling service provider it employed. First appraisal pilot project underway
Lowell Petroleum NL – Molopo	Provided information
Metgasco	Does not extract CSG
Origin Energy	Provided information
Petrofrontier Corp	Did not respond
Planet Gas Limited	Did not respond
QGC BG Business Group	Provided information
Santos Ltd	Provided information
Senex Energy Limited	Did not respond
Proppant manufacturer	
Momentive Specialty Chemicals	Did not respond

† *Arrow Energy did not have a coal seam gas development project approved under the Environment Protection and Biodiversity Conservation Act 1999 during the survey period 2010 to 2012.*

Appendix B – Industry surveys

The three types of survey forms sent to the companies are included in this Appendix.

NICNAS coal seam gas industry survey – hydraulic fracturing service providers

Company name:

Address for correspondence:

Contact:

Telephone:

Email:

Thank you for completing this survey.

Please indicate (by highlighting in red) any information that you request be treated as commercial-in-confidence. Claims for confidentiality must be accompanied by reasoning (see back page).

When completed, please return this survey **by 24 September 2012**:

- via email (preferred) to coal seam gas@nicnas.gov.au
- via post to Graham Harvey, NICNAS, GPO Box 58, Sydney NSW 2001
- via fax to Graham Harvey 02 8577 8888

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Hydraulic fracturing chemicals

Question 1

Provide information for each **hydraulic fracturing formulation** or **pre-treatment** mixture introduced and/or used in Australia within the past 2 years.

Identity (product name) of the formulation or pre-treatment mixture	Description of the intended use or fluid stage	Total volume (L) or mass (kg) per year of the formulation imported or manufactured or acquired locally	Physical state as delivered to site. If in solid form, note type of solid (i.e. pellets, crystalline or fine powder)	Container size
e.g. pre-frac 05	e.g. acid flush prior to frac		e.g. solid – fine powder	e.g. 100 kg bag

Add more rows if required.

Question 2

For each **hydraulic fracturing formulation or pre-treatment mixture**, provide details of the constituents. Please duplicate tables as necessary to cover all formulations/mixtures.

For example, formulation or pre-treatment identity: <u>e.g. Hybrid Frac 03</u>

Chemical Abstract Services (CAS) Number	Chemical Name	Concentration (g/kg or g/L) in formulation delivered to the site	Concentration (g/kg or g/L) after final dilution prior to injection	Function
e.g. 50-00-0	e.g. formaldehyde			e.g. biocide

Question 3

Provide information for any **additional chemicals** (other than water) used in **hydraulic fracturing fluids** or **pre-treatments** used within the past 2 years (e.g. proppants, pH adjusters, viscosity agents, radiological isotopes used for monitoring, etc.).

Chemical Abstract Services (CAS) Number	Chemical Name	Physical state as delivered to site. If in solid form, note type of solid (i.e. pellets, crystalline or fine powder)	Concentration (g/kg or g/L) delivered to the site	Container size	Concentration (g/kg or g/L) after final dilution prior to injection	Total volume (L) or mass (kg) per year of the chemical imported or manufactured or bought locally	Function
e.g. 7647-01-0	e.g. hydrochloric acid	e.g. liquid		e.g. 1000 L			e.g. pH adjuster

Question 4

Provide comment on trends in substitution of chemicals in hydraulic fracturing fluids/pre-treatments and examples where substitutions have occurred.

Hydraulic fracturing operations

Question 5

For each **hydraulic fracturing formulation** or **pre-treatment formulation**, provide estimations of the total volume of fluids (ML) injected after final dilution for a normal pre-treatment operation or hydraulic fracturing operation and the number of hydraulic fracturing operations (including pre-treatments) expected over the life of a well.

Identity of formulation or pre-treatment	Typical total volume of injected fluid per operation (ML)	Maximum total volume of injected fluid per operation (ML)	Typical number of operations per well	Maximum number of operations per well
e.g. Hybrid Frac 05	e.g. 0.1	e.g. 10	e.g. 2	e.g. 5

Question 6

Provide **detail of company operating procedures, practices and/or policies, including standard operating procedures,** that are employed to ensure that hydraulic fracturing activities do not cause new connections or exacerbate existing connections between target formations and another aquifer. If adopting industry guidance and best practice, provide details of this guidance and how your company ensures that this guidance is adhered to. If operations are based on modelling, provide details of the modelling employed.

Chemical introduction, handling and disposal

Question 7

For hydraulic fracturing chemicals and pre-treatment chemicals, provide a complete **description of the chemical life cycle** for formulations or individual chemicals.

