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)



The national assessment of chemicals associated with coal seam gas extraction in Australia was commissioned by the Department of the Environment and Energy and prepared in collaboration with NICNAS and CSIRO

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| Technical report number | Title | | Authoring agency | |
| --- | --- | --- | --- | --- |
| Reviewing existing literature | | | | |
| 1 | | Literature review: Summary report | | NICNAS |
| 2 | | Literature review: Human health implications | | NICNAS |
| 3 | | Literature review: Environmental risks posed by chemicals used coal seam gas operations | | Department of the Environment and Energy |
| 4 | | Literature review: Hydraulic fracture growth and well integrity | | CSIRO |
| 5 | | Literature review: Geogenic contaminants associated with coal seam gas operations | | CSIRO |
| 6 | | Literature review: Identification of potential pathways to shallow groundwater of fluids associated with hydraulic fracturing | | CSIRO |
| Identifying chemicals used in coal seam gas extraction | | | | |
| 7 | | Identification of chemicals associated with coal seam gas extraction in Australia | | NICNAS |
| Modelling how people and the environment could come into contact with chemicals during coal seam gas extraction | | | | |
| 8 | | Human and environmental exposure conceptualisation: Soil to shallow groundwater pathways | | CSIRO |
| 9 | | Environmental exposure conceptualisation: Surface to surface water pathways | | Department of the Environment and Energy |
| 10 | | Human and environmental exposure assessment: Soil to shallow groundwater pathways – A study of predicted environmental concentrations | | CSIRO |
| Assessing risks to workers and the public | | | | |
| 11 | | Chemicals of low concern for human health based on an initial assessment of hazards | | NICNAS |
| 12 | | Human health hazards of chemicals associated with coal seam gas extraction in Australia | | NICNAS |
| 13 | | Human health risks associated with surface handling of chemicals used in coal seam gas extraction in Australia | | NICNAS |
| Assessing risks to the environment | | | | |
| 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* (theAssessment).

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]](#footnote-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 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.

Steps involved in the National assessment of chemicals associated with coal seam gas extraction
1. Identifying chemicals used in coal seam gas extraction
2. Reviewing existing literature
3. Modelling how people and the environment could come into contact with chemicals during coal seam gas extraction
4. Assessing risks to workers and the public
5. Assessing risks to the environment

Figure F. 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, CH4) 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 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 |
| 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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# Methodology to identify chemicals

## 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.

## 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.

## 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.

## 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.

# 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.

## 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.

### 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 |
| --- | --- | --- | --- | --- |
|  | Aldacide G | Biocide | Liquid | 19 480 L |
|  | Aquagel Goldseal | Viscosifier | Powder | 153 775 kg |
|  | Barascav D | Oxygen scavenger | Solid | 6 275 kg |
|  | Barazan D | Viscosifier | Powder | 64 200 kg |
|  | Barite | Weight additive | Solid | 1 587 400 kg |
|  | Barofibre F/M/C | Loss circulation material | Powder | 127 414 kg |
|  | Baro-Seal | Loss circulation material | Solid | 276 210 kg |
|  | Bentonite | Weight additive | Solid - beige | Variable |
|  | Bicarbonate of Soda | Buffer | Solid | 20 000 kg |
|  | Caustic Soda | pH control | Solid | 27 975 kg |
|  | Citric Acid | pH control | Crystalline powder | 15 000 kg |
|  | Defoam W300/Foam Zapper | Defoamer | Liquid | 6 000 L |
|  | Diamond Seal | Loss circulation material | Solid granules | 2 966 kg |
|  | EZ-Mud DP | Shale inhibitor | Solid | 34 325 kg |
|  | Lime | pH control | Solid | 12 000 kg |
|  | N-Plex/N-Seal N-Squeeze | Loss circulation material | Liquid / fibre / solid | 5 000 kg |
|  | Omyacarb 10/CaCO3 F | Weighting agent / Control fluid loss | Powder | 6 250 kg |
|  | Omyacarb 20/CaCO3 M | Weighting agent / Control fluid loss | Powder | 6 250 kg |
|  | Omyacarb 40/CaCO3 C | Weighting agent / Control fluid loss | Powder | 6 250 kg |
|  | PAC L/LE | Fluid loss additive | Powder | 71 375 kg |
|  | Pac R/RE | Fluid loss additive | Solid powder | 59 525 kg |
|  | PHPA | Shale inhibitor | Liquid | 8 650 kg |
|  | Potassium Chloride | Shale inhibitor | Solid | 15 000 kg |
|  | Potassium Sulfate | Shale inhibitor | Granules or powder | 1 183 725 kg |
|  | Quik Foam | Foaming agent | Liquid | 44 650 kg |
|  | SAPP | Dispersant | Solid | 27 600 kg |
|  | Sawdust | Loss circulation material | Granular flake | 10 000 kg |
|  | Soda Ash | Buffer | Powder | 15 000 kg |
|  | Walnut / Barofibre F/M/C | Loss circulation material | Solid granules or fibre | 11 748 kg |

