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

Technical report number 14 Environmental risks associated with surface handling of chemicals used in coal seam gas extraction in Australia

This report was prepared by the Chemicals and Biotechnology Assessments Section (CBAS), in the Chemicals and Waste Branch of the Department of the Environment and Energy



National Industrial Chemicals Notification and Assessment Scheme 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

Copyright

© Copyright Commonwealth of Australia, 2017.



This report is licensed by the Commonwealth of Australia for use under a Creative Commons Attribution 4.0 International licence, with the exception of the Coat of Arms of the Commonwealth of Australia, the logo of the agencies involved in producing and publishing the report, content supplied by third parties, and any images depicting people. For licence conditions see: <u>https://creativecommons.org/licenses/by/4.0/</u>

For written permission to use the information or material from this report, please contact the Department of the Environment and Energy at e-mail <u>http://www.environment.gov.au/webform/website-feedback</u> or by phone on 1800 803 772. Alternatively, you can write requesting copyright information to:

Office of Water Science Department of the Environment and Energy GPO Box 787 CANBERRA ACT 2601 <u>Australia</u>

Citation

This report should be cited as:

Department of the Environment and Energy 2017, *Environmental risks associated with surface handling of chemicals used in coal seam gas extraction in Australia*, Project report prepared by the Chemicals and Biotechnology Assessments Section (CBAS), in the Chemicals and Waste Branch of the Department of the Environment and Energy as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.

Acknowledgements

This report is one in a series prepared under the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia. It was prepared by the Chemicals and Biotechnology Assessments Section (CBAS), in the Chemicals and Waste Branch of the Department of the Environment and Energy. The report was prepared between 2013 and 2016.

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

This report was subject to internal review and independent, external peer review processes during its development. This report was externally peer reviewed by Emeritus Professor John Chapman and by staff of the US EPA. Their input is gratefully acknowledged.

Disclaimer

The information contained in this publication comprises general statements based on scientific and other research. Reasonable efforts have been made to ensure the quality of the information in this report. However, before relying on the information for a specific purpose, users should obtain appropriate advice relevant to their particular circumstances. This report has been prepared using a range of sources, including information from databases maintained by third parties, voluntary surveys, and data supplied by industry. The Commonwealth has not verified and cannot guarantee the

correctness or completeness of the information obtained from these sources. The Commonwealth cannot guarantee and assumes no legal liability or responsibility for the accuracy, currency, completeness or interpretation of the information in this report, or for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this publication.

The material in this report may include the views or recommendations of third parties and does not necessarily reflect the views and opinions of the Australian Government, the Minister for the Environment and Energy, the Minister for Health and Aged Care, or the IESC; nor does it indicate a commitment to a particular course of action.

Accessibility

The Commonwealth of Australia is committed to providing web accessible content wherever possible. If you are having difficulties with accessing this document please call the Department of the Environment and Energy on 1800 803 772 (free call).

Reports in this series

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

| 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 | |

| Technical report number | Title | Authoring agency |
|------------------------------------|---|--|
| 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 (the Assessment).

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

This research assessed and characterised the risks to human health and the environment from surface handling of chemicals used in coal seam gas extraction during the period 2010 to 2012. This included the transport, storage and mixing of chemicals, and the storage and handling of water pumped out of coal seam gas wells (flowback or produced water) that can contain chemicals. International evidence¹ showed the risks of chemical use were likely to be greatest during surface handling because the chemicals were undiluted and in the largest volumes. The Assessment did not consider the effects of chemical mixtures that are used in coal seam gas extraction, geogenic chemicals, or potential risks to deeper groundwater.

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

Australia's regulatory framework

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

Approach

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

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

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

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

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



Figure F.1 Steps in the assessment

Collaborators

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

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

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

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

This report: *Environmental risks associated with surface handling of chemicals used in coal seam gas extraction*

The environmental risk assessments described in this report considered the potential risks to the environment (surface and near surface water environments) of the 113 chemicals identified as being used for coal seam gas extraction in Australia in the period 2010 to 2012.

The environmental assessments used two approaches:

- A deterministic (quantitative) approach was developed to assess 59 chemicals for which sufficient physico-chemical and ecotoxicological data was available to allow for modelling and calculations of the predicted environmental concentrations that might occur as a result of release of the chemical under a variety of scenarios.
- A qualitative assessment approach, based on expert judgement and weight of evidence, was used for the risk assessment of the remaining 54 chemicals.

In total, 61 chemicals were assessed to be of low concern to the environment. These chemicals are unlikely to have adverse environmental impacts if they are used in accordance with the relevant State and Territory regulations that are designed to manage and mitigate the risks of handling, transport, use and waste disposal of industrial chemicals, including coal seam gas chemicals.

The deterministic assessment approach used a tiered process whereby the values used for modelling evolve from standard conservative values at Tier 1 to more realistic values at Tiers 2 and 3. By using this approach, 15 chemicals were identified at Tier 3 as being of potential concern in the event of direct release of the chemical to an aquatic ecosystem through accidental releases from transport accidents, such as a truck roll-over, at specific coal seam gas work-sites. The chemicals in this group include mineral salts, alkaline salts, mineral acids, oxidisers, carbohydrates and synthetic organic chemicals including polymers and biocides.

There were also 34 chemicals identified at Tier 1 as being of potential concern. These chemicals would normally have been assessed at higher tiers. However, industry advised that they were not in use as of July 2015. Consequently, there was no site-specific data available to assess these 34 chemicals at Tiers 2 and 3. If the data required became available and these 34 chemicals were assessed at higher tiers their categorisation as 'of potential concern' might change.

Qualitative assessments of three boron-containing chemicals indicated that these are of potential concern. This is because the use of coal seam gas wastewater for agricultural irrigation or road dust suppression may lead to accumulation of boron in soils at concentrations that are toxic to plants. This consideration is also relevant to boric acid, which was identified, using deterministic methods, as one of the 15 chemicals of concern in the event of direct release to an aquatic ecosystem. Thus, a total of four boron-containing chemicals are assessed to be of potential concern.

The potential impacts of boron compounds to the environment is considered to be limited if coal seam gas wastewater containing boron compounds is only used for agricultural irrigation or road dust suppression in circumstances where accumulation of boron in soils is not expected to occur.

The findings of this study underscore the importance of handling and transporting all coal seam gas chemicals in accordance with the relevant regulations and codes of practice. Additionally, the findings on boron chemicals provide information for the responsible management of wastes that contain residues of these chemicals.

Abbreviations

| General abbreviations | Description |
|-----------------------|--|
| CAS RN | Chemical Abstracts Services Registry Number |
| СВІ | Commercial business information |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| EPA | Environmental Protection Authority |
| EPBC Act | Environment Protection and Biodiversity Conservation Act 1999 |
| ERIN | Environmental Resources Information Network |
| GIS | Geographic Information System |
| ha | Hectare |
| HF | Hydraulic fracturing |
| Kd | Partitioning coefficient |
| kg | Kilogram |
| km | Kilometre |
| kL | Kilolitre |
| Kow | n-octanol water partition coefficient |
| L | Litre |
| LC(x) | Lethal concentration to x % of the test population |
| LNG | Liquefied natural gas |
| LOEC | Lowest observed effect concentration |
| L/day | Litres per day |
| m | Metre |
| mm | Millimetre |
| m ² | Metres squared |
| m ³ | Cubic metres |
| mg/L | Milligrams per litre |
| ML | Megalitre |
| ML/day | Megalitres per day |
| MNES | Matters of National Environmental Significance |
| NICNAS | National Industrial Chemicals Notification and Assessment Scheme |
| NOEC | No observed effect concentration |
| OECD | Organisation for Economic Co-operation and Development |
| PBT | Persistent bioaccumulative toxic |
| PEC | Predicted environmental concentration |
| PNEC | Predicted no effect concentration |

| General abbreviations | Description |
|--------------------------|--|
| QSAR | Quantitative structure activity relationships |
| RQ | Risk quotient |
| SIDS | Screening information data set |
| Т | Tonnes |
| US EPA | United States Environmental Protection Agency |
| UVCB | Substances of unknown or variable composition, complex reaction products or biological materials |

Glossary

| Term | Description |
|--------------------------------------|--|
| Assessment endpoint | An expression of the values we want to protect; here includes two elements: (i) identification of the specific ecological entity that is to be protected, such as a species, a community, an ecosystem, or other entity of concern, and (ii) a characteristic of the entity that is important to protect (e.g. reproductive ability of an animal, plant growth, etc.) |
| Assessment factor | Composite (reductive) factor by which an observed or estimated toxicity endpoint (e.g. LC50, EC50 or no-observed-adverse-effect level) is divided to arrive at a criterion or standard that is considered safe or without appreciable risk |
| Bioregion | A geographic land area within which coal seam gas and / or coal mining developments are, or could, take place, which will be the subject of a bioregional assessment |
| Bounding estimate | A bounding estimate captures the highest possible exposure, or theoretical upper bound, for a given exposure pathway |
| Catalogic | Catalogic is proprietary software able to model degradation of chemicals based on mechanistic considerations of degradation including catalysing enzymes, enzyme inhibitors or promoters. The probabilities of the degradation pathways occurring has been modelled on the basis of a set of 583 kinetic curves with more than 15 000 Biological Oxygen Demand values measured using the ease of biotic, oxidative degradation studies, OECD 301F test and other OECD test guidelines |
| Chemical of low concern | These chemicals are assessed to be unlikely to have adverse environmental effects if they are released to the environment from coal seam gas operations. Chemicals of low concern do not require specific risk management measures. For deterministic risk assessment purposes, chemicals of low concern have a RQ < 1 |
| Chemical of potential concern | These chemicals have the potential to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures may be necessary to ensure that chemicals of potential concern do not harm the environment. For deterministic risk assessment purposes, chemicals of potential concern have a RQ \geq 1 and < 10 |
| Chemical of potentially high concern | These chemicals are likely to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures are likely to be required to ensure that chemicals of potentially high concern do not harm the environment. For deterministic risk assessment purposes, chemicals of potentially high concern have $RQ \ge 10$ |
| Coal seam | Coal seams or coal deposits are layers containing coal (sedimentary rock). Coal seams store both water and gas. Coal seams generally contain more salty groundwater than aquifers that are used for drinking water or agriculture |
| Coal seam gas | A form of natural gas (generally 95 to 97% pure methane, CH ₄) typically extracted from permeable coal seams at depths of 300 to 1 000 m. Also called coal seam methane (CSM) or coal bed methane (CBM) |

| Term | Description |
|--|--|
| Conservative approach/assessment | An assessment aimed at deliberately overestimating the potential risks to humans and the environment (after US EPA 1992) |
| Deterministic risk assessment | Risk assessment methodology that use point estimates (a point estimate of exposure and a point estimate of effects) to determine risk. The point estimates are often 'bounding estimates' or very conservative estimates |
| 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 mud |
| 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 |
| DT50 | Degradation time; the time taken for 50% of the chemical to degrade in a given environmental compartment |
| EC50 | Effective concentration; the concentration which affects 50% of a test population after a specified exposure time. The EC50 usually relates to effects other than lethality (e.g. growth rate, immobilisation) in 50% of the test population |
| Environmental compartment | Distinctive components of the environment - principally, the atmosphere, freshwater and marine aquatic systems, suspended and bottom sediments, terrestrial soils and terrestrial and aquatic biota |
| Environmental / Ecological risk assessment | The method(s) for determining risk posed by a stressor (contaminant or perceived threat) to the survival and health of ecosystems |
| Flowback water | The initial flow of water returned to a well after fracture stimulation and prior to production |
| Geogenic chemical | A naturally occurring chemical originating, for example, from geological formations |
| Groundwater-dependent ecosystems | Ecosystems that require groundwater to maintain the communities of plants and animals, ecological processes they support, and ecosystem services they provide |
| 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 |
| Henry's Law | A law stating that the mass of a dissolved gas in a given volume of solvent at equilibrium is proportional to the partial pressure of the gas |
| Hydraulic fracturing | Also known as 'fracking' or 'fracture stimulation'. A process by which hydrocarbon (oil and gas) bearing geological formations are 'stimulated' to enhance the flow of hydrocarbons and other fluids towards the well. May be 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 |

| Term | Description |
|--------------------------------|--|
| | to modify the fluid properties |
| Modelled data | Where no measured values were available, modelled values were obtained from Catalogic (see Catalogic) |
| Physico-chemical properties | Relating to both the physical and chemical properties of chemicals |
| Produced water | Water that is pumped out of the 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 back 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 is stopped |
| Point estimate | A single estimated value given as an estimate of a parameter of a given population |
| Risk | The likelihood of an adverse effect in an organism, system, or (sub) population caused under specified circumstances by exposure to an agent |
| Risk assessment | A process intended to calculate or estimate the risk, including the consideration of uncertainty, to a given target organism, system, or (sub)population, posed by exposure to an agent of concern, taking into account the characteristics of the agent and the target |
| Risk management | Decision making process involving considerations of political, social, economic, and technical factors with relevant risk assessment information relating to a hazard so as to develop, analyse, and compare regulatory and non-regulatory options and to select and implement appropriate regulatory response to that hazard |
| Risk quotient | Risk quotients are calculated by dividing exposure estimates (i.e. predicted environmental concentrations or PECs) by the acute and chronic ecotoxicity values (i.e. RQ = PEC/Toxicity value). |
| Toolbox | Toolbox 2.2 and Toolbox 3.1 is software produced by the Laboratory of Mathematical Chemistry in cooperation with the OECD and European Chemicals Agency. This software contains a comprehensive database of experimental results from the literature for thousands of chemicals as detailed previously |
| Toxicity | Inherent property of an agent to cause an adverse biological effect |
| Wellbore | The hole produced by drilling for production of oil, gas or water |

Contents

| Fo | orewo | rd | v |
|----|-------------|---|-----|
| | Purp | ose of the Assessment | ۷ |
| | Aust | ralia's regulatory framework | v |
| | Appr | oach | v |
| | Colla | aborators | vi |
| | This gas | report: Environmental risks associated with surface handling of chemicals used in coal seam | /ii |
| Al | obrev | iations | ix |
| G | lossa | ry | xi |
| С | onten | tsx | iv |
| 1 | Intro | duction | 1 |
| | 1.1 | Overview of the environmental risk assessment | 1 |
| 2 | The | deterministic risk assessment approach | 6 |
| | 2.1 | Process to develop the deterministic risk assessment approach | 6 |
| | 2.2 | Problem formulation | 6 |
| | 2.3 | Hazard and effects characterisation | 8 |
| | 2.4 | Exposure characterisation1 | 1 |
| | 2.5 | Risk characterisation 1 | 8 |
| 3 | Key | findings of the deterministic risk assessment approach2 | 25 |
| | 3.1 | Hazard and effects characterisation of chemicals2 | 25 |
| | 3.2 | Exposure characterisation of chemicals using the deterministic risk assessment approach 3 | \$4 |
| | 3.3 | Risk characterisation | 60 |
| | 3.4 | Risk management 1 | 0 |
| 4 | The | qualitative risk assessment approach1 | 3 |
| | 4.1 | Introduction1 | 3 |
| | 4.2 | Qualitative risk assessments1 | 3 |
| | 4.3 | Problem formulation1 | 4 |
| | 4.4 | Pre-assessment profile1 | 4 |
| | 4.5 | Grouping1 | 5 |
| | 4.6 | Sources of information1 | 5 |
| | 4.7 | Analogue and modelled data1 | 6 |
| | 4.8 | Reliability, relevance, and adequacy of data1 | 6 |
| | 4.9 | Weight of evidence1 | 6 |
| | 4.10 | Peer review1 | 7 |
| | 4.11 | Limitations1 | 7 |
| 5 | Key | findings of the qualitative risk assessment approach1 | 8 |
| | 5.1 | Findings1 | 8 |
| 6 | Con | clusions | 21 |
| | 6.1 | Chemicals of low concern | 21 |

| | 6.2 | Chemicals of potential concern | 22 |
|---|------|--------------------------------|----|
| | 6.3 | Summary of Conclusions | 24 |
| 7 | Refe | erences | 25 |

Tables

| Table 2.1 | Standard studies for determining endpoints | . 10 |
|--------------------------------|---|------------|
| Table 2.2 EPH | Summary of proposed assessment factors for estimating a PNEC (OECD 2002c and C 2009a) | . 11 |
| Table 3.1 | Drilling chemicals with Koc, DT50 and H values | . 25 |
| Table 3.2 | Hydraulic fracturing chemicals with Koc, DT50 and H values | . 26 |
| Table 3.3 | Drilling chemicals with aquatic ecotoxicity data | . 28 |
| Table 3.4 | Hydraulic fracturing chemicals with aquatic ecotoxicity | . 29 |
| Table 3.5 | Drilling and hydraulic fracturing chemicals that did not have aquatic ecotoxicity data | . 33 |
| Table 3.6 | Tiered approach for exposure characterisation | . 35 |
| Table 3.7 | Area contributing runoff to aquatic receptor | . 38 |
| Table 3.8 | The final selection of rivers in each bioregion | . 39 |
| Table 3.9 | Minor creeks and rivers in closest proximity to each individual well site or well site area | . 39 |
| Table 3.10 site a | D Location and bioregion of selected aquatic receptors and distance to the well site or well area | ll . 42 |
| Table 3.1 ² Stan | 1 Daily stream discharge and rainfall data for rivers selected for use in the assessment. dard errors (SE) are given in parenthesis. | . 43 |
| Table 3.12 | 2 Environmental aquatic receptor volumes estimated for each tier of assessment | . 44 |
| Table 3.13 | 3 Chemicals that have $RQ \ge 1$ after Tier 1 assessment | . 50 |
| Table 3.14 | 4 Chemicals assessed at Tier 2 | .54 |
| Table 3.18 | 5 Chemicals that have $RQ \ge 1$ after Tier 2 assessment for NIC Bioregion | . 55 |
| Table 3.16 | S Chemicals that have $RQ \ge 1$ after Tier 2 assessment for NSB Bioregion | . 56 |
| Table 3.17 | 7 Chemicals for Tier 3 Site-Specific assessment | . 57 |
| Table 3.18 Biore | 3 Tier 3 assessment chemicals for Working Site 1 Northern Sydney Basin Bioregion gion | . 59 |
| Table 3.19 | Θ Drilling chemicals that have RQ \geq 1 for Working Site 1 after Tier 3 assessment | 60 |
| Table 3.20 asse |)Hydraulic fracturing chemicals that have RQ ≥ 1 for Working Site 1 after Tier 3 ssment | . 60 |
| Table 3.2 | 1 Tier 3 assessment chemicals for Working Site 2 Northern Sydney Basin Bioregion | . 61 |
| Table 3.22 asse | 2 Hydraulic fracturing chemicals that have RQ ≥ 1 for Working Site 2 after Tier 3 ssment | . 61 |
| Table 3.23 | 3 Tier 3 assessment chemicals for Working Site 3 Northern Sydney Basin Bioregion | . 62 |
| Table 3.24 | 4 Drilling chemicals that have RQ ≥ 1 for Working Site 3 after Tier 3 assessment | . 63 |
| Table 3.25 asse | 5 Hydraulic fracturing chemicals that have RQ ≥ 1 for Working Site 3 after Tier 3 ssment | . 63 |
| Table 3.26 | 5 Tier 3 assessment chemicals for Working Site 4 Northern Sydney Basin Bioregion | . 64 |

| Table 3.27 | Drilling chemicals that have $RQ \ge 1$ for Working Site 4 after Tier 3 assessment | 5 |
|----------------------|---|----|
| Table 3.28 assess | Hydraulic fracturing chemicals that have $RQ \ge 1$ for Working Site 4 after Tier 3 sment | 6 |
| Table 3.29 | Tier 3 assessment chemicals for Working Site 5 Northern Sydney Basin Bioregion 6 | 57 |
| Table 3.30 | Drilling chemicals that have $RQ \ge 1$ for Working Site 5 after Tier 3 assessment | 6 |
| Table 3.31 assess | Hydraulic fracturing chemicals that have $RQ \ge 1$ for Working Site 5 after Tier 3 sment | 68 |
| Table 3.32 | Tier 3 assessment chemicals for Storage Site 6 Northern Sydney Basin Bioregion 6 | ;9 |
| Table 3.33 | Drilling chemicals7 | '1 |
| Table 3.34 | Hydraulic fracturing chemical | 2 |
| Table 3.35 | Coal seam gas chemicals assessed to be of low concern | 3 |
| Table 3.36 | Coal seam gas chemicals assessed to be of potential concern | 4 |