Include information about:

- how formulations or individual chemicals are obtained (e.g. imported, manufactured or purchased from local suppliers)
- how formulations or individual chemicals are stored, handled and transported to site, including modes of transport and container types and sizes. Include descriptions of categories of workers who handle the chemicals (i.e. storemen, transport drivers, forklift drivers, well site workers, etc.). For each category of worker, include a description of the nature of the work undertake (i.e. what they do, daily frequencies of potential chemical exposures (how often they do tasks) and the maximum duration of potential chemical exposure (hours per day and days per year))
- on site, how formulations or individual chemicals are mixed prior to injection. Include similar descriptions as above for any chemical handling for mixing prior to injection
- how unused formulations or individual chemicals are disposed of and/or recycled
- details of any site monitoring or personal exposure monitoring for exposures of workers to chemicals used in hydraulic fracturing
- finally, for each part of the chemical lifecycle, include descriptions of the controls used to limit human and environmental exposures (e.g. operating procedures, engineering controls or personal protective equipment).

Health and environmental impact information

Question 8

Provide a list of **unpublished studies** on human health and/or environmental impacts of hydraulic fracturing chemicals. NICNAS will contact you for copies of relevant studies. If you are aware of any **published studies** on these impacts, please also provide a link to these studies.

Question 9

Provide **details of company operating procedures, practices and/or policies including standard operating procedures** for rectification measures to be used in response to any changes in water quality in aquifers other than the target formation.

Question 10

Where hydraulic fracturing chemicals were **UNINTENTIONALLY RELEASED to the environment** due to a specific incident (e.g. a spill) provide the identity, concentration and volume of chemicals released and the nature of the incident.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Concentration of chemical released (mg/L)	Estimated volume (L) or mass (kg) of release	Nature of incident*

** Please indicate stage of chemical lifecycle (i.e. transport, pre-use storage, mixing, well injection or post-fracturing storage and handling).*

Question 11

Please also provide details of any **recovery** of chemicals.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Estimated volume (L) or mass (kg) of chemical recovered

Question 12

Please provide details of any **remedial measures taken** for these incidents and whether these incidents required revisions of operating procedures.

Other Information (e.g. justification for claims of confidentiality).

NICNAS coal seam gas industry survey – well drilling service providers

Company name:

Address for correspondence:

Contact:

Telephone:

Email:

Thank you for completing this survey.

Please indicate (by highlighting in red) any information that you request be treated as commercial-in-confidence. Claims for confidentiality must be accompanied by reasoning (see back page).

When completed, please return this survey **by 24 September 2012**:

- via email (preferred) to coal seam gas@nicnas.gov.au
- via post to Graham Harvey, NICNAS, GPO Box 58, Sydney NSW 2001
- via fax to Graham Harvey 02 8577 8888.

Drilling chemicals

Question 1

Provide information for each **drilling fluid formulation** introduced and/or used in Australia within the past 2 years.

Identity (product name) of the formulation	Description of the intended use or fluid stage	Total volume (L) or mass (kg) per year of the formulation imported or manufactured or acquired locally	Physical state as delivered to site. If in solid form, note type of solid (i.e. pellets, crystalline or fine powder)	Container size

e.g. deep drilling fluid 1.0	e.g. used during in production zone		e.g. solid – fine powder	e.g. 100 kg bag

Add more rows if required.

Question 2

For each **drilling fluid formulation**, provide details of the constituents. Please duplicate tables as necessary to cover all formulations/mixtures.

For example, formulation or pre-treatment identity: <u>e.g. shallow drilling fluid 1.0</u>

Chemical Abstract Services (CAS) Number	Chemical Name	Concentration (g/kg or g/L) in formulation delivered to the site	Concentration (g/kg or g/L) used during drilling	Function
e.g. 64742-93-4	e.g. oxidised asphalt			e.g. stabiliser

Question 3

Provide information for any **additional drilling fluids chemicals** used within the past 2 years that are added to the pre-formulated fluid during the drilling process (e.g. pH adjusters, viscosity modifiers, etc.).

Chemical Abstract Services (CAS) Number	Chemical Name	Physical state as delivered to site. If in solid form, note type of solid (i.e. pellets, crystalline or fine	Concentration (g/kg or g/L) delivered to the site	Container size	Concentration (g/kg or g/L) after final dilution prior to addition to	Total volume (L) or mass (kg) per year of the chemical imported or manufactured or	Function

		powder)			drilling fluid	bought locally	
e.g. 7647-01-0	e.g. hydrochloric acid	e.g. liquid		e.g. 1000 L			e.g. pH adjuster

Question 4

Provide comment on trends in **substitution of chemicals** in drilling fluids and examples where substitutions have occurred.

Hydraulic fracturing operations

Question 5

For each drilling fluid formulation, provide estimations of the **total volume of fluids (L) used** for a complete drilling operation for coal seam gas.