### 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) |
| --- | --- | --- | --- | --- |
|  | 107-22-2 | Ethanedial | CBI | n.s. |
|  | 111-30-8 | Pentanedial | 100 − 300 | 0.503 − 6.54 |
|  | 11138-66-2 | Xanthan gum | 600 − 1 000 | 0‒3.8 |
|  | 1302-78-9 | Bentonite | 0 − 1 000 | n.s. |
|  | 1303-96-4 | Borax (B4Na2O7.10H2O) | 10 − 24 | n.s. |
|  | 1305-62-0 | Calcium hydroxide (Ca(OH)2) | 600 − 1 000 | n.s. |
|  | 1310-73-2 | Sodium hydroxide (Na(OH)) | 10 − 1 000 | >0.76 |
|  | 1317-65-3 | Limestone | >990 | n.s. |
|  | 144-55-8 | Carbonic acid sodium salt (1:1) | 600 − 1 000 | 0 ‒ 2.156 |
|  | 14464-46-1 | Cristobalite (SiO2) | 0 − 10 | n.s. |
|  | 14808-60-7 | Quartz (SiO2) | 10 − 50 | n.s. |
|  | 15468-32-3 | Tridymite (SiO2) (9CI) | 0 − 10 | n.s. |
|  | 497-19-8 | Carbonic acid sodium salt (1:2) | 600 − 2 532 | 0.17 ‒ CBI |
|  | 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) | 180 - 250 | 0 ‒ 0.357 |
|  | 64-17-5 | Ethanol | 50 − 100 | n.s. |
|  | 64742-47-8 | Distillates (petroleum), hydrotreated light | 100 − 600 | n.s. |
|  | 67-56-1 | Methanol | CBI | n.s. |
|  | 67-63-0 | 2-Propanol | 50 − 100 | n.s. |
|  | 7447-40-7 | Potassium chloride (KCl) | 500 − 1 000 | 0.04 ‒ 160 |
|  | 7647-14-5 | Sodium chloride (NaCl) | 990 | 28 ‒ 127 |
|  | 7727-43-7 | Sulfuric acid, barium salt (1:1) | 600 − 1 000 | n.s. |
|  | 7732-18-5 | Water | CBI | n.s. |
|  | 7757-83-7 | Sulfurous acid, sodium salt (1:2) | 600 − 1 000 | n.s. |
|  | 7758-16-9 | Diphosphoric acid, sodium salt (1:2) | 600 − 1 000 | n.s. |
|  | 7778-80-5 | Sulfuric acid potassium salt (1:2) | 600 − 1 000 | 3.5 |
|  | 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | 600 − 1 000 | 0 ‒ 4.194 |
|  | 9000-30-0 | Guar gum | CBI | n.s. |
|  | 9003-06-9 | 2-Propenoic acid, polymer with 2-propenamide | CBI | n.s. |
|  | CBI | 2-Ethylhexanol heavies | CBI | n.s. |
|  | CBI | Ester alcohol | CBI | n.s. |
|  | CBI | Fatty acids ester | 600 − 1 000 | n.s. |
|  | n.s. | Natural fibres I | CBI | n.s. |
|  | n.s. | Natural fibres II | CBI | n.s. |
|  | CBI | Natural fibres III | CBI | n.s. |
|  | n.s. | Nut hulls | 600 − 1 000 | n.s. |
|  | CBI | Organic acid salt | CBI | n.s. |
|  | CBI | Organic sulfate | CBI | n.s. |
|  | CBI | Polyacrylamide/polyacrylate copolymer | 900 − 950 | n.s. |
|  | n.s. | Polyanionic cellulose PAC | n.s. | n.s. |
|  | n.s. | Polyesters | CBI | n.s. |
|  | CBI | Polymer I | CBI | n.s. |
|  | CBI | Polymer II | CBI | n.s. |
|  | CBI | Polymer with substituted alkylacrylamide salt | CBI | n.s. |
|  | CBI | Polysaccharide | 600 − 1 000 | n.s. |
|  | n.s. | Walnut hulls | 600 − 1 000 | n.s. |
|  | n.s. | Wood dust | CBI | n.s. |
|  | n.s. | Wood fibre | CBI | n.s. |