Figures

| Figure F.1 | Steps in the assessment | vi |
|----------------------|--|----|
| Figure 2.1 | Life cycle stages of chemicals used to extract coal seam gas in Australia | 7 |
| Figure 2.2 coal s | The eight conceptualised potential points of release from the chemical lifecycle within a eam gas working site | 3 |
| Figure 2.3 | Transfer pathways for chemicals associated with coal seam gas extraction 1 | 4 |
| Figure 2.4 | Bioregional Assessment regions and subregions 1 | 6 |
| Figure 2.5 | Tiered approach for risk assessment 1 | 9 |
| Figure 2.6 | Typical percentile of exposure | 20 |
| Figure 2.7 | Simplified tiered approach for the estimation of PECs | 23 |

1 Introduction

1.1 Overview of the environmental risk assessment

The purpose of the environmental risk assessment described in this report was to consider the potential risks to the environment (surface and near-surface water environments) of the 113 chemicals identified as being used for coal seam gas extraction in Australia in the period 2010 to 2012; to identify the chemicals that may pose potential risks to the environment; and to differentiate these from the chemicals that are of low concern.

The principles and methodology used by the Department of the Environment and Energy and industry assessors for environmental risk assessment of industrial chemicals are described in the Environmental Risk Assessment Guidance Manual for Industrial Chemicals (EPHC 2009a).

The EPHC (2009a) manual recommends that a deterministic (quantitative) approach be used for risk assessments of chemicals when there is sufficient physico-chemical and ecotoxicological data available for the necessary modelling and calculations. The manual also provides advice on qualitative assessments, which are necessary when data gaps preclude deterministic assessments. In this assessment:

- A deterministic (quantitative) approach was used to assess 59 chemicals for which sufficient physico-chemical and ecotoxicological data were available to allow for modelling and calculations of the predicted environmental concentrations that might occur as a result of release of the chemical under a variety of scenarios.
- A qualitative assessment approach, based on expert judgement and weight of evidence, was used for the risk assessment of the remaining 54 chemicals for which insufficient data were available for quantitative calculations.

1.1.1 Approach

The purpose of chemical risk assessments is to inform the management and mitigation of risk and ensure the safe use of chemicals. An environmental risk assessment evaluates the potential adverse effects that human activities have on the environment. When conducted for a particular environmental compartment such as a water catchment, the environmental risk assessment can be used to identify vulnerable and valued resources and prioritise data collection. Environmental risk assessments provide a basis for comparing different management options and enabling better informed decisions about the management of risks.

The industry survey (NICNAS 2017a) and the available scientific literature (NICNAS 2017b) did not provide comprehensive physico-chemical and ecotoxicological data for all 113 chemicals. Physico-chemical and ecotoxicological data available for 59 chemicals were sufficiently robust to support a deterministic risk assessment.

Gaps in the data for the remaining 54 chemicals precluded a deterministic (quantitative) risk assessment. In particular, there were no aquatic ecotoxicity data suitable for these chemicals. These chemicals were subjected to a qualitative assessment involving an intensive process to compile, analyse and interpret the available scientific literature on each of the chemicals. The chemicals were then assessed using a qualitative risk assessment approach based on weight of evidence and expert judgement.

The deterministic and qualitative methods that are presented in this environmental assessment conform to Australia's national environmental risk assessment guidance manual (EPHC 2009a and 2009b) and were informed by the principles outlined in Organisation for Economic Co-operation and Development (OECD 2014) and the US Environmental Protection Agency's *Framework for ecological risk assessment* (US EPA 2014b). The US EPA Framework is based on principles described in a series of publications from the US National Research Council on scientific risk assessment methods (US NRC 1983, 1994, 2009).

1.1.1.1 Deterministic assessment approach

The chemicals reported to be used by the Australian coal seam gas industry are common industrial chemicals, but the way in which these chemicals are used by the coal seam gas industry is different from other industrial processes.

When the National Assessment was established there was no deterministic risk assessment approach available specifically designed for industrial chemicals used in coal seam gas extraction. Consequently, a deterministic (quantitative) risk assessment approach was developed for the analyses of the chemicals for which sufficient physico-chemical and ecotoxicological data were available to support such an approach. The deterministic approach that was developed for the National Assessment is detailed in Sections 2 and 3 of this report and the key features of this approach are summarised below.

The deterministic assessment approach includes four main stages (EPHC 2009a and 2009b):

- Stage 1: problem formulation provides the foundation for the environmental risk assessment
- Stage 2: hazard and effects characterisation characterises the ecotoxicity of chemicals based on available data
- Stage 3: exposure characterisation characterises the potential exposure of environmental receptors (such as an aquatic ecosystem) to a chemical if it is released into the environment.
- Stage 4: risk characterisation quantifies and describes the environmental risk of a chemical used under specified scenarios.

At Stage 1 the appropriate environmental compartments are identified.

For the purposes of this assessment, the risks from coal seam gas chemicals were considered only in the context of soils and surface and near surface water.

The focus on surface operations was informed by reviews of unconventional gas operations in the United States (US) that showed that accidents and malfunctions causing spills and leaks of chemicals at the surface represented a clearer and more significant risk for contamination of surface water and shallow groundwater than sub-surface operations such as drilling and fracturing (Groat and Grimshaw 2012; Rozell and Reaven 2012; Vidic et al. 2013; Adgate et al. 2014, Stringfellow et al. 2014). Consistent with the US experience, incidents involving surface spills and leaks from coal seam gas operations have occurred in Australia (Rutovitz et al. 2011; Mallants et al. 2017a).

At Stage 2 hazard data are used to calculate a predicted no effect concentration (PNEC) for the organism most sensitive to the chemical under consideration.

For the purposes of this assessment the relevant organisms for use in Stage 2 are freshwater aquatic species.

At Stage 3 mathematical models are used to calculate the predicted environmental concentration (PEC) of the chemical in the relevant compartment. The models used at Stage 3 of this environmental assessment were developed to calculate PECs for coal seam gas extraction operations in Australian conditions and under specified scenarios.

The scenarios under which chemicals may be released to surface environments by coal seam gas activities in Australia were investigated using a tiered process whereby the values used for modelling evolve from standard conservative values to more realistic values. This is consistent with the US EPA Framework for ecological risk assessment (US EPA 2014b). The three tiers were:

- Tier 1 uses simple models and equations to represent generic environmental conditions to represent any working site in Australia and to calculate PECs and PNECs. The inputs to the models include readily available standard values, bounding estimate values, assumptions and point estimates.
- Tier 2 includes more detailed modelling of bioregional conditions and more complex equations for calculation of PECs and PNECs. The inputs include real data for the bioregion, high-end estimate values, assumptions and point estimates.
- Tier 3 includes complex and detailed modelling to represent working site conditions in the bioregion and for the determination of PECs and PNECs. The inputs include real data for the bioregion, site-specific data, typical or average values for the site or closely related sites and point estimates.

Finally, at Stage 4, the PEC is compared with the PNEC to calculate a risk quotient:

$$RQ = \frac{exposure}{toxicity} = \frac{PEC}{PNEC}$$
 [Equation 1]

Where:

RQ = the Risk Quotient

PEC = the Predicted Environmental Concentration [mg/L], and

PNEC = the Predicted No Effect Concentration [mg/L].

The risk classification (based on the RQ) for each chemical evaluated is determined in accordance with the principles outlined by EPHC (2009a) and the Australia and New Zealand Conservation Council and Agriculture Resources Management Council of Australia and New Zealand (ANZECC and ARMCANZ 2000) guidelines. The classifications of risk for each chemical or chemical group assessed are:

- Chemicals of 'low concern' (RQ < 1). These chemicals are assessed to be unlikely to have adverse environmental effects if they are released to the environment from coal seam gas operations. Chemicals of low concern do not require specific risk management measures.
- **Chemicals of 'potential concern'** (RQ ≥ 1: and < 10). These chemicals have the potential to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures may

be necessary to ensure that chemicals of potential concern do not harm the environment.

• Chemicals of 'potentially high concern' (RQ ≥ 10). These chemicals are likely to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures are likely to be required to ensure that chemicals of potentially high concern do not harm the environment.

These low concern, potential concern and potentially high concern risk classifications are used throughout this environmental assessment.

The deterministic assessment is detailed in Sections 2 and 3.

1.1.1.2 Qualitative assessment approach

Of the 113 chemicals identified as being used for coal seam gas extraction in Australia, there were 54 chemicals for which there were either no ecotoxicity data or the available ecotoxicity data were unsuitable for deterministic risk assessment purposes. Additionally, there were limited physico-chemical data available for many of these 54 chemicals. Therefore, these 54 were assessed using qualitative risk assessments. Qualitative environmental risk assessment of the 54 chemicals with limited data was conducted in accordance with the Inventory Multi-tiered Assessment and Prioritisation Framework (NICNAS 2015a) and the approach developed by Environment Canada (Environment Canada 2003).

This approach is informed by intensive compilation, analysis and interpretation of the available scientific literature on each chemical.

The Environmental Risk Assessment Guidance Manual for Industrial Chemicals (EPHC 2009a) recommends the approach developed by Environment Canada (2003) for applying expert judgement to matters including:

- creating a weight of evidence to support the selection of pivotal information
- qualitative analysis of degradation and persistence of chemicals
- qualitative analysis of bioaccumulation
- qualitative analysis of inherent ecotoxicity

The Canadian approach to qualitative assessment of chemicals with limited data informed the methodology used in Australia to assess industrial chemicals under the Inventory Multitiered Assessment and Prioritisation Framework (IMAP). This Framework operates under the National Industrial Chemicals Notification and Assessment Scheme (NICNAS 2015a).

Consistent with the deterministic approach, the risk classification for each chemical evaluated is determined in accordance with the principles outlined by EPHC (2009a) and the Australia and New Zealand Conservation Council Agriculture and Resources Management Council of Australia and New Zealand (ANZECC and ARMCANZ 2000) guidelines. The classifications of risk for each chemical or chemical group assessed are:

- **Chemicals of 'low concern'**: These chemicals are assessed to be unlikely to have adverse environmental effects if they are released to the environment from coal seam gas operations. Chemicals of low concern do not require specific risk management measures.
- **Chemicals of 'potential concern'**: These chemicals have the potential to cause adverse environmental effects if they are released to the environment from coal seam

gas operations. Specific risk management measures may be necessary to ensure that chemicals of potential concern do not harm the environment.

• **Chemicals of 'potentially high concern'**: These chemicals are likely to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures are likely to be required to ensure that chemicals of potentially high concern do not harm the environment.

Further details regarding the qualitative assessment are presented in Sections 4 and 5.

2 The deterministic risk assessment approach

Of the 113 chemicals² reported to be in use by the Australian coal seam gas industry in the period between 2010 and 2012, sufficient data for a deterministic risk assessment were available for 59 chemicals. This Section presents the development of this deterministic risk assessment.

2.1 Process to develop the deterministic risk assessment approach

The first component was to develop a deterministic risk assessment approach to assess the potential risks to the environment of the chemicals identified as being used in drilling and hydraulic fracturing operations for coal seam gas extraction in Australia.

The deterministic risk assessment approach was developed through four distinct risk assessment processes:

- problem formulation
- hazard and effects characterisation
- exposure characterisation
- risk characterisation.

2.2 **Problem formulation**

For this study, the problem formulation phase involved:

- analysis of the literature
- conceptualisation of chemical exposure (chemical use, release, transport, and fate).

2.2.1 Review of available information

An extensive review and analysis of the available literature (Apte et al. 2017, DoEE 2017a, Jeffrey et al. 2017, Mallants et al. 2017a, NICNAS 2017b) was undertaken to:

- provide the foundation for the environmental risk assessment
- generate the hypotheses concerning the ecological effects
- define the problem and regulatory action
- determine the assessment endpoints
- determine the conceptual models that represents predicted key relationships between stressor(s) and assessment endpoint(s)
- plan the risk assessment.

² For ease of discussion, the term 'chemicals' will be used to refer to all chemicals, substances and / or materials identified in NICNAS (2015a, 2015b, and 2016a).

2.2.2 Conceptual model of chemical lifecycle within coal seam gas working site

The chemical lifecycle within a coal seam gas working site was conceptualised early in the National Coal Seam Gas Chemicals Assessment as including transport, storage, industrial use and disposal (Figure 2.1). A number of controls that are used by industry to minimise chemical releases (spills or intentional releases) to the environment were considered in the conceptualisation. This work was undertaken by CBAS³ and is reported in DoEE (2017b) *Environmental exposure conceptualisation: Surface to surface water pathways*.



Source: DoEE (2017b)

Figure 2.1 Life cycle stages of chemicals used to extract coal seam gas in Australia

This conceptualisation was based on information sourced from an extensive review and analysis of the available scientific literature (Apte et al. 2017, DoEE 2017a,

³ Chemical and Biotechnology Assessments Section in the Department of the Environment

Jeffrey et al. 2017, Mallants et al. 2017a, NICNAS 2017b) and research undertaken to inform the Assessment.

2.3 Hazard and effects characterisation

The hazard and effects characterisation aimed to identify and characterise each of the 113 chemicals, and determine the toxicity of each chemical in the environment. Where possible, breakdown products were also identified and fully characterised. Many could not be fully characterised due to the limited data that were available.

The methodology presented in Sections 2 and 3 of this report describes the hazard and effects characterisation undertaken for 59 of the 113 chemicals that were found to have sufficiently robust physico-chemical and ecotoxicological data to support a deterministic risk assessment.

There were limited ecotoxicity and physico-chemical data available for the remaining 54 chemicals. In particular, there were no suitable aquatic ecotoxicity data available for any of these chemicals. These chemicals were assessed using a qualitative process (Sections 4 and 5).

2.3.1 Chemical identification and characterisation

The chemical characterisation stage included:

- verifying chemical identities
- collecting physico-chemical and ecotoxicity data used for models
- determining the PNEC (predicted-no-effect-concentration).

A summary of the methodology used to obtain the chemical data and the process undertaken to establish PNEC for risk characterisation is provided below, and in more detail at Appendix A.

2.3.1.1 Verifying chemical identity

The identities and concentrations of the chemicals involved in coal seam gas operations and presented in DoEE (2017e) were needed to model the potential quantities released from the different stages of the chemical life cycle.

The identity of each of the 113 chemicals, plus relevant measured physico-chemical properties and measured ecotoxicological data were obtained for the supplied Chemical Abstracts Services Registry Number (CAS RN) using the Organisation for Economic Cooperation and Development (OECD) Quantitative Structure Activity Relationships (QSAR) Toolbox v2.2 (OECD 2013a) and OECD QSAR Toolbox v3.1 (OECD 2013a). Where data for a specific chemical were absent, this information was inferred by interpolation or extrapolation from similar chemicals for which this information was available. To achieve this, the QSAR modelling approach (ECHA 2008) was used (see Appendix A).

Although the CAS RN is unique for each chemical substance, it can refer to substances comprised of mixtures of 'unknown or variable composition, complex reaction products or biological materials (UVCB) and polymers' (ACS 2014 and ACS 2015). All but one of the 113 chemicals were uniquely identified with confidence in the first instance; however, after further review that chemical was assigned as sodium bentonite (CAS RN 85049-30-5).

Once all of the 113 chemicals were unequivocally identified, the QSAR Toolbox v2.2 and v3.1 databases were interrogated for ecotoxicity and physico-chemical data. The database contains numerous ecotoxicological endpoints for numerous species.

2.3.1.2 Physico-chemical data

Physico-chemical data were sought to infer the degradation and potential for chemicals to move from one environmental compartment to another. The chemical fate pathways which may result in loss of chemicals (e.g. through degradation), or subsequent exposure in a secondary receiving environment, need to be understood to predict the environmental exposure of chemicals associated with coal seam gas (DoEE 2017b).

The two parameters of most interest are the $DT50^4$ and the partitioning coefficient (*Kd*). *Kd* is a major determinant of the mobility of chemicals from soil to water or from water to sediment and is determined using a series of accepted partitioning coefficient values (such as the specific organic carbon partitioning coefficient, *Koc*). More details are provided at Appendix A. In addition, Henry's Law constant (*H*) allows the estimation of partitioning between water and air for volatile chemicals.

No values were found for DT50 or *Kd* for any of the chemicals. Instead, these values were extrapolated from the commonly tested parameters of ready biodegradation using sewage sludge as determined by OECD TG 301 A-F, 302 A-C and 310 (OECD 1981, 1992b, 1992c, 2006d, 2009d) and the *n*-octanol water partition coefficient (*Kow*), determined by OECD TG 107, 117 or 123 (OECD 1995b, 2004a, 2006e). Measured values were obtained from the OECD Toolbox database (OECD 2013a) and the Catalogic database (LMC 2011a, 2011b, 2012). These were checked against peer-reviewed published data from OECD Screening Information Data Set (SIDS) Initial Assessment Reports (OECD 2006a, 2006b, 2006c, 2006d, 2007b, 2007c, 2007d, 2009a, 2009b, 2009c, 2011b).