Identity of formulation	Typical volume (L)	Maximum volume (L)
e.g. ECODRILL	e.g. 100	e.g. 200

Question 6

Provide **detail of company operating procedures, practices and/or policies including standard operating procedures** that are employed to ensure that drilling activities do not cause new connections, or exacerbate existing connections, between target formations and another aquifer. If adopting industry guidance and best practice, provide details of this guidance and how your company ensures that this guidance is adhered to. If operations are based on modelling, provide details of the modelling employed.

Chemical introduction, handling and disposal

Question 7

For drilling fluid chemicals, provide a complete **description of the chemical life cycle** for formulations or individual chemicals.

Include information about:

- how formulations or individual chemicals are obtained (e.g. imported, manufactured or purchased from local suppliers)
- how formulations or individual chemicals are stored, handled and transported to site, including modes of transport and container types and sizes. Include descriptions of categories of workers who handle the chemicals (i.e. storemen, transport drivers, forklift drivers, well site workers, etc.). For each category of worker, include a description of the nature of the work undertake (i.e. what they do, daily frequencies of potential chemical exposures (how often they do tasks) and the maximum duration of potential chemical exposure (hours per day and days per year))
- on site, how formulations or individual chemicals are mixed prior to drilling. Include similar descriptions as above for any chemical handling for mixing prior to drilling
- how unused formulations or individual chemicals are disposed of and/or recycled
- details of any site monitoring or personal exposure monitoring for exposures of workers to chemicals used in drilling fluids

- finally, for each part of the chemical lifecycle, include descriptions of the controls used to limit human and environmental exposures (e.g. operating procedures, engineering controls, personal protective equipment).

Health and environmental impact information

Question 8

Provide a list of **unpublished studies** on human health and/or environmental impacts of drilling fluid chemicals. NICNAS will contact you for copies of relevant studies. If you are aware of any **published studies** on these impacts, please also provide a link to these studies.

Question 9

Provide **details of company operating procedures, practices and/or policies including standard operating procedures** for rectification measures to be used in response to any changes in water quality in aquifers other than the target formation.

Question 10

Where drilling fluid chemicals were **UNINTENTIONALLY RELEASED to the environment** due to a specific incident (e.g. a spill) provide the identity, concentration and volume of chemicals released and the nature of the incident.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Concentration of chemical released (mg/L)	Estimated volume (L) or mass (kg) of release	Nature of incident*

** Please indicate stage of chemical lifecycle (i.e. transport, pre-use storage, mixing, well injection or post-fracturing storage and handling).*

Question 11

Please also provide details of any **recovery** of chemicals.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Estimated volume (L) or mass (kg) of chemical recovered

Question 12

Please provide details of any **remedial measures** taken for these incidents and whether these incidents required revisions of operating procedures.

Other Information (e.g. justification for claims of confidentiality).

NICNAS coal seam gas industry survey – site operators

Company name:

Address for correspondence:

Contact:

Telephone:

Email:

Thank you for completing this survey.

Please indicate (by highlighting in red) any information that you request be treated as commercial-in-confidence. Claims for confidentiality must be accompanied by reasoning (see back page).

When completed, please return this survey **by 24 September 2012**:

- via email (preferred) to coal seam gas@nicnas.gov.au
- via post to Graham Harvey, NICNAS, GPO Box 58, Sydney NSW 2001
- via fax to Graham Harvey 02 8577 8888.

Monitoring and remediation

Question 1

For chemicals in hydraulic fracturing formulations or pre-treatments, provide the **proportion of injected chemical mass RECOVERED in flowback and/or produced waters**. Please also note the source of data – estimated or from monitoring and also details of the method or technique.

Formulation or pre-treatment or individual chemical	Chemical Abstract Services (CAS) Number (if appropriate)	Proportion (%) of injected mass RECOVERED in flowback and/or produced waters	Method of determination (estimated or from monitoring)	Analytical method/monitoring technique
e.g. hydrochloric acid	e.g. 7647-01-0	e.g. 70%	e.g. monitoring	

Question 2

For **GEOGENIC CHEMICAL CONTAMINANTS** (e.g. NATURALLY OCCURRING OR NEWLY FORMED trace metals, organics, salts, radionuclides, etc.) mobilised as a result of hydraulic fracturing, provide data from any monitoring or estimations of the presence of these chemicals in flowback and/or produced waters. Please also note the analytical method or monitoring technique.

Geogenic chemical/chemical group	Chemical Abstract Services (CAS) Number (if appropriate)	Maximum concentration in flowback and/or produced waters (ng/L)	Method of determination (estimated or from monitoring)	Analytical method/monitoring technique
e.g. lead	e.g. 7439-92-1	e.g. 7 ng/L	e.g. monitoring	

Question 3

For **DRILLING FLUID CHEMICALS,** provide data from any monitoring or estimations of the presence of these chemicals in flowback and/or produced waters. Please also note the analytical method or monitoring technique.