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

### 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.

### 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.

### 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.

## 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.

### 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 |
| --- | --- | --- | --- | --- |
|  | Acetic Acid 60% | Buffer / Solvent | Liquid | 79 073.4 L |
|  | BC-140 C X-linker | Crosslinker | Liquid | 47 851.4 L |
|  | BE-09 | Biocide | Liquid | n.s. |
|  | BE-6 Bactericide | Bactericide | Powder | 5.4 kg |
|  | BE-7 | Biocide | Liquid | 44 919.6 L |
|  | BF-3 | pH buffer | Solid | n.s. |
|  | BF-7L | pH buffer | Liquid | n.s. |
|  | BF10L, L401 | pH buffer | Liquid | n.s. |
|  | Boric Acid 3.6% | Crosslinker | Liquid | 8 000 L |
|  | Caustic Soda, 50% solution | Buffer | Liquid | 2 646 L |
|  | Citric Acid | Chelating | Solid - crystalline | 25 kg |
|  | CL-28M Crosslinker | Crosslinker | Liquid | n.s. |
|  | Clatrol | Clay control | Liquid | 400 L |
|  | Clayfix II Plus | Clay stabiliser | Liquid | 10 601 L |
|  | ClayTreat-3C | Clay control | Liquid | 400 L |
|  | FE-2 | Iron control agent | Solid granular | 174.6 kg |
|  | FE-300 | pH buffer | Powder / granules | n.s. |
|  | FR-46 | Friction reducer | Liquid | n.s. |
|  | GasPerm 1000 | Surfactant | Liquid | 104.1 L |
|  | GasPerm 1100 | Non-ionic surfactant | Liquid | 10 595.4 L |
|  | GBW-12CD | Breaker | Liquid | 69 L |
|  | GBW-18 | Breaker | Powder | n.s. |
|  | GBW-30 | Breaker | Powder | n.s. |
|  | Gelatine | Corrosion inhibitor | Solid - crystalline | 50 kg |
|  | Gel-Sta L | Gel stabiliser | Liquid | 15 879.8 L |
|  | GLFC-5 | Slurry guar gum | Liquid | 3 000 L |
|  | GS-1L | Chlorine neutraliser | Liquid | 200 L |
|  | GW-3 | Guar gum | Powder | 5 000 kg |
|  | HC-2 | Foaming agent | Liquid | 749.5 L |
|  | HC-2A | Foaming agent | Liquid | 1 203.8 L |
|  | HCl 32-35% | pH control | Liquid | 400 L |
|  | HpH Breaker | Breaker | Liquid | 2 386.7 L |
|  | Hydrochloric acid, 22 baume | Acid/Solvent | Liquid | 10 031.3 L |
|  | J218, GBW-5, EB-CLEAN, J479 LT Encapsulated Breaker | Breaker | Granules | n.s. |
|  | J494 | pH buffer | Granules | n.s. |
|  | J580, GW-3, GW-4, GW-38, WG-36, WG-11 | Gelling agent | Powder | n.s. |
|  | K-34 | Buffer | Solid | 1 696.4 kg |
|  | K-35, Sodium Carbonate | Buffer | Powder | 1 733.9 kg |
|  | K-38 | Biocide, crosslinker | Solid | n.s. |
|  | L010 | Crosslinker | Liquid | n.s. |
|  | M003, Soda Ash | pH buffer | Solid | n.s. |
|  | Magnacide-575 | Bactericide | Liquid | 832 L |
|  | Magnacide 575 Microbiocide | Biocide | Liquid | n.s. |
|  | M275, Biocide BPA68915 | Biocide | Liquid | n.s. |
|  | Optiflo HTE | Breaker | Solid | 179.2 kg |
|  | Oxygon | Oxygen scavenger | Powder | n.s. |
|  | Potassium Chloride | Additive | Solid or liquid | n.s. |
|  | ScaleChek LP-55 | Scale inhibitor | Liquid | n.s. |
|  | Sodium Hypochlorite 12.5% | Bactericide | Liquid | 12 000 L |
|  | Sodium Hydroxide 10% | pH buffer | Liquid | 4 000 L |
|  | SuperFlo 2000 | Surfactant | Liquid | n.s. |
|  | Temporary Clay Stabiliser L64, ClayTreat-3C | Clay control | Liquid | n.s. |
|  | Tolcide PS75 | Biocide | Liquid | 77.6 L |
|  | Vicoon NF Breaker | Breaker | Liquid | n.s. |
|  | WG-19 | Gelling agent | Powder | 687.2 kg |
|  | WG-21, WG-17 | Gelling agent | Solid | n.s. |
|  | WG-36 | Gelling agent | Powder | 93 628 kg |
|  | XLW-10A | Crosslinker | Liquid | 2 288 L |
|  | YF-120LG | Crosslinked gel prop frac | Fluid system | n.s. |