The affinity for organic carbon is related to its chemical structure and hence its affinity for the *n*-octanol phase, and values obtained for *Kow* were extrapolated to *Koc* values using an accepted equation (US EPA 1996). They were then converted to *Kd* values by considering a default value for organic carbon in Australian soil based on ANRA (2001) and a standard conversion (EPHC 2009a), consistent with the US EPA's deterministic approach (US EPA 2014c)⁵.

The DT50 values for soil and water were derived by categorising the ease of biotic, oxidative degradation according to the four accepted test categories (e.g. readily biodegradable, inherently biodegradable, and non-biodegradable). For soil DT50 values for chemicals, the ease of biotic, oxidative degradation categories was considered in conjunction with the *Kd* values of that chemical using a method described by EPHC (2009a), citing EC (2003). For DT50 values in water, the values were extrapolated from the four accepted categories of ease of biotic, oxidative degradation.

Values for Henry's Law constants were obtained from Toolbox v2.2 (OECD 2013a).

2.3.1.3 Ecotoxicity data and deriving PNEC (predicted no effect concentration)

The methodology used to obtain the chemical data and the process undertaken to establish PNEC for risk characterisation is summarised below, and detailed at Appendix A.

Ecotoxicity endpoints (e.g. the effect concentration to 50% of the population (EC50); lethal concentration to 50% of the population (LC50); no observed effect concentration (NOEC))

⁴ Time taken for 50% of the chemical to degrade in a given environmental compartment.

⁵ Approximately 75% of Australia's soils have organic carbon contents of less than 1% (Spain et al. 1983). The more productive soils have levels greater than 5%, but their areal extent is small. Therefore, this project used 1% organic carbon, which (with the *Kd* value) would in general indicate a lower partitioning to soil.

are needed to establish the chemical PNEC. The PNEC is used during the risk assessment to characterise the potential concern in the receiving environments.

To derive PNECs, the chemical of interest needs to be uniquely and unequivocally identified, and have measured ecotoxicity endpoints from laboratory studies or, where laboratory data are lacking, have endpoints estimated using the chemical structure and measured data from chemically similar compounds (OECD 2007a).

The 113 chemicals were uniquely identified and selected data regarding their physicochemical properties and ecotoxicity were obtained (where available) from the QSAR Toolbox version 2.2 and 3.1 (OECD 2013a). The ecotoxicity data were restricted to studies conducted under standard OECD test guidelines (TG) 201, 202, 203, 210, 211 and 215 (OECD 1992a, 2000b, 2004a, 2011a, 2012, 2013a, 2013b).

Where no measured data were available, endpoints were estimated using QSAR modelling. This was conducted using ECOSAR version 1.1 (US EPA 2000-2012), which is also the primary component of Toolbox's QSAR model for ecotoxicity endpoints, but available as a standalone product. This analysis is not applicable to inorganic or organometallic compounds, or to substances of unknown or variable composition, complex reaction products or biological materials (i.e. UVCBs). The method is also regarded as limited in estimating the ecotoxicity of surfactant chemicals (Mayo-Bean et al. 2012a, 2012b). Therefore, suitable chemical analogues for surfactants were used in preference to QSAR modelled values.

The ecotoxicity data for the surfactant analogues were obtained from published literature (Madsen et al. 2001). The endpoints generated by these studies, which are routinely used in risk assessments, are presented in Table 2.1.

| Endpoint | | OECD TG | Reference |
|----------|--|--------------|------------------------------|
| Acute | EC50 algae (growth rate 72 or 96 h) | 201 | OECD (2011a) |
| | EC50 Daphnia (immobilisation 48 h) | 202 | OECD (2004b) |
| | LC50 fish (mortality 96 h) | 203 | OECD (1992a) |
| Chronic | NOEC algae (growth rate 72 h or 96 h) | As for acute | |
| | NOEC Daphnia (Reproduction and mortality 14 -21 d) | 211 | OECD (2012) |
| | NOEC fish (hatching, morphology, mortality up to 60 days post hatch) | 210 and 215 | OECD (2013b) OECD (2000b) |

 Table 2.1 Standard studies for determining endpoints

* NOEC = no observed effect concentration; acute = short-term; chronic = long-term.

All values were converted to mg/L from other units using standard values for molecular weight and density (for example, Aylward and Findlay 1974 and Atkins 1986).

2.3.1.4 Estimating PNEC (predicted no effect concentration)

The ecotoxicity endpoint values used for each chemical and the process used to derive the PNECs are provided at Appendices A and B. A brief summary of the approach is provided below.

The PNEC for a chemical is calculated using toxicity test data such as LC50, EC50, other L(E)Cx values, NOEC (no observed effect concentration) and LOEC (lowest observed effect

concentration). The MATC (maximum allowable toxicant concentration is also used in effects assessment (OECD 2002c) and can be calculated using Equation 2:

$$MATC = (NOEC \times LOEC)^{\frac{1}{2}}$$
 [Equation 2]

Deriving a PNEC commonly relies on using assessment (or safety) factors. Assessment factors are used to ensure that the PNEC is low enough that there is no appreciable risk to the organism under consideration. The use of assessment factors reflects the following uncertainties inherent in most datasets:

- intra-species and inter-species variation
- the extrapolation of short-term toxicity to long-term toxicity
- the extrapolation of laboratory results to the field (OECD 2002c and EPHC 2009a).

To derive a PNEC, laboratory or field toxicity data are divided by a carefully selected assessment factor. Table 2.2 summarises the range assessment factors that are used for common toxicity tests. In general, the selected assessment factor should reflect the level of uncertainty about the dataset. For instance, an assessment factor of 1 000 is often applied to acute toxicity data for *Daphnia* because it is known that other species of crustacea may respond differently to particular chemical stressors and because the extrapolation of short-term toxicity data to obtain a PNEC that is protective of long-term exposure is uncertain. On the other hand, there is usually less uncertainty in deriving a PNEC for fish from chronic toxicity data obtained from field tests on several different species of fish. Consequently, an assessment factor of 10 may be appropriate for such a dataset. Additionally, assessment factors should be applied with care to acute data for substances which are suspected of having a specific mode of action (e.g. endocrine-disrupting chemicals), have a high log *Kow* or which bioaccumulate. Moreover, assessment factors should be applied cautiously to data on chemicals of low solubility and no observed toxicity, such as some inorganic salts, or insoluble chemicals such as polystyrene or silicon.

The assessment factors used for estimating a PNEC in this study are shown in Table 2.2.

| Case | Data available | Range of assessment factors |
|------|--|-----------------------------|
| а | EC50 algae (72 h) EC50 <i>Daphnia</i> (24–48 h acute test) LC50 fish (96 h) | 100–1 000 |
| b | NOEC <i>Daphnia</i> (14–21d chronic toxicity test) NOEC algae (72 h) NOEC fish (chronic toxicity test) | 10–100 |

Table 2.2 Summary of proposed assessment factors for estimating a PNEC (OECD 2002c and EPHC 2009a)

This methodology is detailed at Appendix A.

2.4 Exposure characterisation

The environmental exposure characterisation determines the potential exposure of environmental receptors (such as aquatic organisms, protected species, ecological communities, etc) to chemicals in specific environmental compartments (that is, soil, water, air, etc). This characterisation includes information on how often, how long, and the amount of chemical to which the environment may be exposed. It is based on environmental fate and chemical transport data as well as modelling and monitoring information.

2.4.1 Conceptual surface exposure pathway model development

To characterise the potential exposure of the environmental receptors to chemicals used for coal seam gas extraction, a conceptual model was developed early in the National Coal Seam Gas Chemicals Assessment. This work is reported in: DoEE (2017c) *Environmental exposure conceptualisation: Surface to surface water pathways*.

Environmental exposure conceptualisation is important as it directly informs the development of the environmental risk assessment approach, and it provides mathematical expressions for use at the risk characterisation phase of the study.

The exposure scenarios were determined by considering:

- points of chemical release to the environment within a coal seam gas working site (e.g. transport spill, storage spill, industrial use spill, intentional disposal)
- chemical fate pathways once released (i.e. a chemical's movement through the environment, such as runoff, airborne deposition, partitioning and sedimentation, volatilisation, degradation, infiltration)
- receiving environments (soil, surface water, shallow groundwater, sediment and air)
- environmental receptors (aquatic and terrestrial ecosystems).

The values and assumptions used in conceptual modelling were based on analysis of the available literature (DoEE 2017a).

2.4.1.1 Potential points of chemical release at a working site

The methodology for the identification of the specific release points from the chemical life cycle at working gas extraction sites, and the corresponding mathematical expressions to estimate the chemical quantities released from each point of release, were determined during the environmental exposure conceptualisation report (DoEE 2017b). A brief summary of this information is provided below.

Eight potential points of release at a working site were conceptualised, based on where in the lifecycle an accidental spill of chemical (or intentional release) to the environment may occur. They were:

- transport of chemicals
- storage of chemicals at intermediate warehouse sites
- storage of chemicals at individual well sites
- use of chemicals at individual well sites
- management of coal seam gas waste fluids (i.e. flowback and produced waters)
- storage of coal seam gas waste fluids
- irrigation
- dust suppression.

Figure 2.2 shows the eight potential points of release at a working site.



Figure 2.2 The eight conceptualised potential points of release from the chemical lifecycle within a coal seam gas working site

2.4.1.2 Chemical fate pathways

The methodology used to identify chemical transfer pathways, and estimate the PECs after the chemicals are released and before they reach the environmental receptors was developed during the environmental exposure conceptualisation for surface to surface water pathways work (reported in DoEE 2017b). A brief summary of the methodology is provided below.

The chemical fate pathways (i.e. a chemical's movement through the environment) included runoff, airborne deposition, partitioning and sedimentation, volatilisation, degradation, infiltration (Figure 2.3). The chemical fate (transfer) pathways for chemicals used, stored and transported within a coal seam gas working site to the environment were determined to include:

- **Runoff:** Runoff may occur during a rainfall event resulting in the transport of contaminants in the soil compartment to a secondary site in the soil compartment or into an aquatic compartment.
- Adsorption to soil particles and sedimentation: Contaminants may have an affinity for particulates in the water and sediment at the bottom of the aquatic ecosystem. A chemical may adsorb directly to the sediment. Otherwise, it may first adsorb to suspended particles in water, followed by settling to the sediment. The chemical's

physico-chemical properties and the turbidity (a measure of concentration of suspended particles) of the water will determine whether the predominant pathway involves direct partitioning to sediment, or settling to sediment over time.

- **Degradation:** Degradation results in the removal of a contaminant from a compartment through transformation. Transformation can occur in storage ponds or elsewhere in aquatic and soil compartment via various mechanisms including biodegradation, photolysis and hydrolysis.
- **Airborne deposition:** Airborne deposition occurs when contaminants in the soil compartment become airborne in dust (as particulates) and are transported through the air before settling in a secondary site. This transport mechanism is driven by wind and may result in exposure to the aquatic compartment.
- Volatilisation: Volatilisation may occur when contaminants partition to air from the surface of water bodies in which contaminants are present, such as storage dams holding wastewater and drilling fluids or rivers. The likelihood and extent of a chemical volatilising from water is determined by individual chemical properties and environmental factors.
- **Infiltration to groundwater:** Infiltration occurs when contaminants in soil, for instance from a spillage, leach through the soil profile towards groundwater. This may also arise from storage dam leaks.



Figure 2.3 provides a representation of these transfer pathways.

Source: DoEE (2017b)



2.4.1.3 Identifying and categorising environmental receptors

The environmental receptors are the environmental compartments into which a chemical may be released or enter via a chemical transfer pathway. Receiving environments were identified during the conceptualisation work (reported in DoEE 2017c) as soil, surface water, shallow groundwater, sediment and air.

On the basis that the highest risk from chemical release to the environment is expected to be in receiving environments near the source of gas extraction operations, receiving environments near working sites were characterised. This characterisation included:

- collating physico-chemical parameters for modelling
- identifying important and relevant environmental receptors

An approach was developed to characterise the receiving environment in each of the six priority bioregions⁶ of the Australian Government Bioregional Assessment Program (http://www.bioregionalassessments.gov.au), with a focus on identifying important environmental receptors near operational coal seam gas sites (Figure 2.4).



Six bioregions: Lake Eyre Basin (yellow), Northern Inland Catchments (green), Clarence-Moreton (purple), Northern Sydney Basin (orange/brown), Sydney Basin (blue), Gippsland Basin (red/pink).

⁶ The six bioregions (announced by the Minister for the Environment in 2012) were chosen as regions with significant existing or anticipated mining pressure where there was a lack of information to assess and understand the potential impacts and where there are water assets of concern to the Australian Government.

Figure 2.4 Bioregional Assessment regions and subregions

Environmental receptors in the surface aquatic, terrestrial and groundwater-dependent ecosystems were identified through the approach described below.

Approach

A detailed, interactive geographic information system (GIS) dataset was created by the Environmental Resources Information Network (ERIN) of the Department of the Environment and Energy to identify and map the relevant land area with coal seam gas tenements or areas containing coal seam gas wells (ERIN 2013). This GIS dataset also assisted with the delineation of environmental receptors (including terrestrial and aquatic ecosystems) in each bioregion. The following information was layered and intersected through standardised GIS processes:

- coal seam gas and large coal mining bioregions
- subregions within each bioregion
- areas that contain tenements with coal seam gas wells within each subregion
- operational coal seam gas wells and chemical storage areas
- the area the operational coal seam gas wells occupy (cadastre⁷) within each subregion
- major and minor rivers in the bioregion and within 2 km⁸ from coal seam gas extraction wells
- assessment endpoints related to Matters of National Environmental Significance
 (MNES) protected under the *Environment Protection and Biodiversity Conservation Act* 1999
- aquatic, terrestrial and groundwater-dependent receptors.

Ecological receptors

The focus of this study was identifying MNES (listed under the EPBC Act) in the receiving environments because they are:

- significant ecological sites
- rare or unique ecosystems
- important habitats for conservation of biological diversity, or
- facing the risk of extinction in the wild in the immediate, near and medium-term future.

The criterion for identifying key MNES protected under the EPBC Act are presented below:

- aquatic ecosystems containing listed species (e.g. algae, fish and frogs and aquatic birds)
- ecosystems declared as protected National or World Heritage in the bioregion
- ecosystems declared as protected Wetlands of International Importance (Ramsar sites) and other nationally important wetlands (DIWA sites)
- ecosystems containing threatened ecological communities

⁷ The specific area where the coal seam gas wells are located.

⁸ Estimated distance for chemicals concentrations to decrease to threshold levels (Mallants et al. 2016b and 2016c; NICNAS 2016c).

• ecosystems declared as protected groundwater-dependent ecosystem (e.g. terrestrial flora and fauna; river base flow systems; aquifer and cave ecosystems; springs and wetlands, estuarine and near-shore marine ecosystems).

Surface aquatic receptors

In addition to the ecological receptors already identified, additional criteria for identifying and selecting the aquatic receptors of importance (or relevance) near operational coal seam gas well sites (that is, the aquatic ecosystems that would be considered during the risk characterisation process) included:

- major and minor rivers within 2 km of a coal seam gas site (and their nearest downstream gauging stations)
- rivers that have protected aquatic organisms (e.g. algae, fish or frogs)
- rivers that are directly connected to protected National Heritage places, World Heritage properties, Ramsar wetlands, EPBC-listed threatened species/ecological communities, and / or groundwater-dependent ecosystems
- rivers that are directly connected to other rivers that have protected aquatic organisms
- rivers that are directly connected to a river (minor or major) that is connected to protected National Heritage places, World Heritage properties, Ramsar wetlands, EPBC-listed threatened species/ecological communities, and / or groundwaterdependent ecosystems.

Subsurface receptors

Subsurface ecosystems are recognised as supporting diverse species (DoEE 2017a). Efforts are being directed towards building knowledge of subsurface ecosystems (DoEE 2017a). However, this field of knowledge is in its infancy and much remains unknown about the diversity, distribution, functional roles and interdependencies of species in subsurface ecosystems (DoEE 2017a). While knowledge of subsurface ecosystems is incomplete, the early evidence suggests that receptors of chemicals in subsurface ecosystems would be similar to those of surface ecosystems (DoEE 2017a).

At least one threatened ecological community occurring within the six priority areas is known to be a groundwater-dependent ecosystem (DoEE 2017a). For example, the EPBC-listed ecological community known as '*The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin*' comprises assemblages of plant and animal taxa that depend on the springs and wetland areas located at points where the Great Artesian Basin groundwater naturally discharges. Other groundwater dependencies may exist for the identified matters of national significance that may or may not rely on the surface expression of groundwater (DoEE 2017a). A small number of subsurface ecosystems and obligate subsurface species are protected matters under the EPBC Act, including five aquatic root mat communities in Western Australia, the blind gudgeon, the blind eel and a cave-dwelling crustacean. However, none of these protected matters are known to occur within the six priority regions (DoEE 2017a).

2.4.2 Mathematical expressions for environmental risk assessment

The mathematical expressions developed during the environmental exposure conceptualisation work form the basis of the models developed and used in this study to estimate risk. Using Microsoft Excel, the mathematical expressions were linked in a logical sequence to create a quantitative model that represented the movement of a chemical

associated with coal seam gas extraction, under different scenarios and at progressive levels of scrutiny (that is, tiered risk assessment – Tiers 1 to 3 in this approach).

The mathematical expressions enable the model to relate the chemical quantities, points of release and transfer pathways to the final concentrations at environmental receptors. Descriptions of the mathematical expressions and inputs used to model chemical risks at the risk estimation stage of this study are detailed at Appendices A and B.

2.5 Risk characterisation

Risk characterisation is the final stage of the risk assessment process and must be transparent, clear, consistent, and repeatable. It includes:

- risk estimation where exposure data are compared to effects data, the interaction of exposure and effects is considered, and the potential for risk is estimated using mathematical equations
- risk description the results of the risk estimation are used to interpret the risk posed to ecological entities
- risk management where risks are described in the context of existing regulation and operations controls which are (or to be) applied by the coal seam gas extraction industry.

2.5.1 Risk estimation

2.5.1.1 Deterministic approach

The risk estimation methodology used in this assessment is known as a tiered 'deterministic' approach. This is a widely accepted approach to environmental risk assessment, and is implemented by many international regulatory agencies such as the US EPA (US EPA 1998, 2014a, 2014b, 2014c) and the European Community (EC 1996, 2003) and promoted by the OECD (2014).