Drilling chemical name	Chemical Abstract Services (CAS) Number (if appropriate)	Maximum concentration in flowback and/or produced waters (ng/L)	Method of determination (estimated or from monitoring)	Analytical method/monitoring technique
e.g. lead	e.g. 7439-92-1	e.g. 7 ng/L	e.g. monitoring	

Question 4

Where hydraulic fracturing chemicals or drilling chemicals were **UNINTENTIONALLY RELEASED to the environment** due to a specific incident (e.g. a spill, well integrity failure, etc.) provide the identity, concentration and volume of chemicals released and the nature of the incident.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Concentration of chemical released (mg/L)	Estimated volume (L) or mass (kg) of release	Nature of incident*

** Please indicate stage of chemical lifecycle (i.e. transport, pre-use storage, mixing, well injection, post-drilling or post-fracturing storage and handling).*

Question 5

Please also provide details of any **RECOVERY** of chemicals.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Estimated volume (L) or mass (kg) of release

Question 6

Where geogenic chemicals in flowback and/or produced waters were **UNINTENTIONALLY RELEASED to the environment** due to a specific incident (e.g. a spill, storage tank leak, etc.) provide the identity, concentration and volume of chemicals released and the nature of the incident.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Concentration of chemical released (mg/L)	Estimated volume (L) or mass (kg) of release	Nature of incident*

** Please indicate stage of chemical lifecycle (i.e. during flowback and/or produced water storage or release of treatment waste containing geogenic chemicals).*

Question 7

Please also provide details of any **recovery** of chemicals.

Formulation identity or chemical identity	Chemical Abstract Services (CAS) Number (if appropriate)	Estimated volume (L) or mass (kg) of chemical recovered

Question 8

Please provide details of any remedial measures taken for these incidents and whether these incidents required revisions of operating procedures.

Health and environmental impact information

Question 9

Provide a list of **unpublished studies** on human health and/or environmental impacts of chemicals in flowback and/or produced water. NICNAS will contact you for copies of relevant studies. If you are aware of any **published studies** on these impacts, please also provide a link to these studies.

Other information (e.g. claims for confidentiality).

Appendix C – Studies reported in the survey

Table C 1 lists the published and / or unpublished studies on human health and / or environmental impacts of chemicals used in drilling or hydraulic fracturing or found in flowback and / or produced water as provided by three companies.

Table C 1 List of studies

Author and year	Title	Link (if available)
Allen, B, Gentry, R, Shipp, A and Van Landingham, C 1995	'Calculation of benchmark doses for reproductive and developmental toxicity observed after exposure to isopropanol', *Regulatory Toxicology and Pharmacology,* vol. 28, pp. 38-44.	n.s.
Alpha Environmental Consultants September 2009	Technical consulting reports prepared in support of the *Draft supplemental generic environmental impact statement for natural gas production in New York State*.	http://www.nyserda.ny.gov/Publications/Research-and-Development-Technical-Reports/Other-Technical-Reports/Natural-Gas-Enviromental-Impact.aspx
Bevan, C 2001	'Monohydric alcohols – C1 to C6', in *Patty's Industrial Hygiene and Toxicology*, 5th edition.	n.s.
Bevan, C, Tyler, TR, Gardiner, TH, Kapp, RW, Andrews, L and Beyer, BK 1995	'Two-generation reproduction toxicity study with isopropanol in rats', *Journal of Applied Toxicology,* vol. 15, pp. 117-23.	n.s.
Biesinger, KE, Lemke, AE, Smith, WE and Tyo, R 1976	'Comparative toxicity of polyelectrolytes to selected aquatic animals', *Journal – Water Pollution Control Federation,* vol. 48, pp. 183-7.	Cited in New Zealand (NZ) Hazardous Substances and New Organisms (HSNO) regulations – Chemical Classification and Information Database (CCID): http://www.epa.govt.nz/search-databases/Pages/ccid-details.aspx?SubstanceID=1930
Canadian Council of Ministers of the Environment 2009	*Scientific criteria document for the development of the Canadian water quality guidelines for boron*, Canadian Council of Ministers of the Environment.	n.s.
European Chemicals Agency (ECHA)	Database for REACH registrations.	http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances
Environmental Risk Sciences March 2012	*Human health and ecological risk assessment – hydraulic fracturing* (unpublished report)	

Author and year	Title	Link (if available)
US EPA Office of Water June 2004	*Evaluation of impacts to underground sources of drinking water by hydraulic fracturing of coalbed methane reservoirs*.	http://water.epa.gov/type/groundwater/uic/upload/completestudy.zip
European Union (EU) October 2007	Draft: Boric acid and sodium tetraborates v2.0, Substance evaluation report.	http://www.reach24h.com/en2010/ftp/News/boricacidcrudereport423A.pdf
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Author and year	Title	Link (if available)
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