n.s. = not specified

### 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) |
| --- | --- | --- | --- | --- |
|  | 10043-35-3 | Boric acid (H3BO3) | 36 - 800 | 0.1532 − 0.216a |
|  | 10043-52-4 | Calcium chloride (CaCl2) | CBI | CBI |
|  | 102-71-6 | Ethanol, 2,2',2''-nitrilotris - | n.s | n.s |
|  | 10377-60-3 | Nitric acid, magnesium salt (2:1) | 10 - 50 | 0.0069 |
|  | 107-21-1 | 1,2-Ethanediol | 150 – 496 | 0.08 – 0.496 |
|  | 108-10-1 | 2-Pentanone, 4-methyl- | CBI | CBI |
|  | 111-76-2 | Ethanol, 2-butoxy- | 300 ‒ 600 | 0.04 |
|  | 111-90-0 | Ethanol, 2-(2-ethoxyethoxy)- | CBI | CBI |
|  | 11138-66-2 | Xanthan gum | CBI | 0.01 |
|  | 112926-00-8 | Silica gel, pptd., cryst.-free | n.s | n.s |
|  | 12008-41-2 | Boron sodium oxide (B8Na2O13) | 600 ‒ 1 000 | n.s. |
|  | 124-38-9 | Carbon dioxide | 1 000 | n.s. |
|  | 127-09-3 | Acetic acid, sodium salt (1:1) | n.s | n.s |
|  | 1303-96-4 | Borax (B4Na2O7.10H2O) | 100 ‒ 372 | 0.372 |
|  | 1305-78-8 | Calcium oxide (CaO) | CBI | CBI |
|  | 1310-73-2 | Sodium hydroxide (Na(OH)) | 0 ‒ 1 000 | 0.019 − 0.1375a |
|  | 141-43-5 | Ethanol, 2-amino- | <15 | CBI |
|  | 144-55-8 | Carbonic acid sodium salt (1:1) | 600 ‒ 1 000 | CBI |
|  | 144588-68-1 | Bauxite (Al2O3.xH2O)​, sintered | CBI | CBI |
|  | 14464-46-1 | Cristobalite (SiO2) | n.s. | 0.0007a |
|  | 14807-96-6 | Talc (Mg3H2(SiO3)4) | n.s. | 0.0006 |
|  | 14808-60-7 | Quartz (SiO2) | 100 ‒ 2 650 | 89.3494 − 119.8263a |
|  | 25038-72-6 | 2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene | n.s. | 0.0152 |
|  | 26038-87-9 | Boric acid (H3BO3), compd. with 2-aminoethanol (1:?) | 300 ‒ 600 | CBI |
|  | 26062-79-3 | 2-Propen-1-aminium, N,N-dimethyl-N-2-propen-1-yl-, chloride (1:1), homopolymer | 651 | 1.302 |
|  | 26172-55-4 | 3(2H)-Isothiazolone, 5-chloro-2-methyl- | 100 | 0.003 - 0.01 |
|  | 2634-33-5 | 1,2-Benzisothiazol-3(2H)-one | CBI | CBI |
|  | 2682-20-4 | 3(2H)-Isothiazolone, 2-methyl- | 50 | 0.001 - 0.0014 |
|  | 463-79-6 | Carbonic acid | n.s | n.s |
|  | 497-19-8 | Carbonic acid sodium salt (1:2) | 600 ‒ 2 532 | 0.316 − CBI |
|  | 52-51-7 | 1,3-Propanediol, 2-bromo-2-nitro- | 600 ‒ 1 000 | CBI |
|  | 533-96-0 | Carbonic acid, sodium salt (2:3) | 600 ‒ 1 000 | 0.8317 |
|  | 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) | 300 - 750 | 0.04125a |
|  | 56-81-5 | 1,2,3-Propanetriol | CBI | CBI |
|  | 584-08-7 | Carbonic acid, potassium salt (1:2) | 400 ‒ 500 | n.s. |
|  | 6381-77-7 | D-erythro-Hex-2-enonic acid, γ‑lactone, sodium salt (1:1) | 600 ‒ 1 000 | n.s. |
|  | 64-02-8 | Glycine, N,N'-1,2-ethanediylbis[N-(carboxymethyl)-, sodium salt (1:4) | n.s | n.s |
|  | 6410-41-9 | 2-Naphthalenecarboxamide, N-(5-chloro-2,4-dimethoxyphenyl)-4-[2-[5-[(diethylamino)sulfonyl]-2-methoxyphenyl]diazenyl]-3-hydroxy-methoxyphenyl]azo]-3-hydroxy- | CBI | CBI |
|  | 64-17-5 | Ethanol | 100 ‒ 300 | CBI |
|  | 64-19-7 | Acetic acid | 300 ‒ 1 050 | 0.0005 − 0.525 |
|  | 67-48-1 | Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, chloride (1:1) | n.s. | n.s. |
|  | 67-56-1 | Methanol | 50 ‒ 100 | CBI |
|  | 67-63-0 | 2-Propanol | 50 ‒ 300 | 0.0134a |
|  | 68130-15-4 | Guar gum, carboxymethyl 2-hydroxypropyl ether, sodium salt | 450 ‒ 1 000 | n.s. |
|  | 68187-17-7 | Sulfuric acid, mono-C6-10-alkyl esters, ammonium salts | n.s. | n.s. |
|  | 68439-45-2 | Alcohols, C6-12, ethoxylated | n.s. | n.s. |
|  | 68647-72-3 | Terpenes and Terpenoids, sweet orange-oil | 10 ‒ 300 | CBI |
|  | 7447-40-7 | Potassium chloride (KCl) | 10 ‒ 1 987 | 0.0028 - 22.9629 |
|  | 75-57-0 | Methanaminium, N,N,N-trimethyl-, chloride (1:1) | 300 ‒ 612 | 0.612 − 1.2733a |
|  | 7631-86-9 | Silica | CBI | 0.0059a |
|  | 7647-01-0 | Hydrochloric acid | 300 ‒ 600 | <1a |
|  | 7647-14-5 | Sodium chloride (NaCl) | 100 ‒ 1 000 | 0.0002 ‒ 0.4a |
|  | 7681-52-9 | Hypochlorous acid, sodium salt (1:1) | 100 ‒ 300 | 0.05775a |
|  | 7722-84-1 | Hydrogen peroxide (H2O2) | n.s. | n.s. |
|  | 7727-37-9 | Nitrogen | 1 000 | n.s. |
|  | 7727-54-0 | Peroxydisulfuric acid ([(HO)S(O)2]2O2), ammonium salt (1:2) | 600 ‒ 1 000 | 0.4521 - <1 |
|  | 7732-18-5 | Water | 100 ‒ 1 000 | 905.298 |
|  | 7757-82-6 | Sulfuric acid sodium salt (1:2) | CBI | CBI |
|  | 7757-83-7 | Sulfurous acid, sodium salt (1:2) | CBI | CBI |
|  | 7758-19-2 | Chlorous acid, sodium salt (1:1) | 80 ‒ 100 | n.s. |
|  | 7772-98-7 | Thiosulfuric acid (H2S2O3), sodium salt (1:2) | 300 ‒ 600 | 0.175a |
|  | 7775-27-1 | Peroxydisulfuric acid ([(HO)S(O)2]2O2), sodium salt (1:2) | 990 ‒ 1 000 | n.s. |
|  | 7783-20-2 | Sulfuric acid ammonium salt (1:2) | 100‒300 | n.s. |
|  | 7786-30-3 | Magnesium chloride (MgCl2) | 100 | 0.0028 ‒ 0.01 |
|  | 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | 600 ‒ 1 000 | 0.0001 - 1.76504a |
|  | 81741-28-8 | Phosphonium, tributyltetradecyl-, chloride (1:1) | 50 ‒ 100 | n.s. |
|  | 9000-30-0 | Guar gum | 450 ‒ 1 050 | 0.001−2.6 |
|  | 9000-70-8 | Gelatins | 1 000 | 2.99566 |
|  | 9003-05-8 | 2-Propenamide, homopolymer | 300 ‒ 600 | n.s. |
|  | 9004-62-0 | Cellulose, 2-hydroxyethyl ether | 600 ‒ 1 000 | n.s. |
|  | 9012-54-8 | Cellulase | 50 ‒ 150 | n.s. |
|  | 9025-56-3 | Hemicellulase | 1 000 ‒ 1 200 | 0.03636a |
|  | 90622-53-0 | Alkanes, C12-26 -branched and linear | 520 | 2.6 |
|  | 91053-39-3 | Diatomite, calcined | n.s. | 0.0344 |
|  | CBI | Amine salt | CBI | CBI |
|  | CBI | Enzyme | CBI | CBI |
|  | CBI | Ethoxylated fatty acid I | CBI | CBI |
|  | CBI | Ethoxylated fatty acid II | CBI | CBI |
|  | CBI | Ethoxylated fatty acid III | CBI | CBI |
|  | CBI | Inner salt of alkyl amines | 300 ‒ 1 000 | CBI |
|  | CBI | Polyamine | CBI | CBI |
|  | CBI | Quaternary amine | CBI | CBI |
|  | CBI | Terpenes and terpenoids | CBI | CBI |
|  | 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