In Australia, a deterministic approach is commonly used for environmental risk assessments undertaken as part of the regulatory systems for industrial, agriculture and veterinary chemicals (EPHC 2009a, 2009b).

In this approach, the risk of a chemical being released to the environment (in this case, from coal seam gas operations) is analysed by comparing the predicted environmental concentration (PEC) with the predicted no effect concentration (PNEC) to calculate a risk quotient using Equation 3:

$$RQ = \frac{exposure}{toxicity} = \frac{PEC}{PNEC}$$
 [Equation 3]

Where:

RQ = the Risk Quotient

PEC = the Predicted Environmental Concentration [generally mg/L], and

PNEC = is the Predicted No Effect Concentration [generally, mg/L].

The RQ is calculated by dividing a point estimate of exposure by a point estimate of effects. A value greater than one (i.e. PEC greater than PNEC) indicates potential concern, while a value less than one indicates low concern to the environment. Deterministic assessments

produce estimates that allow for ready identification of high-concern or low-concern situations. Generally, deterministic risk assessments are straightforward to interpret (US EPA 2014b, 2014b, 2014c).

2.5.1.2 Tiered assessment

The US EPA *Framework for ecological risk assessment* (US EPA 2014b) advocates a tiered risk assessment process wherever possible. Therefore the deterministic assessment approach that was developed for this project has a tiered structure that is based on the principles described in the US EPA *Framework for ecological risk assessment*.

A tiered assessment process systematically examines the potential concerns to receiving environments by incorporating successively higher levels of refinement into the modelling to increase the confidence of the prediction at each tier (Figure 2.5). Low-concern scenarios can typically be eliminated from the assessment at Tier 1, enabling ready identification of high-concern scenarios that require further (higher tier) assessment.

Using a tiered approach, the values for each modelling component evolve from standard conservative values (Tier 1) to more realistic values (Tier 2) and, finally, to more specific values (Tier 3). Tier 3 assessments are generally detailed, site-specific assessments that are often resource intensive and relatively costly. Depending on available data and the requirements for the assessment, they may be either deterministic or probabilistic in their approach.



Adapted from Volume III of EPA's Risk Assessment Guidance for Superfund (1)

Source: US EPA (2004)

Figure 2.5 Tiered approach for risk assessment

The tiered structure of the deterministic risk assessment approach that was used in this project is consistent with the US EPA *Framework for ecological risk assessment* and was specifically developed to account for Australian conditions.

- Tier 1 uses simple models and equations to represent generic environmental conditions to represent any working site in Australia and to calculate PECs and PNECs. The inputs to the models include readily available standard values, bounding estimate values, assumptions and point estimates. Variability and uncertainty are not considered here. Sensitivity testing is not included.
- Tier 2 includes more detailed modelling to represent bioregional conditions and more complex equations for calculation of PECs and PNECs. The inputs include real data for the bioregion, high-end estimate values, assumptions and point estimates. Variability and uncertainty are not considered here. Sensitivity testing is not included.
- Tier 3 includes complex and detailed modelling, to represent working site conditions in the bioregion and for the determination of PECs and PNECs. The inputs include site-specific data, typical or average values for the site or closely related sites, realistic assumptions, and point estimates. Variability and uncertainty are estimated by using similar methodologies as reported for the deterministic approach by US EPA (2014b). Simple statistical analysis can be introduced into the risk predictions.

2.5.1.3 Data selection and treatment

As indicated above, Tier 1 uses bounding estimate values as inputs to a simple model. Tier 2 uses high-end estimate values as inputs to a more detailed model. Tier 3 uses central tendency values as inputs to a more complex and detailed model, which follows the 'deterministic exposure assessments' principle provided by US EPA (Figure 2.6).

Data selection and treatment involved the selection of a combination of point values considered either highly conservative (i.e. high end values for Tier 1 and Tier 2) or to represent a 'typical' exposure (i.e. central tendency values for Tier 3) following the guidance provided by US EPA for deterministic tiered approach assessment (2014c). The resulting exposure estimate is a point estimate that falls somewhere within the full distribution of possible exposures.



Source: US EPA (2014b)

Figure 2.6 Typical percentile of exposure

The US EPA also indicates that default point estimates can be used for a screening-level assessment to create a basic picture of high end exposures. If the results of the initial assessment are not sufficient for use in decision-making, a refined deterministic assessment can be completed using more site-specific data, if available, to create a more precise picture of expected exposures (US EPA 2014b). In this assessment, following the US EPA principle, highly conservative values were selected at Tiers 1 and 2 because these values are sufficient to cover any potential exposure that can arise across Australia (Tier 1) or in a
bioregion (Tier 2) and therefore these values are conservative. At the Tier 3 level central tendency values were selected because Tier 3 assessments are site-specific and therefore these values are intended to represent typical exposures that can arise at a specific working site.

• Details on the selection and treatment of values for the different parameters in the models under each tier, as determined during this study, are provided at Appendix B.

2.5.1.4 Release quantity (Q)

The chemical quantity released (*Q*) from the identified points of release (transport of chemicals, storage of chemicals at intermediate warehouse sites, storage of chemicals at individual well sites, management of coal seam gas waste fluids, storage of coal seam gas waste fluids, irrigation, and dust suppression) is estimated using release equations developed in the environmental exposure conceptualisation report (DoEE 2017b) and in Appendices A and B of this report.

It is expected that chemicals (individual or in formulations) are transported in one or more trucks to intermediate storage sites, and from there to one or more well sites. Therefore, for the purposes of this study it is assumed that at a single point in time the greatest quantity of an individual chemical is at the intermediate storage site. Likewise, the quantity of chemical used, returned to the surface and stored and disposed with waste fluid, cannot exceed the quantity stored at an individual well site. On this basis, it is expected that:

- the quantity of imported chemical in warehousing must be <u>greater than or equal to</u> that held an intermediate storage facility
- the quantity for intermediate storage must be greater than or equal to that for transport
- the quantity for intermediate storage must be <u>greater than or equal to</u> that for well site storage
- the quantity for well site storage must be <u>greater than or equal to</u> the quantity used at one well which is <u>greater than or equal to</u> the quantity returned and stored in waste which is <u>greater than or equal to</u> the quantity disposed
- there is no rule regarding quantities that must be met when comparing transport and well site storage.

2.5.1.5 Estimating PECs

A tiered approach was used for calculating the PECs for chemicals used in coal seam gas operations. The environmental exposure conceptualisation work (DoEE 2017b) outlined the general concepts, values and mathematical expressions for the risk assessment, provided a description of potential surface exposure scenarios, and included a general discussion of the available chemical information. The mathematical expressions included equations for calculating the chemical quantities released from different exposure scenarios and transport pathways to aquatic and terrestrial receiving environments; and equations for calculating the quantity and concentration (PECs) in terrestrial and aquatic receiving environments.

This study incorporates the mathematical expressions in DoEE (2017b) into a tiered approach to create a series of chemical and environmental models that ultimately derive PEC values. A summary of this is provided below, with more detail on the models at Appendix B. Refer to Section 2.4.2 of this report for more detail on the mathematical expressions.

The modelled exposure scenarios for which PECs were derived in this study (using the point of release, transfer pathways, and environmental receptor models) are based on short time releases and runoff to near surface environments for chemicals used by people and stored for a limited period at a coal seam gas operational site. This study also modelled the exposure scenarios of spills, overflow and intentional usages from storage dams.

Slow releases over time (e.g. years and decades to centuries) from storage dams were outside the scope of this study. The transfer pathway for this scenario would be via infiltration to groundwater (and not runoff to surface environments).

2.5.1.6 General models linkages for calculating the PECs

Chemical release (*Q*) to the environment may occur during any of the chemical lifecycle stages in coal seam gas operations (Figure 2.1). These releases are generally represented by the following linkages to the modelling components.

- Direct release to an aquatic receiving environment:
 - assumes that the chemical quantity or concentration estimated in a point of release is directly released to an aquatic receptor.
 - the chemical concentration in the receiving aquatic environment from direct release is calculated by using the release equations described in the environmental exposure conceptualisation report (DoEE 2017b) and as presented in Appendices A and B.
- Direct release to a terrestrial receiving environment:
 - assumes that the chemical quantity or concentration estimated in a point of release is directly released to a terrestrial receptor.
 - the chemical concentration in the receiving terrestrial environment from direct release is calculated by using the release equations described in the environmental exposure conceptualisation report (DoEE 2017b) and as presented in Appendices A and B.
- Indirect release to an aquatic receiving environment:
 - assumes that the chemical quantity or concentration estimated in a release scenario uses a soil pathway to an aquatic receptor.
 - the chemical concentration in the receiving aquatic environment from indirect release is calculated by using the release equations described in the environmental exposure conceptualisation report (DoEE 2017b) and as presented in Appendices A and B.

During the assessment, it can be assumed that each point of release can lead to:

- direct exposure to terrestrial environments
- indirect exposure to an aquatic receiving environment via runoff
- direct release to an aquatic environment via a transport accident

For each PEC calculation, the variables and equations leading up to the final PEC reflect a logical progression from release quantity (*Q*) at a specific point of release to aquatic and terrestrial PECs. Where aquatic exposure is indirect, runoff equations are calculated following determination of terrestrial PECs, thereby ultimately also calculating runoff for aquatic PECs.

Figure 2.7 summarises the main parameters considered under each modelling component and shows how their values change from Tier 1 to Tier 3 for the calculation of PECs for the risk assessment. Appendix B provides detailed information of the values used (including assumptions and justifications) for each parameter under each tier.



Figure 2.7 Simplified tiered approach for the estimation of PECs

2.5.1.7 Classification of risk quotient (RQ)

In this deterministic risk assessment, the risk classification (i.e. the characterisation of the RQ) for each chemical is determined in accordance with the principles outlined by EPHC (2009a) and the ARMCANZ and ANZECC (2000) guidelines.

The classification of risk quotients is made in the context of Australia's regulatory framework for environmental management of industrial chemicals. In general, these regulations mandate responsible management and use of chemicals which require users to take all reasonable measures to avoid unnecessary release of chemicals to the environment from handling, transport, use or waste disposal.

- Chemicals of 'low concern' (RQ < 1): These chemicals are assessed to be unlikely to have adverse environmental effects if they are released to the environment from coal seam gas operations. Chemicals of low concern do not require specific risk management measures.
- Chemicals of 'potential concern' (RQ ≥ 1: and < 10). These chemicals have the potential to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures may be necessary to ensure that chemicals of potential concern do not harm the environment.

• Chemicals of 'potentially high concern' (RQ ≥ 10). These chemicals are likely to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures are likely to be required to ensure that chemicals of potentially high concern do not harm the environment.

Where a chemical is screened out at Tier 1 (RQ < 1), this means it is considered to be of low concern for the scenario assessed and not require further assessment. The Tier 1 assessment is conservative by design (e.g. uses bounding estimate values, and assumes that the coal seam gas working site is anywhere in Australia). Chemicals presenting a potential concern (RQ \ge 1) proceed to Tier 2 assessment.

Similarly, where a chemical is screened out at Tier 2 (RQ < 1), this means it is considered to be of low concern for the scenario assessed and not require further assessment. The Tier 2 assessment is more focussed than Tier 1 (i.e. uses high-end estimate values, and assesses coal seam gas chemical use at the bioregion level). Chemicals presenting a potential concern (RQ \ge 1) proceed to Tier 3 assessment.

At Tier 3, a range of site-specific and environmental processes are applied to a deterministic model to derive more refined PEC and RQ values. At Tier 3, the risks associated with the assessed chemicals are classified according to the system described above.

3 Key findings of the deterministic risk assessment approach

The site-specific deterministic risk assessment was developed to evaluate industrial chemicals used by the Australian coal seam gas industry, for which sufficient data were available. This section presents the findings of the deterministic risk assessment undertaken for the 59 chemicals with sufficient data.

3.1 Hazard and effects characterisation of chemicals

3.1.1 Chemical physico-chemical properties

Physico-chemical data were sought to infer the degradation and potential for chemicals to move from one environmental compartment to another. Of the 113 chemicals identified for consideration in the risk assessment, physico-chemical data were available for 48 chemicals:

- 13 drilling chemicals
- 30 hydraulic fracturing chemicals
- 5 chemicals common to both uses.

Of the drilling chemicals, seven had values for both Koc and DT50 (these two parameters are considered the most important in determining transport between soil and water), while six of these seven also had values for Henry's Law constant (H).

The modelling results suggest that two drilling chemicals have very high Koc values, which is an indication that the chemical can accumulate in sediments, soils and, potentially, in biota (for more detail see Appendix A). The physico-chemical data for drilling chemicals are presented in Table 3.1.

| CAS RN | Chemical name | Кос | DT50 | H Ba m2/mal |
|------------|---|-----------------------|------|------------------------|
| | | | | Fa-1113/11101 |
| СВІ | 2-Ethylhexanol heavies | 485.00 | 17 | 2.6845 |
| 107-22-2 | Ethanedial | 0.02 | 30 | 0.0003 |
| 111-30-8 | Pentanedial (glutaraldehyde) | 0.66 | 30 | - |
| 144-55-8 | Carbonic acid, monosodium salt | 0.0001 | - | - |
| СВІ | Ester alcohol | - | 30 | - |
| 64-17-5 | Ethanol | 0.73 | 17 | 0.5065 |
| 64742-47-8 | Distillates, petroleum, hydrotreated light | 1.34 x10 ⁶ | - | - |
| 67-56-1 | Methanol | 0.24 | 17 | 0.4609 |
| 67-63-0 | 2-Propanol | 1.87 | 30 | 0.8205 |
| СВІ | Organic acid salt | 1 870* | - | - |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | 0.02 | 90 | 4.38x10 ⁻⁰⁹ |
| СВІ | Polymer with substituted alkylacrylamide salt | 0.22 | - | 0.0002 |

| CAS RN | Chemical name | Кос | DT50 | H Pa-m3/mol |
|--------|---------------|------------------------|------|----------------|
| СВІ | Polymer II | 8.32 x10 ¹⁶ | - | - |

* Value estimated using Catalogic (KOWWINTM) but is regarded as an estimate as the chemical is a surfactant. Highlighted cells = the modelling results suggest these chemicals can accumulate in sediment, soils and potentially in biota. Blank cells = information is unavailable.

For hydraulic fracturing, 30 chemicals had data for at least one parameter (Koc, DT50, or H), 14 had both Koc and DT50 values, while 11 had data for all three. Also, the modelling results suggest that three hydraulic fracturing chemicals have very high Koc values, which is an indication that the chemical can accumulate in sediments, soils and potentially in biota (for more detail see Appendix A). These results are presented in Table 3.2.

| CAS RN | Chemical name | Кос | DT50 | H Pa- m ³ /mol |
|------------|---|-------------------------|------|------------------------------|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | 0.61 | - | - |
| 107-21-1 | 1,2-Ethanediol | 0.06 | 17 | 0.006 |
| 108-10-1 | 2-Pentanone, 4-methyl- | 17.60 | 30 | 13.979 |
| 111-76-2 | Ethanol, 2-butoxy- | 5.43 | 17 | 0.162 |
| 111-90-0 | Ethanol, 2-(2-ethoxyethoxy)- | 0.25 | 30 | 0.002 |
| 141-43-5 | Ethanol, 2-amino- | 0.04 | 30 | - |
| 144-55-8 | Carbonic acid, monosodium salt | 0.0001 | - | - |
| 26062-79-3 | 2-Propen-1-aminium, N,N-dimethyl-N-2- propenyl-, chloride, homopolymer | 0.004 | - | - |
| 26172-55-4 | 3(2H)-Isothiazolone, 5-chloro-2-methyl- | 0.46 | - | - |
| 2634-33-5 | 1,2-Benzisothiazol-3(2H)-one | 4.23 | 30 | - |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | 0.15 | 30 | - |
| 52-51-7 | 1,3-Propanediol, 2-bromo-2-nitro- | 0.23 | 30 | 1.34 x10 ⁻⁶ |
| 56-81-5 | 1,2,3-Propanetriol | 0.02 | 30 | 0.002 |
| СВІ | Amine salt | - | 30 | - |
| СВІ | Inner salt of alkyl amines | 4.74 | - | - |
| СВІ | Ethoxylated fatty acid I | 0.008 | - | - |
| СВІ | Ethoxylated fatty acid II | 2.78 x10 ^{16*} | - | - |
| СВІ | Ethoxylated fatty acid III | 1 440 | - | - |
| 6381-77-7 | D-Erythro-hex-2-enonic acid, .gamma lactone, monosodium salt | - | 17 | - |
| 6410-41-9 | 2-Naphthalenecarboxamide, N-(5-chloro- 2,4-dimethoxyphenyl)-4-[[5- [(diethylamino)sulfonyl]-2- methoxyphenyl]azo]-3-hydroxy- | - | 360 | - |
| 64-17-5 | Ethanol | 0.74 | 17 | 0.5065 |
| 64-19-7 | Acetic acid | 0.68 | 17 | 0.010 |

Table 3.2 Hydraulic fracturing chemicals with Koc, DT50 and H values

| CAS RN | Chemical name | Кос | DT50 | H Pa- m³/mol |
|------------|---|------------------------|------|-----------------|
| 67-56-1 | Methanol | 0.20 | 17 | 0.4609 |
| 67-63-0 | 2-Propanol | 1.35 | 30 | 0.8205 |
| 68439-45-2 | Alcohols, C6-12, ethoxylated | 26* | - | - |
| 68647-72-3 | Terpenes and terpenoids, orange oil | 5.56 x10 ⁴ | - | - |
| СВІ | Quaternary amine | 1.44 | - | 10.535 |
| 75-57-0 | Methanaminium, N,N,N-trimethyl-, chloride | 7.76 x10 ⁻⁵ | - | - |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | 0.02 | 90 | 4.38 x109 |
| 81741-28-8 | Phosphonium, tributyltetradecyl-, chloride | 2.35 x10 ⁵ | - | - |

* Value estimated using Catalogic (KOWWINTM) but is regarded as an estimate as the chemical is a surfactant. Highlighted cells = the modelling results suggest these chemicals can accumulate in sediment, soils and potentially in biota. Blank cells = information is unavailable.

3.1.2 Chemical ecotoxicity endpoints

Aquatic ecotoxicity endpoints were available for 59 of the 113 chemicals identified as being used for coal seam gas extraction in Australia. There were no aquatic ecotoxicity endpoints available for the remaining 54 chemicals. There were no terrestrial ecotoxicity endpoints available for any of the 113 chemicals so it was not possible to assess risk to soil-dwelling organisms such as earthworms.

3.1.2.1 Surface aquatic ecosystems endpoints

The potential concerns to surface ecosystems are only considered for aquatic receptors, as terrestrial ecotoxicity endpoints were not available to assess potential concerns to terrestrial environmental receptors.

The search for ecotoxicity data focussed on the QSAR Toolbox database which compiles available study data. Where actual data were not available for a given chemical, modelled ecotoxicity data were obtained using QSAR, which extrapolates from the known properties of other functionally similar chemicals (see Appendix A). There are limitations to this method and it is generally only applicable to organic chemicals. Inorganic chemicals cannot be modelled in this manner. There are also limitations to the application of this method for mixtures, natural substances and polymers.

Aquatic ecotoxicity results were modelled for 15 of the 29 organic chemicals. Chemicals in other categories were unsuited or had limited suitability for the application of the QSAR approach.

Of the 113 chemicals, aquatic ecotoxicity data or modelled ecotoxicity endpoints were available for 59 of the chemicals (see tables 3.3 and 3.4). These were:

- 23 drilling chemicals
- 46 hydraulic fracturing chemicals
- 10 chemicals were used in both activities.

| CAS RN | Chemical Name | Data source | Ecotoxicity endpoint type (species) | Ecotoxi city endpoi nt value (mg/L) | Assessme nt factor (AF) | PNEC (mg/L) |
|----------------|--|----------------|--|--|-------------------------------|----------------|
| СВІ | 2-Ethylhexanol heavies | Modelled | Acute Algae | 14.1 | 100 | 0.14 |
| 107-22-2 | Ethanedial/glyoxal | Measure d | Acute Fish | 215 | 100 | 2.15 |
| 111-30-8 | Pentanedial/Glutarald ehyde | Measure d | Chronic <i>Daphnia</i> | 2.1 | 10 | 0.21 |
| 11138-66- 2 | Xanthan gum | Measure d | Acute Fish | 420 | 1 000 | 0.42 |
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | Measure d | Acute Fish | 356 | 1 000 | 0.36 |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | Measure d | Chronic <i>Daphnia</i> | 240 | 100 | 2.4 |
| 144-55-8 | Carbonic acid, monosodium salt | Measure d | Chronic <i>Daphnia</i> | 576 | 100 | 5.76 |
| СВІ | Ester alcohol | Measure d | Acute Algae | 18.4 | 100 | 0.18 |
| 497-19-8 | Carbonic acid, disodium salt | Measure d | Chronic <i>Daphnia</i> | 424 | 100 | 4.24 |
| 64-17-5 | Ethanol | Measure d | Chronic <i>Daphnia</i> | 7 800 | 10 | 780 |
| 64742-47- 8 | Distillates, petroleum, hydrotreated light | Modelled | Acute Daphnia | 0.018 | 100 | 0.0001 8 |
| 67-56-1 | Methanol | Measure d | Chronic <i>Daphnia</i> | 32 000 | 10 | 3200 |
| 67-63-0 | 2-Propanol | Measure d | Chronic Daphnia | 5 000 | 10 | 500 |
| СВІ | Organic sulphate | Measure d | Chronic <i>Daphnia</i> | 0.37 | 10 | 0.037 |
| СВІ | Organic acid salt | Modelled | Acute Algae | 13 | 100 | 0.13 |
| 7447-40-7 | Potassium chloride (KCl) | Measure d | Chronic Daphnia | 373 | 100 | 3.73 |
| 7757-83-7 | Sulfurous acid, disodium salt | Measure d | Chronic <i>Daphnia</i> | 3 780 | 100 | 37.8 |
| 7758-16-9 | Diphosphoric acid, disodium salt | Measure d | Acute Algae | 63 | 1 000 | 0.06 |
| 7778-80-5 | Sulfuric acid, dipotassium salt | Measure d | Acute Fish | 680 | 1 000 | 0.68 |
| 77-92-9 | 1,2,3- Propanetricarboxylic acid, 2-hydroxy- | Measure d | Chronic Daphnia | 153 | 10 | 15.3 |

 Table 3.3 Drilling chemicals with aquatic ecotoxicity data

| CAS RN | Chemical Name | Data source | Ecotoxicity endpoint type (species) | Ecotoxi city endpoi nt value (mg/L) | Assessme nt factor (AF) | PNEC (mg/L) |
|-----------|---|----------------|--|--|-------------------------------|----------------------------|
| СВІ | Polymer with substituted alkylacrylamide salt | Modelled | Algae | 0.397 | 100 | 0.0039 7 |
| 9000-30-0 | Guar gum | Measure d | Acute Fish | 218 | 1 000 | 0.22 |
| СВІ | Polymer II | Modelled | Acute Fish | 9.06 x10 ¹² | 100 | 9.06 x 10 ¹⁴ |

| Table 3.4 | Hydraulic | fracturing | chemicals | with aquatic | ecotoxicity |
|-----------|-----------|------------|-----------|--------------|-------------|
|-----------|-----------|------------|-----------|--------------|-------------|

| CAS RN | Chemical Name | Data source | Ecotox endpoint type (species) | Ecotox endpoi nt value (mg/L) | Assessme nt factor (AF) | PNEC (mg/L) |
|----------------|--|----------------|---|---|-------------------------------|----------------|
| 10043-35- 3 | Boric acid (H ₃ BO ₃) | Measured | Chronic Fish | 2.1 | 100 | 0.021 |
| 10043-52- 4 | Calcium chloride (CaCl ₂) | Measured | Chronic <i>Daphnia</i> | 920 | 100 | 9.2 |
| 107-21-1 | 1,2-Ethanediol | Measured | Chronic <i>Daphnia</i> | 100 | 10 | 10 |
| 108-10-1 | 2-Pentanone, 4- methyl- | Measured | Chronic <i>Daphnia</i> | 7.8 | 10 | 0.78 |
| 111-76-2 | Ethanol, 2-butoxy- | Measured | Chronic <i>Daphnia</i> | 1 000 | 10 | 100 |
| 111-90-0 | Ethanol, 2-(2- ethoxyethoxy)- | Modelled | Acute Algae | 3 393 | 100 | 33.9 |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | Measured | Chronic <i>Daphnia</i> | 240 | 100 | 2.4 |
| 141-43-5 | Ethanol, 2-amino- | Measured | Chronic <i>Daphnia</i> | 0.85 | 10 | 0.09 |
| 144-55-8 | Carbonic acid, monosodium salt | Measured | Chronic <i>Daphnia</i> | 576 | 100 | 5.76 |
| 26172-55- 4 | 3(2H)-Isothiazolone, 5-chloro-2-methyl- | Measured | Acute Algae | 0.062 | 100 | 0.00062 |
| 2634-33-5 | 1,2-Benzisothiazol- 3(2H)-one | Modelled | Acute Algae | 0.28 | 100 | 0.0028 |
| 2682-20-4 | 3-Isothiazolone, 2- methyl- | Measured | Acute Fish | 0.07 | 100 | 0.0007 |
| 497-19-8 | Carbonic acid, disodium salt | Measured | Chronic <i>Daphnia</i> | 424 | 100 | 4.24 |
| 52-51-7 | 1,3-Propanediol, 2- bromo-2-nitro- | Modelled | Acute Algae | 0.11 | 100 | 0.0011 |

| CAS RN | Chemical Name | Data source | Ecotox endpoint type (species) | Ecotox endpoi nt value (mg/L) | Assessme nt factor (AF) | PNEC (mg/L) |
|----------------|---|----------------|---|---|-------------------------------|----------------|
| 55566-30- 8 | Phosphonium, tetrakis(hydroxymethy l)-, sulfate (2:1) (salt) | Measured | Acute Fish | 94 | 100 | 0.94 |
| 56-81-5 | 1,2,3-Propanetriol | Modelled | Acute Algae | 10 798 | 100 | 108 |
| СВІ | Amine salt | Measured | Acute Algae | 0.19 | 100 | 0.0019 |
| СВІ | Inner salt of alkyl amines | Modelled | Acute Algae | 211 | 100 | 2.11 |
| СВІ | Ethoxylated fatty acid | Measured | Acute Algae | 2.2 | 100 | 0.022 |
| СВІ | Ethoxylated fatty acid | Measured | Acute Daphnia | 5 | 100 | 0.05 |
| СВІ | Ethoxylated fatty acid | Modelled | Acute Algae | 7.1 | 100 | 0.071 |
| 6381-77-7 | D-Erythro-hex-2- enonic acid, .gamma lactone, monosodium salt | Measured | Acute Algae | 1 020 | 100 | 10.2 |
| 6410-41-9 | 2- Naphthalenecarboxa mide, N-(5-chloro-2,4- dimethoxyphenyl)-4- [[5- [(diethylamino)sulfonyl]-2- methoxyphenyl]azo]- 3-hydroxy- | Modelled | Acute Daphnia | 0.0014 | 100 | 0.00001 |
| 64-17-5 | Ethanol | Measured | Chronic Daphnia | 7 800 | 10 | 780 |
| 64-19-7 | Acetic acid | Measured | Chronic <i>Daphnia</i> | 150 | 10 | 15 |
| 67-56-1 | Methanol | Measured | Chronic <i>Daphnia</i> | 32 000 | 10 | 3 200 |
| 67-63-0 | 2-Propanol | Measured | Chronic <i>Daphnia</i> | 5 000 | 10 | 500 |
| 68187-17- 7 | Sulfuric acid, mono- C_{6-10} -alkyl esters, ammonium salts | Measured | Acute Daphnia | 33 | 100 | 0.33 |
| 68439-45- 2 | Alcohols, C ₆₋₁₂ , ethoxylated | Measured | Sub-chronic Fish | 4.87 | 50 | 0.1 |
| 68647-72- 3 | Terpenes and terpenoids, orange oil | Modelled | Acute Daphnia | 0.24 | 100 | 0.0024 |
| 7447-40-7 | Potassium chloride (KCl) | Measured | Chronic <i>Daphnia</i> | 373 | 100 | 3.73 |

| CAS RN | Chemical Name | Data source | Ecotox endpoint type (species) | Ecotox endpoi nt value (mg/L) | Assessme nt factor (AF) | PNEC (mg/L) |
|----------------|--|----------------|---|---|-------------------------------|----------------|
| СВІ | Quaternary amine | Modelled | Acute Daphnia | 20.9 | 100 | 0.21 |
| 75-57-0 | Methanaminium, N,N,N-trimethyl-, chloride | Measured | Acute Fish | 462 | 100 | 4.62 |
| 7647-01-0 | Hydrochloric acid | Measured | Chronic <i>Daphnia</i> | 62 | 10 | 6.2 |
| 7647-14-5 | Sodium chloride (NaCl) | Measured | Chronic <i>Daphnia</i> | 314 | 100 | 3.14 |
| 7681-52-9 | Hypochlorous acid, sodium salt | Measured | Acute Fish | 0.023 | 1 000 | 0.00002 3 |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | Measured | Acute Daphnia | 92 | 100 | 0.92 |
| 7757-82-6 | Sulfuric acid, disodium salt | Measured | Chronic <i>Daphnia</i> | 653 | 10 | 65.3 |
| 7757-83-7 | Sulfurous acid, disodium salt | Measured | Chronic <i>Daphnia</i> | 3 780 | 100 | 37.8 |
| 7758-19-2 | Chlorous acid, sodium salt | Measured | Acute Daphnia | 0.063 | 100 | 0.00006 3 |
| 7775-27-1 | Peroxydisulfuric acid, disodium salt | Measured | Chronic <i>Daphnia</i> | 10 | 100 | 0.1 |
| 7783-20-2 | Sulfuric acid, diammonium salt | Measured | Chronic Fish | 11 | 100 | 0.11 |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | Measured | Acute Fish | 2 120 | 1 000 | 2.12 |
| 77-92-9 | 1,2,3- Propanetricarboxylic acid, 2-hydroxy- | Measured | Chronic Daphnia | 153 | 10 | 15.3 |
| 81741-28- 8 | Phosphonium, tributyltetradecyl-, chloride | Modelled | Acute Daphnia | 16.8 | 1 000 | 0.017 |
| 9000-30-0 | Guar gum | Measured | Acute Fish | 218 | 1 000 | 0.22 |

3.1.2.2 Applicability of the derived PNECs

The approach used here to estimate the PNEC is consistent with the ANZECC and ARMCANZ (2000) and OECD (1995a and 2007e) principles of risk assessment for chemicals. The derived PNEC is used for the protection of all the species within an ecosystem during a short exposure period. This study did not consider long-term exposure (e.g. decades) and related effects (e.g. endocrine disruption). Long-term exposure (and related effects) arises from slow releases of chemicals over extended period.

Modelling of long-term exposure (i.e. chemicals infiltration to subsurface environment and slow releases over longer periods (i.e. years)) was considered in Mallants et al. (2017b and

2017c). However, the potential effects from the resulting exposure to low chemical concentrations over the long term have not been determined because the current testing regime is largely based on short-term exposure and the results of short-term tests cannot be reliably extrapolated to predict long-term effects (Caldwell et al. 2008; Myers et al. 2011; US EPA 2014a).

Assessment factors can be used when methodologies are not available to estimate the concern from particular types of effects. The safety factors used under this approach provide protection for acute and sub-chronic affects arising from short-term exposure only (OECD 2002c). These safety factors are not protective of endocrine-disrupting effects as indicated by OECD (2002c) and demonstrated by the Caldwell et al. (2010) study where a much larger safety factor was needed for an endocrine-disrupting chemical. In addition, it is unknown if these safety factors provide protection for other effects such as mixture toxicity effects. For these reasons future assessments should investigate the appropriate values that can provide protection for effects such as endocrine disruption and mixture toxicity.

More detail on how the PNECs were derived is provided at Appendix A.

3.1.3 Limitations to the available data

3.1.3.1 Terrestrial/sediment ecotoxicity endpoints

No measured terrestrial or sediment ecotoxicity endpoints were found for any of the 113 chemicals so it was not possible to assess risk to soil-dwelling organisms such as earthworms.

3.1.3.2 Biodegradation data

Biodegradation studies are only applicable to organic chemicals and are not applicable to inorganic chemicals. Biodegradation studies also have limited applicability and are not routinely conducted for mixtures, natural chemicals and polymers.

3.1.3.3 Subsurface aquatic ecosystems endpoints

Ecotoxicity endpoints for groundwater organisms are not available for any of the 113 chemicals as groundwater organisms have not yet been accepted internationally for regulatory risk assessment purposes.

3.1.3.4 Physico-chemical data gaps

Studies on partitioning between *n*-octanol and water are conducted on discrete neutral organic chemicals (Schwarzenbach et al. 2003)). Of the 113 chemicals considered in this risk assessment, there were 38 such chemicals for which *n*-octanol / water partition data were available.

3.1.3.5 Ecotoxicity data gaps

Of the 113 chemicals considered in this risk assessment, 54 chemicals (Table 3.5) did not have aquatic ecotoxicity data. These chemicals included:

- 21 drilling chemicals
- 37 hydraulic fracturing chemicals
- 4 chemicals common to both uses.

| CAS RN | Chemical | Associated with drilling or hydraulic fracturing |
|-----------------|---|---|
| 1302-78-9 | Bentonite | Drilling |
| 1303-96-4 | Borax (Na ₂ (B4O ₇).10H ₂ O) | Drilling; Hydraulic fracturing |
| 1317-65-3 | Limestone | Drilling |
| CBI | Fatty acids ester | Drilling |
| 14464-46-1 | Cristobalite (SiO ₂) | Drilling; Hydraulic fracturing |
| 14808-60-7 | Quartz (SiO ₂) | Drilling; Hydraulic fracturing |
| 15468-32-3 | Crystalline silica, tridymite | Drilling |
| СВІ | Polymer with substituted alkylacrylamide salt | Drilling |
| CBI | Polymer I | Drilling |
| 7727-43-7 | Sulfuric acid, barium salt (1:1) | Drilling |
| 9003-06-9 | 2-Propenoic acid, polymer with 2- propenamide | Drilling |
| CBI | Polysaccharide | Drilling |
| CBI | Natural fibres | Drilling |
| n.s.1 | Cedar fibre | Drilling |
| n.s.2 | Pecan hulls | Drilling |
| n.s.3 | Almond hulls | Drilling |
| n.s.4 | Polyanionic cellulose PAC | Drilling |
| n.s.5 | Polyesters | Drilling |
| n.s.6 | Walnut hulls | Drilling; Hydraulic fracturing |
| n.s.7 | Wood dust | Drilling |
| n.s.8 | Wood fibre | Drilling |
| 12008-41-2 | Boric acid, $(H_2B_8O_{13})$, disodium salt | Hydraulic fracturing |
| 124-38-9 | Carbon dioxide | Hydraulic fracturing |
| 10377-60-3 | Nitric acid, magnesium salt | Hydraulic fracturing |
| 1305-78-8 | Calcium oxide | Hydraulic fracturing |
| 144588-68- 1 | Sintered bauxite | Hydraulic fracturing |
| 14807-96-6 | Talc (Mg ₃ H ₂ (SiO ₃) ₄) | Hydraulic fracturing |
| 14808-60-7 | Quartz (SiO ₂) | Hydraulic fracturing |
| 25038-72-6 | 2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene | Hydraulic fracturing |
| 26038-87-9 | Boric acid (H_3BO_3), compound with 2- aminoethanol | Hydraulic fracturing |
| 26062-79-3 | 2-Propen-1-aminium, N,N-dimethyl-N-2- propenyl-, chloride, homopolymer | Hydraulic fracturing |
| CBI | Enzyme | Hydraulic fracturing |

Table 3.5 Drilling and hydraulic fracturing chemicals that did not have aquatic ecotoxicity data

| CAS RN | Chemical | Associated with drilling or hydraulic fracturing |
|-----------------|--|--|
| 533-96-0 | Carbonic acid, sodium salt (2:3) | Hydraulic fracturing |
| 584-08-7 | Carbonic acid, dipotassium salt | Hydraulic fracturing |
| 68130-15-4 | Guar gum, carboxymethyl 2-hydroxypropyl ether, sodium salt | Hydraulic fracturing |
| CBI | Terpenes and terpenoids | Hydraulic fracturing |
| 7631-86-9 | Silica | Hydraulic fracturing |
| 7727-37-9 | Nitrogen | Hydraulic fracturing |
| 7772-98-7 | Thiosulfuric acid ($H_2S_2O_3$), disodium salt | Hydraulic fracturing |
| 9000-70-8 | Gelatins | Hydraulic fracturing |
| CBI | Polyamine | Hydraulic fracturing |
| 9003-05-8 | 2-Propenamide, homopolymer | Hydraulic fracturing |
| 9004-62-0 | Cellulose, 2-hydroxyethyl ether | Hydraulic fracturing |
| 9012-54-8 | Cellulase | Hydraulic fracturing |
| 9025-56-3 | Hemicellulase | Hydraulic fracturing |
| 90622-53-0 | Alkanes, C_{12-26} branched and linear | Hydraulic fracturing |
| 91053-39-3 | Kieselguhr, calcined | Hydraulic fracturing |
| 102-71-6 | Ethanol, 2,2',2''-nitrilotris | Hydraulic fracturing |
| 112926-00- 8 | Silica gel, precipitated, crystalline free | Hydraulic fracturing |
| 127-09-3 | Acetic acid, sodium salt | Hydraulic fracturing |
| 463-79-6 | Carbonic acid | Hydraulic fracturing |
| 64-02-8 | Glycine, N,N'-1,2-ethanediylbis[N- (carboxymethyl)-, tetrasodium salt | Hydraulic fracturing |
| 67-48-1 | Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, chloride | Hydraulic fracturing |
| 7722-84-1 | Hydrogen peroxide (H ₂ O ₂) | Hydraulic fracturing |

These 54 chemicals were subjected to an intensive process to compile, analyse and interpret the available scientific literature using a qualitative approach (see Sections 4 and 5).