### 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. |
| 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 (H3BO3) | 72.42 |
| 10377-60-3 | Nitric acid, magnesium salt (2:1) | 5.25 |
| 14464-46-1 | Cristobalite (SiO2) | 0.18 |
| 14807-96-6 | Talc (Mg3H2(SiO3)4) | 0.15 |
| 14808-60-7 | Quartz (SiO2) | 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]2O2), ammonium salt (1:2) | 154.34 |
| 7732-18-5 | Water | 612 279.11 |
| 7786-30-3 | Magnesium chloride (MgCl2) | 0.99 |
| 9000-30-0 | Guar gum | 2 096.43 |
| 91053-39-3 | Diatomite, calcined | 49.47 |

### 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.

### 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.

## 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 75th percentile plus three times the difference of the 75th and 25th percentile concentration values; lower threshold was at the 25th percentile minus three times the difference of the 75th and 25th 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 |
| 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 |
| 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 |
| 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 |
| 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 | | | | | | |
| C6-C10 | NHF | 0.0200 | 0.0200 | 0.0200 | 48 | 0 |
| C6-C10 | HF | 0.0300 | 0.1666 | 7.0000 | 48 | 19 |
| C6-C10 less BTEX | NHF | 0.0200 | 0.0200 | 0.0200 | 83 | 0 |
| C6-C10 less BTEX | HF | 0.0200 | 0.1161 | 6.9000 | 83 | 20 |
| > C10-C16 | NHF | 0.0500 | 0.0500 | 0.0500 | 73 | 0 |
| > C10-C16 | HF | 0.0500 | 0.0948 | 0.7200 | 73 | 23 |
| > C10-C16 less Naphthalene | NHF | 0.0500 | 0.0500 | 0.0500 | 73 | 0 |
| > C10-C16 less Naphthalene | HF | 0.0500 | 0.0948 | 0.7200 | 73 | 23 |
| > C16-C34 | NHF | 0.1000 | 0.1000 | 0.1000 | 58 | 0 |
| > C16-C34 | HF | 0.1000 | 0.9101 | 9.9000 | 58 | 18 |
| > C34-C40 | NHF | 0.1000 | 0.1000 | 0.1000 | 83 | 0 |
| > C34-C40 | HF | 0.1000 | 0.2595 | 2.8000 | 83 | 14 |
| C6-C9 | NHF | 0.0100 | 0.0118 | 0.0200 | 54 | 18 |
| C6-C9 | HF | 0.0200 | 0.5974 | 40.0000 | 54 | 18 |
| C10-C14 | NHF | 0.0100 | 0.0173 | 0.0500 | 82 | 18 |
| C10-C14 | HF | 0.0500 | 0.0912 | 1.2000 | 82 | 32 |
| C15-C28 | NHF | 50.0000 | 40.9000 | 50.0000 | 68 | 18 |
| C15-C28 | HF | 0.1000 | 1.7000 | 50.0000 | 68 | 20 |
| C29-C36 | NHF | 50.0000 | 40.9000 | 50.0000 | 76 | 18 |
| C29-C36 | HF | 0.1000 | 1.7000 | 50.0000 | 76 | 20 |
| C10-C36 | NHF | 0.1100 | 0.1082 | 0.1100 | 66 | 18 |
| C10-C36 | 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 (CaCO3) | NHF | 1.0000 | 1.0000 | 1.0000 | 92 | 0 |
| Carbonate as (CaCO3) | 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 NO3-) | NHF | 0.1000 | 0.1000 | 0.1000 | 93 | 0 |
| Nitrate (as NO3-) | HF | 0.1000 | 0.2870 | 8.0000 | 93 | 7 |
| Sulphate (as SO42-) | NHF | 2.0000 | 3.8700 | 10.0000 | 71 | 0 |
| Sulphate (as SO42-) | 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 |
| Calcium (as Ca2+), dissolved | NHF | 12.0000 | 13.5294 | 25.0000 | 0 | 0 |
| Calcium (as Ca2+), 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 Mg2+), dissolved | NHF | 2.2500 | 3.1500 | 9.5000 | 0 | 15 |
| Magnesium (as Mg2+), 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 C15‑C28 and C29‑C36 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 non­hydraulically fractured wells and in the tubing / wellhead for hydraulically fractured wells).

The maximum concentrations of carbon dioxide and carbonate (as CaCO3) 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 C6-C9 | < 20 |
| Total Petroleum Hydrocarbons C10-C14 | < 50 |
| Total Petroleum Hydrocarbons C15-C28 | < 100 |
| Total Petroleum Hydrocarbons C29-C36 | < 50 |
| Total Petroleum Hydrocarbons C10-C36 (sum) | < 50 |
| Total Recoverable Hydrocarbons C6-C10 | < 20 |
| Total Recoverable Hydrocarbons C6-C10 minus BTEX | < 20 |
| Total Recoverable Hydrocarbons C10-C16 | < 100 |
| Total Recoverable Hydrocarbons C16-C34 | < 100 |
| Total Recoverable Hydrocarbons C34-C40 | < 100 |
| Total Recoverable Hydrocarbons C10-C40 (sum) | < 100 |
| Xylenes (meta, and para) | < 2 |
| Xylenes (ortho, meta and para) | < 2 |
| Zinc | 11 |

## Chemicals unintentionally released to the environment

### 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.

# 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 |
| --- | --- | --- | --- | --- |
|  | 10043-35-3 | Boric acid (H3BO3) |  | ✓ |
|  | 10043-52-4 | Calcium chloride (CaCl2) |  | ✓ |
|  | 102-71-6 | Ethanol, 2,2',2''-nitrilotris - |  | ✓ |
|  | 10377-60-3 | Nitric acid, magnesium salt (2:1) |  | ✓ |
|  | 107-21-1 | 1,2-Ethanediol |  | ✓ |
|  | 107-22-2 | Ethanedial | ✓ |  |
|  | 108-10-1 | 2-Pentanone, 4-methyl- |  | ✓ |
|  | 111-30-8 | Pentanedial | ✓ |  |
|  | 111-76-2 | Ethanol, 2-butoxy- |  | ✓ |
|  | 111-90-0 | Ethanol, 2-(2-ethoxyethoxy)- |  | ✓ |
|  | 11138-66-2 | Xanthan gum | ✓ | ✓ |
|  | 112926-00-8 | Silica gel, pptd., cryst.-free |  | ✓ |
|  | 12008-41-2 | Boron sodium oxide (B8Na2O13) |  | ✓ |
|  | 124-38-9 | Carbon dioxide |  | ✓ |
|  | 127-09-3 | Acetic acid, sodium salt (1:1) |  | ✓ |
|  | 1302-78-9 | Bentonite | ✓ |  |
|  | 1303-96-4 | Borax (B4Na2O7.10H2O) | ✓ | ✓ |
|  | 1305-62-0 | Calcium hydroxide (Ca(OH)2) | ✓ |  |
|  | 1305-78-8 | Calcium oxide |  | ✓ |
|  | 1310-73-2 | Sodium hydroxide (Na(OH)) | ✓ | ✓ |
|  | 1317-65-3 | Limestone | ✓ |  |
|  | 141-43-5 | Ethanol, 2-amino- |  | ✓ |
|  | 144-55-8 | Carbonic acid sodium salt (1:1) | ✓ | ✓ |
|  | 144588-68-1 | Bauxite (Al2O3.xH2O)​, sintered |  | ✓ |
|  | 14464-46-1 | Cristobalite (SiO2) | ✓ | ✓ |
|  | 14807-96-6 | Talc (Mg3H2(SiO3)4) |  | ✓ |
|  | 14808-60-7 | Quartz (SiO2) | ✓ | ✓ |
|  | 15468-32-3 | Tridymite (SiO2) (9CI) | ✓ |  |
|  | 25038-72-6 | 2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene |  | ✓ |
|  | 26038-87-9 | Boric acid (H3BO3), compd. with 2-aminoethanol (1:?) |  | ✓ |
|  | 26062-79-3 | 2-Propen-1-aminium, N,N-dimethyl-N-2-propen-1-yl-, chloride (1:1), homopolymer |  | ✓ |
|  | 26172-55-4 | 3(2H)-Isothiazolone, 5-chloro-2-methyl- |  | ✓ |
|  | 2634-33-5 | 1,2-Benzisothiazol-3(2H)-one |  | ✓ |
|  | 2682-20-4 | 3(2H)-Isothiazolone, 2-methyl- |  | ✓ |
|  | 463-79-6 | Carbonic acid |  | ✓ |
|  | 497-19-8 | Carbonic acid sodium salt (1:2) | ✓ | ✓ |
|  | 52-51-7 | 1,3-Propanediol, 2-bromo-2-nitro- |  | ✓ |
|  | 533-96-0 | Carbonic acid, sodium salt (2:3) |  | ✓ |
|  | 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) | ✓ | ✓ |
|  | 56-81-5 | 1,2,3-Propanetriol |  | ✓ |
|  | 584-08-7 | Carbonic acid, potassium salt (1:2) |  | ✓ |
|  | 6381-77-7 | D-erythro-Hex-2-enonic acid, γ-lactone, sodium salt (1:1) |  | ✓ |
|  | 64-02-8 | Glycine, N,N'-1,2-ethanediylbis[N-(carboxymethyl)-, sodium salt (1:4) |  | ✓ |
|  | 6410-41-9 | 2-Naphthalenecarboxamide, N-(5-chloro-2,4-dimethoxyphenyl)-4-[2-[5-[(diethylamino)sulfonyl]-2-methoxyphenyl]diazenyl]-3-hydroxy- |  | ✓ |
|  | 64-17-5 | Ethanol | ✓ | ✓ |