3.2 Exposure characterisation of chemicals using the deterministic risk assessment approach

The exposure characterisation of chemicals under the deterministic risk assessment approach uses a tiered approach, as outlined in Section 2.

For Tier 1, a hypothetical well site anywhere in Australia is considered. Tier 2 assessments are considered in the context of two of the six bioregions (Sydney Basin and Northern Inland Catchments). For Tier 2, a working site representative of each bioregion is considered. Tier 3 considered working sites or storage areas at specific sites within the relevant bioregion. The description of the tiers is based on assessment location as shown in Table 3.6.

| Tie r | Application | Assessment Location |
|----------|---|--|
| 1 | Australia wide assessment | Generic |
| 2 | Bioregional assessment | Northern Sydney Basin (NSB) Bioregion Northern Inland Catchments (NIC) Bioregion |
| 3 | Working Site or Storage Site specific assessment within a Bioregion | Working Site 1 NSB Bioregion Working Site 2 NIC Bioregion Working Site 3 NIC Bioregion Working Site 4 NIC Bioregion Working Site 5 NIC Bioregion Storage Area 6 NIC Bioregion |

Table 3.6 Tiered approach for exposure characterisation

3.2.1 Points of release (Tiers 1 to 3): treatment and assumptions

Under the deterministic risk assessment approach, a coal seam gas working site is categorised on the basis of the chemical lifecycle. The data provided by industry were reviewed and compared to the conceptualised coal seam gas chemical lifecycle, to determine the potential points of release relevant for this assessment. The following release points were included for all tiers, except where noted:

- Accidental release of chemical during transportation:
 - while being transported from city warehouse to an intermediate storage facility near the well sites (under Tier 1 only)
 - while being transported from intermediate storage facility to the operational coal seam gas well site storage area
- Accidental release of chemical during storage:
 - while stored at an intermediate storage facility near a well site
 - while stored at the coal seam gas well site
 - the storage of flowback and / or produced water within the larger coal seam gas working site
- Accidental release of chemical during use and management:
 - while being used (injection) at the coal seam gas well site
 - while managing flowback and / or produced water at the coal seam gas well site
- Intentional release of chemical in flowback and / or produced water:
 - via dust suppression within the coal seam gas working site
 - via irrigation (outside of the coal seam gas working site)

A single-release scenario was assessed for each potential point of release during drilling and hydraulic fracturing. Multiple-release scenarios were also assessed for chemical storage at an intermediate facility or well site, chemical use at the well sites and during the management of flowback and / or produced water. In some instances (see Section 3.3.3.2), a point of release was not included in the assessment because the data showed that it was not

relevant to the particular coal seam gas working site being assessed or the data were not available.

Both direct and indirect releases to an aquatic receptor were considered as both are possible exposure pathways. For other release points, only indirect release was considered because direct releases to an aquatic receptor were considered to be an improbable exposure pathway for those release points. 'Storage of waste', 'dust suppression' and 'irrigation' were not applicable to the lifecycle of a drilling chemical within a coal seam gas working site and, therefore, were not assessed.

Releases of flowback and / or produced waters were assessed for:

- hydraulic fracturing chemicals under four points of release (waste management, waste storage, irrigation and dust suppression)
- drilling chemicals under one point of release (waste management) because these chemicals are normally recycled before the wastewaters are sent to the storage dams.

Information on chemical concentration, composition, absorption or degradation in flowback and produced waters was not available. Thus, it was assumed that 100%, 90% and 50% (Tiers 1, 2, and 3, respectively, following the guidance principle outlined in the US EPA *Framework for ecological risk assessment*) of the hydraulic fracturing chemicals injected are recovered from the flowback and produced waters extracted from the wells and stored in storage dams (degradation and / or sorption are not included in the calculations of the PECs).

Information on chemical compositions, concentrations and the quantities of salt extracted from flowback and produced waters were not available. Therefore, a risk assessment could not be undertaken.

Data on the sources (and number of wells) feeding the storage dams and the volume produced by the wells were provided by the industry data for higher tier assessment and were therefore included in the assessment.

3.2.2 Estimating quantities (Q) from each point of release

Initially the chemical quantity released (Q) from the identified points of release (transport, storage at intermediate site, storage and use at well site) was based on the industry survey (NICNAS 2017). Additional information on the use of 23 of the 113 chemicals was provided by industry in May and June 2015 to better inform the assessment of the environmental risks. This information 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.

The chemical information was requested for chemicals transported to intermediate and well site storages where well sites were within 2 km of an aquatic receptor or its surrounding habitat. A 2 km radius was selected based on the estimated distance for chemicals' concentrations to decrease to equivalent to the modelled limits of detection or to background levels (Mallants et al. 2017b and 2017c; NICNAS 2017c). Additional data were provided by industry describing the quantities and concentrations of chemicals, transported, stored and used at each site within 2 km of an aquatic receptor.

From these data, information on:

- Quantity transported and stored, concentration, container type and size were extracted for each chemical. Data were provided in a range of formats and levels of completeness.
- Where available, values were extracted for highest, high-end, average and lowest quantities.
- In cases where the quantity data provided were incomplete, volumes (litres or kilograms) were calculated based the container type, sizes and number transported or stored.
- Data were compared across industry to identify any outliers to be further queried and potentially excluded from the assessment.
- Where data gaps were identified, a generic value was adopted, preferably from within the same bioregion.
- Concentrations were converted to units of g/L or g/kg for consistency.
- Chemicals in the liquid and solid states were considered in the assessment of 'Transport-Indirect release', 'Intermediate warehouse', and 'Well site' points of release with the following assumptions:
 - Tier 1: i = 1 for liquids and i = 0.5 for solids (bounding estimate)
 - Tier 2: i = 0.90 for liquids and i = 0.45 for solids (high-end estimates)
 - Tier 3: i = 0.5 for liquids and i = 0.25 for solids (central tendency estimate)

Where i = is the proportion of chemical spilled. The chemical state at the time of a spill influences the portion recovered or lost during spillages.

- Liquid chemicals are considered in the assessment of 'Transport-Direct release', 'Use at well site', 'Waste management', 'Waste storage', 'Irrigation' and 'Dust suppression' using the following assumptions:
 - Tier 1: i = 1 (bounding estimate)
 - Tier 2: i = 0.9 (high-end estimates)
 - Tier 3: i = 0.5 (central tendency estimate).

The selections of the above values are based on the US EPA (2004c) principle for tiered risk assessment. Specific data treatments for well sites 1 to 5 and storage area 6 are presented in Appendix B.

3.2.3 Chemical fate pathways

The main transfer pathway considered in this assessment (Tiers 1 to 3) is runoff. Runoff modelling was used for calculating the PECs at the end of the runoff field and before entering into the aquatic receptors. Other transfer pathways (degradation, partitioning, sedimentation and volatilisation) were used during Tier 2 and Tier 3 assessments for calculating PECs for mass-balance and mitigation purposes (see Appendix B).

Infiltration into deeper groundwater is outside the scope of this assessment. Infiltration into shallow groundwater was considered by the CSIRO (Mallants et al. 2017b and 2017c). The CSIRO also estimated the corresponding concentration factors in the receiving subsurface and surface environments.

3.2.3.1 Terrestrial receptors and runoff calculations

Data on the soil types and slope of the terrain were not available for each bioregion. Therefore, standard values obtained from the literature were used in the runoff model. Tier 2 used the same values as Tier 1 except with a reduced land surface slope. At Tier 3 the values for land surface slope and daily precipitation represented the working site and the influence of vegetation buffering and surface heterogeneity within the area.

Chemical fate and behaviour in the runoff is considered through the use of physico-chemical data (see Section 3.1.2). For the other chemicals with no physico-chemical data, it is assumed that there is no degradation and / or partitioning to other environmental compartments, using a conservative approach when data are lacking.

3.2.3.2 Cadastre area for calculating the uncontaminated runoff

The values used in Tiers 2 and 3 are presented in Table 3.7. Further explanation of the runoff area estimates is provided in Appendix B.

| Area contributing runoff to aquatic receptor (ha) | | | | | | | |
|--|------|---------|--------|--------|-------------------|--|--|
| Working Site 1Working Site 2Working Site 3Working Working Site 4W | | | | | Working Site 5 | | |
| Tier 2 single well | 8.5 | 965 | 965 | 965 | 965 | | |
| Tier 2 multiple wells | 34.2 | 6 4654 | 6 4654 | 6 4654 | 6 4654 | | |
| Tier 3 single well | 8.5 | 112 612 | 1 065 | 25.3 | 6 729 | | |
| Tier 3 multiple wells | 34.2 | 563 059 | 56 433 | 126 | 26 917 | | |

Table 3.7 Area contributing runoff to aquatic receptor

*Cadastre area is used to estimate the uncontaminated runoff

3.2.4 Environmental receptors

3.2.4.1 Aquatic receptor selection and characteristics

The approach described in Section 2.4.1.3 was applied in the selection of the aquatic receptors for Tier 2 and Tier 3 assessments. The following websites were used to source observation station⁹ data for selected rivers:

- Real-Time Water Data, NSW Government (http://waterinfo.nsw.gov.au)
- Real-Time Water Data, Queensland Government (http://watermonitoring.derm.qld.gov.au/host.htm)
- Hydrologic Reference Stations, Bureau of Meteorology, Australian Government. (http://www.bom.gov.au/water/hrs/index.shtml#panel=data-download&id=922101B).

All available historical records of daily stream discharge (ML/day) and daily rainfall (mm/day) data were extracted from the relevant databases.

⁹ The role of the observation station is to record daily data (such as rivers gauge height, temperature and rainfall).

The selection of aquatic receptors for each bioregion was identified using GIS datasets and a mapping tool. The final selection of aquatic receptors was limited by the availability of long-term data.

3.2.4.2 Tier 1 – Australia wide assessment

Environmental aquatic receptor volumes were estimated for each tier of assessment. At Tier 1 the aquatic receptor volume was chosen as 1.5 ML.

3.2.4.3 Tier 2 – bioregional assessment

Data were derived from observation stations, which are typically located on major perennial rivers, and rarely, if at all, on ephemeral or other minor rivers, creeks or springs. For this reason, the final selected rivers (aquatic receptors) were determined by the observation station in closest proximity to a well site or well site area (group of well sites). The river selections for each bioregion for Tier 2 assessment are presented in Table 3.8.

These data were then treated to represent the minor rivers, creeks or springs that may be located near the operational coal seam gas sites (storage areas and well site) by estimating the 25th percentile of mean daily flows exceeding 1.5 ML/d (as Tier 1 already covered the most conservative scenario). This was calculated for all representative streams in the bioregion and the lowest value of 6.7 ML was used. This value was used in the estimation of PECs for risk characterisation in each bioregion (see Section 3.2.1).

| Northern Inland Catchments | Sydney Basin |
|----------------------------|------------------|
| Condamine River | Wyong River |
| Moonie River | Gloucester River |
| Weir River | Karuah River |
| Bohena Creek | |

Table 3.8 The final selection of rivers in each bioregion

3.2.4.4 Tier 3 – site-specific assessment

For Tier 3, all well sites included in the assessment were located within 2 km of a minor river or creek (Table 3.9). This was established using GIS datasets and a mapping tool.

| Company | Well site names | Closest minor waterway/s | Basin | | |
|-------------|-----------------|---|---------------|--|--|
| Well site 1 | A11 | Various unnamed | Manning River | | |
| | A12 | creeks, Avon River | Basin | | |
| | A13 | Waukivory Creek | | | |
| | A14 | | | | |
| | A05* | | | | |
| Well site 2 | B06 | Various unnamed | Fitzroy Basin | | |
| | B08 | creeks, Blackwater Creek, Saline Creek, | | | |

Table 3.9 Minor creeks and rivers in closest proximity to each individual well site or well site area

| Company | Well site names | Closest minor waterway/s | Basin |
|-------------|-----------------|----------------------------------|---------------|
| | | Dawson River | |
| | B32 | JB Gully, | Fitzroy Basin |
| | B33 | North Creek | |
| | B34 | | |
| Well site 3 | Group A | | |
| | C140 | Various unnamed | Fitzroy Basin |
| | C104 | Creeks, | |
| | C110 | Bluff Creek | |
| | C075 | Western Creek | |
| | C076 | Eurombah Creek | |
| | C074 | Kurrajong Gully | |
| | C073 | - Pear Gully Slate Hill Creek | |
| | C077R | Scotchy Creek | |
| | C113 | | |
| | C112 | | |
| | C375 | | |
| | C376 | | |
| | C120 | | |
| | C140 | | |
| | C139 | | |
| | C127 | | |
| | C232 | | |
| | C374 | | |
| | C150 | | |
| | C146 | | |
| | C147 | | |
| | C363 | | |
| | C364 | | |
| | C365 | | |
| | Group B | | |
| | D84 | | Fitzroy Basin |
| | D72 | | |
| | D173 |] | |
| | D135 | | |
| | D191 | | |
| | D198 | | |

| Company | Well site names | Closest minor waterway/s | Basin |
|----------------------|-----------------|--|-----------------------------|
| | D190 | | |
| | D181 | | |
| | D189R | | |
| | D175 | | |
| | D176 | | |
| | D174 | | |
| | D182 | | |
| | D183 | | |
| | D165 | | |
| | D185 | | |
| | D179 | | |
| | D180 | | |
| | D106 | | |
| | D108 | | |
| | D107 | | |
| | D93 | | |
| | D124 | | |
| | D126 | | |
| | D94 | | |
| | D265 | | |
| | D99 | | |
| | D100 | | |
| | D102 | | |
| | Group C | | |
| | E24 | | Fitzroy Basin |
| | E23 | | Fitzroy Basin |
| Well site 4 | F109 | Unnamed creeks, | Fitzroy Basin |
| | F119 | Hardknock Creek, | |
| Intermediate storage | F120 | Wandoan Creek | |
| | F129 | | |
| | F111 | | |
| Well site 5 | G3 G4 | Unnamed creeks, Jacks Creek (vicinity) | Fitzroy Basin |
| | G7, G8 | Unnamed creeks, Cottage Creek Six Mile Creek | Balonne- Condamine Basin |

| Company | Well site names | Closest minor waterway/s | Basin |
|----------------|-----------------|-----------------------------|-----------------------------|
| Storage Area 6 | H** | | Balonne- Condamine Basin |

* Drilled well

**Intermediate storage site.

The final selected rivers (aquatic receptors) were determined by the observation station in closest proximity to a well site or well site area (group of well sites). Approximate straight line distances from well site and or well site area to the selected aquatic receptor ranged from 5 km to 86 km (Table 3.10). Distances were calculated using the ArcReader measure tool to estimate distance from the observation station to the approximate centre point of each well site or well site area.

Table 3.10 Location and bioregion of selected aquatic receptors and distance to the well site or well site area

| Company | River name | Subregion | Distance (km) | No. of well / storage sites in area | Cadastre area for well and storage facility (m ²) |
|-------------------|---|--------------------------------|------------------|---|--|
| Well site 1 | Gloucester River at Gloucester | Manning River Basin | 7 | 5 | 341 800 |
| Well site 2 | Isaac River at Deverill | Fitzroy Basin | 25 | 3 | 5 630 590 00 |
| | Dawson River at Beckers | Fitzroy Basin | 5 | 1 | |
| | Mackenzie River at Bingegang | Fitzroy Basin | 15 | 1 | |
| Well site 3 | Dawson River at Utopia Downs | Fitzroy Basin | 15 - 44 | 55* | 553 110 000 |
| Well site 4 | Juandah Creek at Windamere | Fitzroy Basin | 32 | 5* | 1 263 500 |
| Well site 5 | Yuleba Creek at Forestry Station | Balonne- Condamine Basin | 46 | 2** | 269 170 000 |
| | Palm Tree Creek at La Palma | Fitzroy Basin | 86 | 2** | |
| Storage Area 6 | Rivers for other well sites located near site 2 | Balonne- Condamine Basin | | 2*** | 83 760 000 |
| | Rivers for other well sites located near site 2 | Manning River Basin | | 1* | 1870.00 |

^{*}Intermediate storage in the area. **Intermediate storage in the city. *** There are three storage facilities in the region, but only two are at closet distance.

Data (flow, dimensions, rainfall etc.) were generally only available for major perennial rivers within and across bioregions. A summary of the stream flow and rainfall records used in the Tier 3 assessment is provided in Table 3.11. Available data were used to represent various surface aquatic ecosystems (such as low, medium and high-flow minor rivers) according to

the method described in Section 3.2.4.1, and estimate PECs for risk characterisation in each bioregion (see Section 3.2.1).

At Tier 3 daily precipitation was estimated as the median value of daily rainfall (excluding zero rainfall days) at the closest observation station(s). Where multiple observation stations were considered representative of a working site, the average values of medians was used for the working site.

The number of rivers selected, the observation station numbers used for data acquisition in each site, and further details of each observation station (including site numbers, GPS coordinates and the type/s of data acquired and its source) were used to inform the risk assessment.