|  | 64-19-7 | Acetic acid |  | ✓ |
|  | 64742-47-8 | Distillates (petroleum), hydrotreated light | ✓ |  |
|  | 67-48-1 | Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, chloride (1:1) |  | ✓ |
|  | 67-56-1 | Methanol | ✓ | ✓ |
|  | 67-63-0 | 2-Propanol | ✓ | ✓ |
|  | 68130-15-4 | Guar gum, carboxymethyl 2-hydroxypropyl ether, sodium salt |  | ✓ |
|  | 68187-17-7 | Sulfuric acid, mono-C6-10-alkyl esters, ammonium salts |  | ✓ |
|  | 68439-45-2 | Alcohols, C6-12, ethoxylated |  | ✓ |
|  | 68647-72-3 | Terpenes and Terpenoids, sweet orange-oil |  | ✓ |
|  | 7447-40-7 | Potassium chloride (KCl) | ✓ | ✓ |
|  | 75-57-0 | Methanaminium, N,N,N-trimethyl-, chloride (1:1) |  | ✓ |
|  | 7631-86-9 | Silica |  | ✓ |
|  | 7647-01-0 | Hydrochloric acid |  | ✓ |
|  | 7647-14-5 | Sodium chloride (NaCl) | ✓ | ✓ |
|  | 7681-52-9 | Hypochlorous acid, sodium salt (1:1) |  | ✓ |
|  | 7722-84-1 | Hydrogen peroxide (H2O2) |  | ✓ |
|  | 7727-37-9 | Nitrogen |  | ✓ |
|  | 7727-43-7 | Sulfuric acid, barium salt (1:1) | ✓ |  |
|  | 7727-54-0 | Peroxydisulfuric acid ([(HO)S(O)2]2O2), ammonium salt (1:2) |  | ✓ |
|  | 7732-18-5 | Water | ✓ | ✓ |
|  | 7757-82-6 | Sulfuric acid sodium salt (1:2) |  | ✓ |
|  | 7757-83-7 | Sulfurous acid, sodium salt (1:2) | ✓ | ✓ |
|  | 7758-16-9 | Diphosphoric acid, sodium salt (1:2) | ✓ |  |
|  | 7758-19-2 | Chlorous acid, sodium salt (1:1) |  | ✓ |
|  | 7772-98-7 | Thiosulfuric acid (H2S2O3), sodium salt (1:2) |  | ✓ |
|  | 7775-27-1 | Peroxydisulfuric acid ([(HO)S(O)2]2O2), sodium salt (1:2) |  | ✓ |
|  | 7778-80-5 | Sulfuric acid potassium salt (1:2) | ✓ |  |
|  | 7783-20-2 | Sulfuric acid ammonium salt (1:2) |  | ✓ |
|  | 7786-30-3 | Magnesium chloride (MgCl2) |  | ✓ |
|  | 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | ✓ | ✓ |
|  | 81741-28-8 | Phosphonium, tributyltetradecyl-, chloride (1:1) |  | ✓ |
|  | 9000-30-0 | Guar gum | ✓ | ✓ |
|  | 9000-70-8 | Gelatins |  | ✓ |
|  | 9003-05-8 | 2-Propenamide, homopolymer |  | ✓ |
|  | 9003-06-9 | 2-Propenoic acid, polymer with  2-propenamide | ✓ |  |
|  | 9004-62-0 | Cellulose, 2-hydroxyethyl ether |  | ✓ |
|  | 9012-54-8 | Cellulase |  | ✓ |
|  | 9025-56-3 | Hemicellulase |  | ✓ |
|  | 90622-53-0 | Alkanes, C12-26 branched and linear |  | ✓ |
|  | 91053-39-3 | Diatomite, calcined |  | ✓ |
|  | CBI | 2-Ethylhexanol heavies | ✓ |  |
|  | CBI | Amine salt |  | ✓ |
|  | CBI | Enzyme |  | ✓ |
|  | CBI | Ester alcohol | ✓ |  |
|  | CBI | Ethoxylated fatty acid I |  | ✓ |
|  | CBI | Ethoxylated fatty acid II |  | ✓ |
|  | CBI | Ethoxylated fatty acid III |  | ✓ |
|  | CBI | Fatty acids ester | ✓ |  |
|  | CBI | Inner salt of alkyl amines |  | ✓ |
|  | n.s. | Natural fibres I | ✓ |  |
|  | n.s. | Natural fibres II | ✓ |  |
|  | CBI | Natural fibres III | ✓ |  |
|  | n.s. | Nut hulls | ✓ |  |
|  | CBI | Organic acid salt | ✓ |  |
|  | CBI | Organic sulphate | ✓ |  |
|  | CBI | Polyamine |  | ✓ |
|  | CBI | Polyacrylamide/polyacrylate copolymer | ✓ |  |
|  | n.s. | Polyanionic cellulose PAC | ✓ |  |
|  | n.s. | Polyesters | ✓ |  |
|  | CBI | Polymer I | ✓ |  |
|  | CBI | Polymer II | ✓ |  |
|  | CBI | Polymer with substituted alkylacrylamide salt | ✓ |  |
|  | CBI | Polysaccharide | ✓ |  |
|  | CBI | Quaternary amine |  | ✓ |
|  | CBI | Terpenes and terpenoids |  | ✓ |
|  | n.s. | Walnut hulls | ✓ | ✓ |
|  | n.s. | Wood dust | ✓ |  |
|  | 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 |
| 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