Table 3.11 Daily stream discharge and rainfall data for rivers selected for use in the assessment. Standard errors (SE) are given in parenthesis.

| | | Daily discharge (ML/day) | | Daily rainfall (mm/day) | | | | | |
|-------------------------------------|---|--------------------------------|---------------|----------------------------|------------|---------|-------------|---------------|------------------|
| Observation station | Catch ment area (km ²) | Mean (SE) | Min (SE) | Max (SE) | Mean (SE) | M in | M a x | Me an * | Me dia n * |
| Juandah Creek at Windamere | 1 678 | 231 (22) | 79 (9) | 434 (35) | 1.6 (0.08) | 0 | 1 5 7 | 11. 6 | 6 |
| Dawson River at Utopia Downs | 6 039 | 338 (22) | 228 (16) | 467 (28) | 1.5 (0.07) | 0 | 1 2 9 | 10. 1 | 4 |
| Isaac River at Deverill | 4 092 | 649 (49) | 288 (24) | 1107 (77) | 1.6 (0.09) | 0 | 2 3 6 | 10. 8 | 5 |
| Dawson River at Beckers | 40 500 | 2 582 (19) | 2180 (16) | 2996 (22) | 1.6 (0.09) | 0 | 4 0 0 | 11. 5 | 5 |
| Mackenzie River at Bingegang | 50 860 | 2 689 (168) | 2210 (144) | 3187 (190) | 1.3 (0.1) | 0 | 1 0 6 | 9.5 | 4.5 |
| Yuleba Creek at Forestry Station | 1 475 | 120 (9) | 77 (6) | 168 (11) | 1.4 (0.07) | 0 | 9 8 | 10. 2 | 5 |
| Palm Tree Creek at La Palma | 2 660 | 139 (7) | 92 (5) | 190 (8) | 1.7 (0.1) | 0 | 1 1 1 | 10. 3 | 5 |
| Gloucester River at Gloucester | 253 | 210 (9) | 152 (5) | 303 (14) | - | - | - | - | - |
| Mount George | - | - | - | - | 3 (0.1) | 0 | 1 4 5 | 9.3 | 3 |

* Rain days only

At Tier 3 aquatic receptor volumes were estimated from historical stream flow data of representative streams, selected as those gauged streams closest to well sites. At Tier 3

(Table 3.12), aquatic receptor volumes were estimated for lower, intermediate and upper value scenarios at each set of working sites. These were estimated as the minimum, median and maximum of mean daily flows exceeding 6.7 ML/d (used in Tier 2). Where multiple gauged streams were considered representative of a working site, the average values of those streams was used for the working site.

| | Aquatic receptor volume (ML) | | | | | | |
|------------------------|------------------------------|-------------------|-------------------|-------------------|-------------------|--|--|
| | Working Site 1 | Working Site 2 | Working Site 3 | Working Site 4 | Working Site 5 | | |
| Tier 1 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | | |
| Tier 2 | 6.7 | 6.7 | 6.7 | 6.7 | 6.7 | | |
| Tier 3 lower | 80 | 275 | 21 | 53 | 35 | | |
| Tier 3 intermediate | 86 | 311 | 22 | 74 | 42 | | |
| Tier 3 upper | 94 | 373 | 23 | 99 | 48 | | |

Table 3.12 Environmental aquatic receptor volumes estimated for each tier of assessment

3.2.4.5 Ecological receptor selection and characteristics

The approach described above (see Section 2.4.1.3) was applied in the selection of the ecological receptors in each of the bioregions considered in this risk assessment. The specific ecological receptors identified in each well site are provided in Section 3.3.4.

Northern Inland Catchments bioregion

Characteristics

The following information was obtained from the analysis of the available literature (DoEE 2017a). The Northern Inland Catchments is in the northern Murray-Darling Basin (MDB). The MDB covers 14% of Australia and contains around 440 000 km of rivers (of which 40 000 km are major rivers), some 30 000 wetlands covering an area of around 25 000 km², and about 60 000 km² of floodplain. Across the basin, 94% of rainfall evaporates, 2% drains into the ground and 4% ends up as runoff. There is considerable variation in rainfall runoff, with catchments draining the Great Dividing Range on the southeast and southern margins contributing most to total runoff.

The southern part of the MDB is mostly a regulated system. However, the northern part, including the Northern Inland Catchments bioregion, consists mostly of unregulated systems, where many of the rivers and streams are ephemeral and fed by seasonal rainfall. Alluvial sedimentary aquifers are most important for groundwater extraction, contributing to more than 95% of all the extracted groundwater. Further information on each of the major catchments within the priority area is provided below.

Soil types within the Condamine catchment are dominated by fertile black, brown, grey and red vertosols (cracking clays) and hard-setting soils with contrasting texture (sodosols). Vertosols and non-cracking clays (ferrosols, dermosols) are common on the basaltic and Walloon sandstone landscapes and alluvia derived from these areas. Texture-contrast soils (chromosols, sodosols, and kurosols) and shallow sandy soils (tenosols) are common on sandstones, granites and mixed-origin alluvia. The low fertility and moisture-holding capacity of texture-contrast soils render them mostly unsuitable for cropping, and these soils are used for forestry and grazing of native or improved pastures.

Stream flow within the Condamine catchment is highly variable and arises predominantly from unpredictable storm runoff rather than groundwater. Groundwater is used in the Condamine catchment for urban, industrial, stock and domestic water supply, and irrigation. Surface water losses to groundwater in the Condamine catchment are considered significant. This is due to large-scale groundwater extraction since the late 1960s which has contributed to a large depression in groundwater levels and a discharge from the river to groundwater. The majority of the Condamine River, its North Branch and the Oakey Creek tributary are under 'losing' conditions (where surface water infiltrates to groundwater).

The major rivers of the Queensland Border Rivers catchment (in the Northern Inland Catchments bioregion) are the Macintyre, Macquarie, Dumaresq and Severn. The Border Rivers topography includes slopes, undulating country and flat plains. In this catchment, several major water storages support irrigated agriculture on the plains. The Moonie River is nearly unregulated, with only one weir, and the topography is very flat. Land use in this catchment is dominated by grazing and dry land cropping. The floodplains of Macintyre River downstream of Goondiwindi contain large areas of intermittently connected anabranches and billabongs, including many creeks and the Morella Watercourse, Boobera Lagoon and Pungbougal Lagoon, which are listed in the Directory of Important Wetlands in Australia. These wetlands support many significant ecosystems that provide a wide range of aquatic habitats, including wildlife breeding areas and drought refuges.

In New South Wales, the Border Rivers and Gwydir catchments, like many western-draining catchments of New South Wales, Victoria and Queensland, are characterised by rivers that have highly variable flow, depending strongly on local rainfall and runoff. The main rivers of the Border Rivers and Gwydir catchments are the Gwydir, Severn, Macintyre and Barwon.

The Border Rivers-Gwydir catchment has a temperate to subtropical climate, with a considerable gradient from east (cooler and wetter, 1 200 mm annual rainfall) to west (hotter and drier, 600 mm annual rainfall). It contains distinct landform types of tablelands, slopes and plains. The vegetation varies from patches of extensively forested areas in high-altitude areas of the eastern catchment boundary, to more open forest, shrub lands and grassy plains moving westwards. Grazing is the principal agricultural enterprise on the tablelands, with a shift to cropping on the slopes. Further west to the plains there is an increasing use of irrigation, which has led to an intensification of farming enterprises.

To the south, the Namoi River joins the Barwon River at Walgett. Major tributaries of the Namoi River include Cox's Creek and the Mooki, Peel, Cockburn, Manilla, and Macdonald rivers. The freshwater environment of the Namoi catchment comprises an extensive range of aquatic habitats including swamps, floodplains, wetlands, streams and rivers. Within these broad habitat types, niche habitats such as pools and riffles, gravel beds, snags, aquatic vegetation and riparian vegetation are present, diversifying the habitat available to aquatic species. Erosion and sedimentation, loss of native trees, shrubs and grasses and invasion of weeds have all impacted on the health of streams and rivers in the Namoi catchment. Namoi groundwater resources include all unconsolidated alluvial sediment aquifers associated with the Namoi River and its tributaries. Deep bores in the lower Namoi access the Great Artesian Basin.

Ecological receptors

The following information was obtained from the Environmental Resources Information Network (ERIN) in the Department of the Environment and Energy to facilitate the identification of areas containing coal seam gas wells, and the selection of the key receptors (terrestrial and aquatic ecosystems) in each bioregion.

The Northern Inland Catchments bioregion has four subregions comprising the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions. The areas with coal

seam gas wells are mainly located in the Maranoa-Balonne-Condamine and the Namoi subregions. Here, there are many areas with available or granted coal seam gas licences within and outside the boundaries of the bioregion.

In the Maranoa-Balonne-Condamine subregion the following rivers / creeks are located near coal seam gas wells: the Condamine River, Coorauga Creek, Dogwood Creek, Wambo Creek, Wilkie Creek, Western Creek, Cabblegum Creek, Moonie River, Weir River and Yarrill Creek. In addition, the Bohena Creek and the Namoi River in the Namoi subregion pass near a tenement containing coal seam gas wells. The Gwydir and Central West subregions do not have coal seam gas wells.

The aquatic receptors linked to MNES include the Condamine River, Moonie River, Weir River, Bohena Creek, Namoi River, Wilkie Creek, Wambo Creek, Dogwood Creek, Cooranga Creek, Cabblegum Creek, Western Creek, and Yarrill Creek. However, the MNES are located at significant distances¹⁰ from coal seam gas wells.

A summary of the MNES connected to the aquatic receptors near areas containing coal seam gas wells is provided below.

Six MNES (Australian lungfish, Fleay's frog, Murray cod, Groundwater Dependent Ecosystems, threatened ecological communities, and aquatic birds) are identified in this bioregion, with the following distribution:

- The listed Murray cod may be found in the Northern Inland Catchments bioregion. This includes most areas with coal seam gas granted permits, parts of the Maranoa-Balonne-Condamine subregion and in the Namoi subregion.
- The listed Australian lungfish and Fleay's frog may be found in areas connected to the Condamine River that passes through the Maranoa-Balonne-Condamine subregion. However, these listed species are located at significant distances (greater than 2 km) from the tenements with coal seam gas wells.
- One protected community of native species dependent on natural discharge of groundwater from the Great Artesian Basin can be found in the Northern Inland Catchments bioregion. However, this community is located at significant distances from areas with coal seam gas wells.
- Protected threatened ecological communities are found in many places in the Northern Inland Catchments bioregion. Most of these communities can be found in the Maranoa-Balonne-Condamine subregion and some in Gwydir subregion. Many of these communities can be found in areas with or near to coal seam gas wells (especially in the Maranoa-Balonne-Condamine subregion).
- Protected aquatic birds may be found in many places in the Northern Inland Catchments bioregion, including in areas where coal seam gas licences have been granted and in closer proximity to the tenements with coal seam gas wells.

Seven protected Nationally Important Wetlands are identified in the Northern Inland Catchments bioregion, with the following distribution:

• Gums Lagoon is connected to the Cobblegun Creek in the Maranoa-Balonne-Condamine subregion that passes through the area with coal seam

¹⁰ Greater than 2 km, which is the estimated distance for chemicals concentrations to decrease to threshold levels (Mallants et al. 2016b and 2016c; NICNAS 2016c).

gas wells. In addition, Gums Lagoon is located near areas containing coal seam gas wells.

- Lake Broadwater, Dalrymple Creek, and Blackfellow Creek are connected to the Condamine River and Western Creek in the Maranoa-Balonne-Condamine subregion that passes through the tenements containing coal seam gas wells. In addition, Lake Broadwater, Dalrymple Creek, and Blackfellow Creek are located near tenements containing coal seam gas wells.
- Lake Goran in the Namoi subregion and the Gwydir Wetland in the Gwydir subregion are within areas where coal seam gas licences have been granted but at significant distance from coal seam gas wells.
- Other Nationally Important Wetlands are located at significant distances from the tenements containing coal seam gas wells.

Two protected Ramsar Wetlands are identified in the Northern Inland Catchments bioregion, with the following distribution:

• The Gwydir Wetland and Lower Gwydir Wetlands are within areas where coal seam gas licences have been granted but are located at significant distances from the tenements containing coal seam gas wells.

Two National Heritage places were identified in the Northern Inland Catchments bioregion with the following distribution:

- A part of a large National Heritage site (Gondwana Rainforest of Australia) is connected to the Condamine River in the Maranoa-Balonne-Condamine subregion; however, the Gondwana Rainforest is located at a significant distance from tenements containing coal seam gas wells.
- One other National Heritage site is located within areas where coal seam gas licences have been granted but at a significant distance from the tenements containing coal seam gas wells.

One World Heritage site was identified within this bioregion, with the following distribution:

• A part of a large World Heritage site (Gondwana Rainforest of Australia) is connected to the Condamine River in the Maranoa-Balonne-Condamine subregion; however, the Gondwana Rainforest is located at a significant distance from tenements containing coal seam gas wells.

Northern Sydney Basin bioregion

Characteristics

The following information was obtained from the analysis of the available literature (DoEE, 2017a).

The characteristics of the Northern Sydney Basin and Sydney Basin bioregions are considered together in this section of the report. The Northern Sydney Basin and Sydney Basin bioregions lie on the east coast and cover a large part of the catchments of the Hawkesbury-Nepean, Hunter and Shoalhaven Rivers.

The New South Wales National Parks and Wildlife Service describes the IBRA Sydney Basin bioregion as consisting of coastal landscapes of cliffs, beaches and estuaries. As in most

parts of the Great Dividing Range, the most spectacular mountain landscape is found on the coastal side of the divide along the Great Escarpment, where streams have eroded deep gorges and cliff faces back into the uplifted block. Much of the bioregion landscape is elevated sandstone plateau, the exceptions being the Hunter Valley and the low-lying Cumberland Plain.

The coastal area of the bioregion consists of frontal dunes. Dunes behind this accumulate organic matter and begin to develop coloured subsoil. The oldest dunes on the inland side of the barrier and the parabolic dunes high in the landscape, even on headlands, have well-developed podsol profiles. Limited areas of rainforest can be found in the lower Hunter, on the Illawarra escarpment and on the Robertson basalts, as well as in the protected gorges and on richer soil in most subregions. Species composition and structural form are similar on the sandy soils of the sandstone plateaus and the sandy soils of the dunes. Better quality shale soils form caps on sandstone and on the coastal ramps.

The Northern Sydney Basin and Southern Sydney Basin bioregions are dominated by a temperate climate characterised by warm summers with no dry season. A sub-humid climate occurs across significant areas in the north-east. A small area in the west around the Blue Mountains falls in a montane climate zone. Rainfall can occur throughout the year but varies across the bioregion in relation to altitude and distance from the coast, with wetter areas being closer to the coast or in higher altitudes. Mean annual rainfall varies from 522 mm to 2 395 mm. Temperature varies across the bioregions, with areas of higher temperature occurring in the coastal plain just inland from the coast and in the Hunter Valley and areas of lower temperature on the higher plateaus and western edge. The average maximum summer monthly temperature varies between 22.4 and 31.9°C while the average minimum winter monthly temperature varies between -1.4 and 8.1°C.

Many large areas within the Northern Sydney Basin and Southern Sydney Basin bioregions are still in near-pristine condition, largely due to inaccessibility and their being inappropriate for agricultural development. There are other areas, however, that have been severely modified due to the urban expanse of the greater metropolitan area of Sydney and mining practices in the Hunter region. Protection of remnant communities within the most heavily disturbed areas, such as the Cumberland Plain in Southern Sydney Basin bioregion, is a conservation management priority.

Ecological receptors

The following information was also obtained from ERIN to facilitate the identification of the areas containing exploration or pilot testing coal seam gas wells, and the selection of the key receptors (terrestrial and aquatic ecosystems) in the Northern Sydney Basin bioregion.

The Northern Sydney Basin bioregion has the Hunter and Gloucester subregions, both of which contain coal seam gas wells. There are a number of areas in and outside the bioregion with coal seam gas tenements and licences.

In the Hunter subregion the Wyong River passes near the area containing coal seam gas wells. The Gloucester River and the Karuah River in the Gloucester subregion pass near the area that contains coal seam gas wells. The aquatic receptors linked to MNES include the Wyong, the Gloucester, and the Karuah rivers. However, the MNES are located at different distances from the coal seam gas wells.

A summary of the MNES connected to the selected aquatic receptors near areas containing coal seam gas wells is provided below.

Eleven MNES (grey nurse shark, southern bluefin tuna, Macquarie perch, stuttering frog, Australian grayling, hawksbill turtle, loggerhead turtle, leatherback turtle, flatback turtle, green turtle, and aquatic birds) are identified in this bioregion, with the following distribution:

- The protected southern bluefin tuna, leatherback turtle, flatback turtle, green turtle, and loggerhead turtle may be found in marine areas in the Hunter subregion near coal seam gas wells. However, these listed species are found at a significant distances from coal seam gas wells.
- The protected Australian Grayling and Macquarie Perch may be found in areas with approved coal seam gas licences in the Hunter subregion but at a significant distance from the coal seam gas wells.
- Protected aquatic birds may be found anywhere in the bioregion, including the tenements containing coal seam gas wells.

Sixteen Nationally Important Wetlands are identified in this bioregion, with the following distribution:

- The Port Stephens Estuary is within areas with approved coal seam gas licences and is connected to the Karuah River that passes near an area with coal seam gas wells in the Gloucester subregion. However, the Estuary is located at a significant distance from coal seam gas wells.
- The Brisbane Water Estuary, Avoca, Terrigal, Cockrone and Wamberal Lagoons are within areas with approved coal seam gas licences. However, these areas are at a significant distance from coal seam gas wells.
- The Colongra Swamp, Budgewoi Lake, the Wyong Racecourse Swamp, and the Tuggerah Lakes are connected to the Wyong River and Ourimba Creek that pass near areas with coal seam gas tenements in the Hunter subregion. However, these areas are at a significant distance from coal seam gas wells.
- The other Nationally Important Wetlands are located in different parts of the bioregion and at significant distances from coal seam gas wells.

One Ramsar Wetland is identified in this bioregion within areas with approved coal seam gas licences, but it is located at a significant distance from coal seam gas wells.

Eight National Heritage places are identified in this bioregion, with the following distribution:

- The Stroud Gloucester Valley is located in the area with coal seam gas wells in the Gloucester subregion, but at a significant distance from coal seam gas wells.
- The Rathmines Park is connected to the Wyong River but at a significant distance from coal seam gas wells.
- The Great Blue Mountain is located within areas with approved coal seam gas licences, but it is located at a significant distance from coal seam gas wells.
- Other National Heritage areas are located in different parts of the bioregion but at significant distance coal seam gas wells.

One World Heritage place is identified in the Northern Sydney bioregion, located within areas where coal seam gas licences have been approved; however, it is located at a significant distance from coal seam gas wells.