.

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: e.g. Hybrid Frac 03**

| 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: e.g. shallow drilling fluid 1.0**

| 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 powder) | 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 drilling fluid | 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 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) |  |
| 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 |
| Glicksman, M 2008 | ‘Gum technology in the food industry’, cited in:  Yoon, SJ, Chu, DC and Juneja, LR 2008, ‘Chemical and physical properties, safety and application of partially hydrolyzed guar gum as dietary fiber’, *Journal of Clinical Biochemistry and Nutrition,* vol. 42, pp. 1-7. | n.s. |
| Golder Associates 2011 | *Draft coal seam hydraulic fracturing risk assessment, combined stage 1 and stage 2 risk assessment,* prepared for Schlumberger Methodology. | n.s. |
| Gradient 2012 | *Human health risk evaluation for hydraulic fracturing fluid additives*. | n.s. |
| Gradient 2012 | *Evaluation of potential impacts of flowback fluid constituents from hydraulic fracturing on treatment processes in publicly-owned treatment works.* | n.s. |
| Gradient 2009 | *Review of surface impoundment emissions modeling performed by New York State Department of Environmental Conservation*, Draft supplemental generic environmental impact statement on the Oil, Gas and Solution Mining Regulatory Program, prepared for Halliburton Energy Services. | http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/Gradient\_Review\_of\_Surface\_Impoundment\_Emissions\_Modeling\_by\_NewYorkState.pdf |
| Energy and Climate Change Committee, House of Commons, United Kingdom (UK) 2011 | Fifth report, *Shale gas*. | http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/79502.htm |
| ICF International 2009 | *Well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low permeability gas reservoirs*, Technical assistance for the draft supplemental generic environmental impact statement on the Oil, Gas and Solution Mining Regulatory Program, prepared for NYSERDA. | http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/ICF\_Technical\_Assistance\_Draft\_Supplemental\_Generic\_EIS\_Analysis\_Potential\_Impacts\_to\_Air.pdf |
| International Uniform Chemical Information Database (IUCLID) 1997 | IUCLID Data Set for 2-Propanol (CAS RN 67-63-0) | n.s. |
| IUCLID 2005 | IUCLID Data Set for  Ammonium persulfate (CAS RN  7727-54-0)  Potassium persulfate (CAS RN  7727-27-1)  Sodium persulfate (CAS RN 7775‑27-1). | n.s. |
| IUCLID 2004 | IUCLID Data Set for Ethanol (CAS RN 64‑17-5). | n.s. |
| IUCLID 2002 | IUCLID Data Set for Sodium carbonate (CAS RN 497-19-8). | n.s. |
| IUCLID 2002 | IUCLID Data Set for Sodium hydroxide (CAS RN 1310-73-2). | n.s. |
| Joint Food and Agriculture Organisation/World Health Organisation (FAO/WHO) Expert Committee on Food Additives (JECFA) | Acetic acid. | http://apps.who.int/ipsc/database/evaluations/chemical.aspx?chemID=4785 |
| LePage, JN, De Wolf, CA, Bermelaar, JH and Nasr-El-Din, HA 2011 | ‘An environmentally friendly stimulation fluid for high-temperature applications’, *Society of Petroleum Engineers,* vol. 16, pp 104-110. | n.s. |
| New York State Department of Environmental Conservation 2011 | *Revised draft supplemental generic environmental impact statement on the Oil, Gas and Solution Mining Regulatory Program*. | http://www.dec.ny.gov/data/dmn/rdsgeisfull0911.pdf |
| National Toxicology Program (NTP), US Department of Health and Human Services 1982 | *Carcinogenesis bioassay of guar gum (CAS RN 9003-30-0) in F344 rats and B63C3F mice (Feed Study),* Technical report, National Toxicology Program. | n.s. |
| Organisation for Economic Co‑operation and Development (OECD) 1997 | Screening Information Dataset (SIDS) Initial Assessment Report for 2-Propanol (CAS RN 67-63-0). | n.s. |
| OECD 2005 | SIDS Initial Assessment Report for:  Ammonium persulfate (CAS RN  7727-54-0)  Potassium persulfate (CAS RN  7727-27-1)  Sodium persulfate (CAS RN 7775-27-1). | n.s. |
| OECD 2004 | SIDS Initial Assessment Report for Ethanol (CAS RN 64-17-5). | n.s. |
| OECD 2006 | SIDS Initial Assessment Report for Ethylene Glycol Monobutyl Ether (CAS RN 111‑76‑2). | n.s. |
| OECD 2005 | SIDS Initial Assessment Report for Monoethylene Glycol Ethers Category (CAS Nos. 2807-30-9, 111-76-2, 112‑07‑2, 112-25-4). | n.s. |
| OECD 2002 | SIDS Initial Assessment Report for Sodium carbonate (CAS RN 497-19-8). | n.s. |
| OECD 2002 | SIDS Initial Assessment Report for Sodium hydroxide (CAS RN 1310-73-2). | n.s. |
| Hines, RE and Vinson, EF 1991 | *Environmentally safe replacement for fracturing fluids*, Halliburton Services Research. | n.s. |
| University of Texas Energy Institute 2012 | *Fact-based regulation for environmental protection in shale gas development*, a report by the Energy Institute, the University of Texas at Austin. | http://www.velaw.com/UploadedFiles/VEsite/Resources/ei\_shale\_gas\_reg\_summary1202[1].pdf |
| URS Corporation 2011 | *Water-related issues associated with gas production in the Marcellus Shale*, NYSERDA. | http://www.nyserda.ny.gov/Publications/Research-and-Development-Technical-Reports/Other-Technical-Reports/Natural-Gas-Enviromental-Impact.aspx |
| US Department of Energy 2009 | *Modern shale gas development in the United States: a primer*. National Energy Technology Laboratory, Office of Fossil Energy, US Department of Energy. | http://energy.gov/sites/prod/files/2013/03/f0/ShaleGasPrimer\_Online\_4-2009.pdf |
| US EPA 2006 | *Reregistration eligibility decision for aliphatic alkyl quaternaries* (DDAC), Office of Prevention, Pesticides and Toxic Substances (OPPTS). | n.s. |
| US EPA 2012 | High Production Volume Information System (HPVIS) database. | http://www.epa.gov/chemrtk/hpvis/index.html |

n.s. = not specified.

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. [↑](#footnote-ref-1)