3.3 Risk characterisation

3.3.1 Tier 1 Generic assessment

3.3.1.1 Exposure pattern

The Tier 1 risk assessment used a generic and conservative approach to estimating the level of concern for points of release (transport, storage at intermediate site, storage at the well site, usage at the well sites, waste fluid storage at the well site, waste fluid storage at the working site, waste fluid usages for irrigation and dust suppression). The exposure pattern for the Tier 1 assessment includes:

- bounding estimate values for chemical quantities at each point of release
- bounding estimates values for the different model parameters
- generic environmental conditions to represent any working site in Australia. For example:
 - conservative volume of contaminated runoff from the working site
 - dilution from uncontaminated runoff is not included
 - conservative values for rainfall, soil %OC, % slope, etc.
 - conservative (low) volume for the receiving environment
- chemical partitioning and degradation behaviour in the receiving terrestrial or aquatic compartment is not considered
- the assessment considered chemicals reported to be used during the period of 2010 to 2012.

3.3.1.2 Risk estimation

The Tier 1 risk assessment was undertaken for 59 chemicals identified to be used in drilling and hydraulic fracturing activities, which had aquatic ecotoxicity endpoints to enable assessment (Table 3.13). Of the 59 chemicals assessed at Tier 1, three chemicals showed RQs < 1 under the different release points assessed during single and multiple releases to an aquatic environment. Of the 56 chemicals with RQs \geq 1, there were 22 chemicals that continued to Tier 2 assessments. The remaining 34 chemicals with RQs \geq 1 would normally have then been assessed at Tier 2. However, industry advised that they were not in use as of July 2015. Consequently, there were no site-specific data available to enable assessment of these 34 chemicals at Tiers 2 and 3.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 1 | In Use |
|------------|--|---|---------------------------|--------|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | hydraulic fracturing | Yes | Yes |
| 10043-52-4 | Calcium chloride (CaCl ₂) | hydraulic fracturing | No | No |
| 107-21-1 | 1,2-Ethanediol | hydraulic fracturing | Yes | Yes* |
| 107-22-2 | Ethanedial / glyoxal | drilling | No | No |
| 108-10-1 | 2-Pentanone, 4-methyl- | hydraulic fracturing | Yes | No |

Table 3.13 Chemicals that have $RQ \ge 1$ after Tier 1 assessment

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 1 | In Use |
|------------|--|---|---------------------------|--------|
| 111-30-8 | Pentanedial / glutaraldehyde | drilling | Yes | Yes |
| 11138-66-2 | Xanthan gum | drilling, hydraulic fracturing | Yes | Yes |
| 111-76-2 | Ethanol, 2-butoxy- | hydraulic fracturing | Yes | Yes* |
| 111-90-0 | Ethanol, 2-(2-ethoxyethoxy)- | hydraulic fracturing | Yes | No |
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | drilling | Yes | Yes* |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing | Yes | Yes |
| 141-43-5 | Ethanol, 2-amino- | hydraulic fracturing | Yes | No |
| 144-55-8 | Carbonic acid, monosodium salt | drilling | Yes | Yes |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing | Yes | Yes |
| 2634-33-5 | 1,2-Benzisothiazol-3(2H)- one | hydraulic fracturing | Yes | No |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing | Yes | Yes |
| 497-19-8 | Carbonic acid, disodium salt | drilling, hydraulic fracturing | Yes | Yes |
| 52-51-7 | 1,3-Propanediol, 2-bromo-2- nitro- | hydraulic fracturing | Yes | No |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | drilling, hydraulic fracturing | Yes | Yes |
| 56-81-5 | 1,2,3-Propanetriol | hydraulic fracturing | Yes | No |
| 6381-77-7 | D-Erythro-hex-2-enonic acid, .gammalactone, monosodium salt | hydraulic fracturing | Yes | No |
| 6410-41-9 | 2-Naphthalenecarboxamide, N-(5-chloro-2,4- dimethoxyphenyl)-4-[[5- [(diethylamino)sulfonyl]-2- methoxyphenyl]azo]-3- hydroxy- | hydraulic fracturing | Yes | No |
| 64-17-5 | Ethanol | drilling, hydraulic fracturing | Yes | No |
| 64-19-7 | Acetic acid | hydraulic fracturing | Yes | Yes |
| 64742-47-8 | Distillates, petroleum, hydrotreated light | drilling | Yes | No |
| 67-56-1 | Methanol | drilling, hydraulic fracturing | No | No |
| 67-63-0 | 2-Propanol | drilling, hydraulic fracturing | Yes | No |

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 1 | In Use |
|------------|--|---|---------------------------|----------|
| 68187-17-7 | Sulfuric acid, mono-C ₆₋₁₀ - alkyl esters, ammonium salts | hydraulic fracturing | Yes | No |
| 68439-45-2 | Alcohols, C ₆₋₁₂ , ethoxylated | hydraulic fracturing | Yes | No |
| 68647-72-3 | Terpenes and terpenoids, orange oil | hydraulic fracturing | Yes | No |
| 7447-40-7 | Potassium chloride (KCI) | drilling, hydraulic fracturing | Yes | Yes |
| 75-57-0 | Methanaminium, N,N,N- trimethyl-, chloride | hydraulic fracturing | Yes | No |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing | Yes | Yes |
| 7647-14-5 | Sodium chloride (NaCl) | drilling, hydraulic fracturing | Yes | Yes |
| 7681-52-9 | Hypochlorous acid, sodium salt | hydraulic fracturing | Yes | No |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | hydraulic fracturing | Yes | Yes |
| 7757-82-6 | Sulfuric acid, disodium salt | hydraulic fracturing | Yes | No |
| 7757-83-7 | Sulfurous acid, disodium salt | drilling, hydraulic fracturing | Yes | No |
| 7758-16-9 | Diphosphoric acid, disodium salt | drilling | Yes | No |
| 7758-19-2 | Chlorous acid, sodium salt | hydraulic fracturing | Yes | No |
| 7775-27-1 | Peroxydisulfuric acid, disodium salt | hydraulic fracturing | Yes | No |
| 7778-80-5 | Sulfuric acid, dipotassium salt | drilling | Yes | Yes |
| 7783-20-2 | Sulfuric acid, diammonium salt | Hydraulic fracturing | Yes | No |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | hydraulic fracturing | Yes | Yes |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing | Yes | Yes |
| 81741-28-8 | Phosphonium, tributyltetradecyl-, chloride | hydraulic fracturing | Yes | No |
| 9000-30-0 | Guar gum | drilling, hydraulic fracturing | Yes | Yes (HF) |
| СВІ | Ethylhexanol heavies | drilling | Yes | No |
| СВІ | Ester alcohol | drilling | Yes | No |
| СВІ | Organic sulfate | drilling | Yes | No |
| СВІ | Organic acid salt | drilling | Yes | No |
| СВІ | Polymer with substituted | drilling | Yes | Yes |

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 1 | In Use |
|--------|------------------------------|---|---------------------------|--------|
| | alkylacrylamide salt | | | |
| СВІ | Polymer II | drilling | Yes | No |
| СВІ | Amine salt | hydraulic fracturing | Yes | No |
| СВІ | Inner salt of alkyl amines | hydraulic fracturing | Yes | No |
| СВІ | Ethoxylated fatty acid I | hydraulic fracturing | Yes | No |
| СВІ | Ethoxylated HF fatty acid II | hydraulic fracturing | Yes | No |
| СВІ | Ethoxylated fatty acid III | hydraulic fracturing | Yes | No |
| СВІ | Quaternary amine | hydraulic fracturing | Yes | No |

* Reported for transport or storage but not in use at a well site that is near to a receptor according to industry data.

3.3.2 Tier 2 Bioregional assessment

3.3.2.1 Exposure pattern

The Tier 2 risk assessment estimated the level of concern for the points of release within a bioregion (transport, storage at intermediate site, storage at the well site, usage at the well sites, waste fluid storage at the well site, waste fluid storage at the well site, waste fluid storage at the well site, waste fluid storage at the suppression) under single and multiple-release scenarios. In summary, the bioregional approach includes:

- high-end estimate values for chemical quantities at each point of release
- high-end estimate values for the different model parameters
- environmental conditions to represent any working site in the bioregion. For example:
 - bioregional rivers treated to represent river flows near working site
 - high-end estimate values to estimate contaminated runoff from the working site to the receiving aquatic environment
 - high-end estimate values to estimate uncontaminated runoff to the receiving aquatic environment
 - high-end estimate values for rainfall, soil %OC, %slope, etc.
- chemical partitioning and degradation behaviour in the receiving terrestrial compartment is considered
- the assessment considered chemicals reported to be used during the period 2010 to 2012.

The Tier 2 risk assessment was undertaken for 22 chemicals (Table 3.14) that showed RQs \geq 1 in the Tier 1 assessment and identified as used in drilled and hydraulic fractured wells within 2 km from an aquatic receptor in the Northern Inland Catchments bioregion or Sydney Basin bioregion.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|---|---|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | hydraulic fracturing |
| 107-21-1 | 1,2-Ethanediol | hydraulic fracturing* |
| 111-30-8 | Pentanedial / Glutaraldehyde | drilling |
| 11138-66-2 | Xanthan gum | drilling, hydraulic fracturing |
| 111-76-2 | Ethanol, 2-butoxy- | hydraulic fracturing* |
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | drilling* |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing |
| 144-55-8 | Carbonic acid, monosodium salt | drilling |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing |
| 497-19-8 | Carbonic acid, disodium salt | drilling, hydraulic fracturing |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | drilling, hydraulic fracturing |
| 64-19-7 | Acetic acid | hydraulic fracturing |
| 7447-40-7 | Potassium chloride (KCI) | drilling, hydraulic fracturing |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing |
| 7647-14-5 | Sodium chloride (NaCl) | drilling, hydraulic fracturing |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | hydraulic fracturing |
| 7778-80-5 | Sulfuric acid, dipotassium salt | drilling |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | hydraulic fracturing |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing |
| 9000-30-0 | Guar gum | hydraulic fracturing |
| СВІ | Polymer with substituted alkylacrylamide salt | drilling |

 Table 3.14
 Chemicals assessed at Tier 2

* Reported for transport or storage but not in use at a well site that is near to a receptor according to industry data.

3.3.2.2 Northern Inland Catchments bioregion

Risk estimation

Of the 22 chemicals assessed at the Tier 2 level assessment in the Northern Inland Catchments bioregion, two hydraulic fracturing chemicals were predicted to have RQs < 1 under the different release points assessed during single and multiple releases across the bioregion. Conversely, this assessment also found that 20 chemicals (Table 3.15) showed RQs \geq 1 under the assessed conditions in the different release scenarios across the bioregion.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 2 |
|------------|---|--|---------------------|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | hydraulic fracturing | Yes |
| 107-21-1 | 1,2-Ethanediol | hydraulic fracturing* | Yes |
| 111-30-8 | Pentanedial/glutaraldehyde | drilling | Yes |
| 11138-66-2 | Xanthan gum | drilling, hydraulic fracturing* | Yes |
| 111-76-2 | Ethanol, 2-butoxy- | hydraulic fracturing* | No |
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | drilling* | Yes |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing | Yes |
| 144-55-8 | Carbonic acid, monosodium salt | drilling | Yes |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing | Yes |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing | Yes |
| 497-19-8 | Carbonic acid, disodium salt | drilling*, hydraulic fracturing | Yes |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | drilling, hydraulic fracturing | Yes |
| 64-19-7 | Acetic acid | hydraulic fracturing | Yes |
| 7447-40-7 | Potassium chloride (KCI) | drilling, hydraulic fracturing | Yes |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing | Yes |
| 7647-14-5 | Sodium chloride (NaCl) | drilling, hydraulic fracturing | Yes |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | hydraulic fracturing | Yes |
| 7778-80-5 | Sulfuric acid, dipotassium salt | drilling | Yes |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | hydraulic fracturing | No |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing | Yes |
| 9000-30-0 | Guar gum | hydraulic fracturing | Yes |
| СВІ | Polymer with substituted alkylacrylamide salt | drilling | Yes |

Table 3.15 Chemicals that have $RQ \ge 1$ after Tier 2 assessment for NIC Bioregion

* Reported for transport or storage but not in use at a well site that is near to a receptor according to industry data.

Based on the Tier 2 assessment, these 20 chemicals with a predicted RQ exceeding 1 are of potential concern to receiving aquatic ecosystems if released under the assessed conditions from a working site in the Northern Inland Catchment bioregion. Further risk mitigation measures may be required if the chemical is used in coal seam gas extraction. This concern may be overestimated due to the use of high-end estimates and conservative assumptions inherent in the Tier 2 assessment. Therefore, the 20 chemicals used in the Northern Inland Catchment bioregion progressed to a more detailed, site-specific Tier 3 assessment.

3.3.2.3 Northern Sydney Basin bioregion

Risk estimation

Of the 22 chemicals reported to be used by the industry, only 10 chemicals (Table 3.16) were reported to be used (and were assessed) in the Sydney bioregion. None of these chemicals when analysed under the Tier 2 assessment showed RQs < 1 for the different release points or scenarios assessed for the bioregion. This assessment also found that all 10 chemicals showed RQs \geq 1 under the assessed conditions in the different release scenarios across the bioregion. As with the Northern Inland Catchment bioregion assessment, these 10 chemicals are of potential concern if released under the assessed conditions from a working site in the Sydney basin bioregion. Further risk mitigation measures may be required if the chemical is used in coal seam gas extraction. However, the level of concern may be overestimated in the Tier 2 assessment due to the use of high-end conservative estimates. Therefore, the 10 chemicals used in the Sydney bioregion progressed to a more detailed, site-specific Tier 3 assessment.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 2 |
|------------|---|--|---------------------|
| 11138-66-2 | Xanthan gum | drilling | Yes |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing | Yes |
| 497-19-8 | Carbonic acid, disodium salt | drilling | Yes |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | hydraulic fracturing | Yes |
| 64-19-7 | Acetic acid | hydraulic fracturing | Yes |
| 7447-40-7 | Potassium chloride (KCI) | drilling | Yes |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing | Yes |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing | Yes |
| 9000-30-0 | Guar gum | hydraulic fracturing | Yes |
| СВІ | Polymer with substituted alkylacrylamide salt | drilling | Yes |

Table 3.16 Chemicals that have RQ ≥ 1 after Tier 2 assessment for NSB Bioregion
3.3.3 Tier 3 Site Specific assessment

3.3.3.1 Exposure pattern

The Tier 3 risk assessment estimated the level of concern under site-specific conditions using several different release scenarios (transport, storage at intermediate site, storage at the well site, usage at the well sites, waste fluid storage at the well site, waste fluid storage at the working site, waste fluid usages for irrigation and dust suppression) under single and multiple releases across five working sites in the two bioregions. For the Tier 3 risk assessments the following assumptions were made:

- Where well sites were in close proximity to each other they were grouped together as a single working site
- Where well sites were grouped together into a single working site, the estimated values for chemical quantities at each point of release were the average of the quantities for the individual wells
- Modelling parameters incorporated both bioregional and site-specific data. For example:
 - gauge data for rivers closest to each working site for three flow scenarios (low, intermediate and high)
 - average values for rainfall, soil %OC, %slope.
- Where well sites were grouped together into a single working site, the estimated values for the site-specific model parameters were the average of the values for the individual wells.

Other assumptions included:

- No degradation of chemicals occurs in the receiving aquatic environment
- Perennial river flow (the Northern Inland Catchment has a large number of rivers that are ephemeral streams).

The Tier 3 risk assessment was undertaken for 20 chemicals (Table 3.17) that showed RQs \geq 1 in Tier 2 assessments and were identified to be stored at an intermediate site or used in drilled and hydraulically fractured wells within 2 km from an aquatic receptor in the Northern Inland Catchments bioregion and Sydney Basin bioregion.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 2 | Work Site Specific |
|------------|--|---|------------------------|-----------------------|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | hydraulic fracturing | Yes | Yes |
| 107-21-1 | 1,2-Ethanediol | hydraulic fracturing* | Yes | Yes |
| 111-30-8 | Pentanedial / glutaraldehyde | drilling | Yes | Yes |
| 11138-66-2 | Xanthan gum | drilling, hydraulic fracturing** | Yes | Yes (D***) |

| Tabla 2 17 | Chamicals for | Tior 2 Sito S | nacific accordent |
|------------|---------------|---------------|-------------------|
| | | | |

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing | RQ ≥ 1 after Tier 2 | Work Site Specific |
|------------|---|---|------------------------|-----------------------|
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | drilling* | Yes | Yes |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing | Yes | Yes |
| 144-55-8 | Carbonic acid, monosodium salt | drilling | Yes | Yes |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing | Yes | Yes |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing | Yes | Yes |
| 497-19-8 | Carbonic acid, disodium salt | drilling*, hydraulic fracturing | Yes | Yes |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | drilling, hydraulic fracturing | Yes | Yes |
| 64-19-7 | Acetic acid | hydraulic fracturing | Yes | Yes |
| 7447-40-7 | Potassium chloride (KCI) | drilling, hydraulic fracturing | Yes | Yes |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing | Yes | Yes |
| 7647-14-5 | Sodium chloride (NaCl) | drilling**, hydraulic fracturing | Yes | Yes (HF****) |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | hydraulic fracturing | Yes | Yes |
| 7778-80-5 | Sulfuric acid, dipotassium salt | drilling | Yes | Yes |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing | Yes | Yes |
| 9000-30-0 | Guar gum | hydraulic fracturing | Yes | Yes |
| CBI | Polymer with substituted alkylacrylamide salt | drilling | Yes | Yes |

* Reported for intermediate storage only. ** Not in use at a work site near to a receptor. *** Used only in drilling activities. ****Used only in hydraulic fracturing activities

Of the 20 chemicals assessed at Tier 3, a subset is specific to each working site (that is, proximal well sites or a storage area). Tier 3 risk estimation for these subsets of chemicals is set out below. A brief description of the locations of the wells, nearby rivers and aquatic receptors is provided to conceptualise the working sites and their risk characterisation profile.

3.3.3.2 Well site characterisation

Working Site 1 Northern Sydney Basin Bioregion

Well location and aquatic receptors

Working Site 1 has five well sites. These wells are located at a distance of 0.4 to 0.5 km apart from each other in the Gloucester subregion. The Waukivory Creek is located at a distance of 0.15 to 0.32 km from these wells. An unnamed water body is located approximately 0.03 km from one of the wells.

Neither Waukivory Creek nor the unnamed water body have gauging stations for the collection of flow or water quality data. Therefore, the nearest gauged river or water body was used to represent the rivers near the well sites. Refer to Appendix B for more detailed information on methodology for calculating PECs at aquatic receptor sites.

Ecological receptors

Many ecological receptors identified as MNES or protected areas are present in the area but all are located more than 2 km from the well sites.

Risk estimation

The subset of chemicals used in drilling and fracturing activities for Working Site 1 are listed in Table 3.18.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|---|---|
| 11138-66-2 | Xanthan gum | drilling |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing |
| 497-19-8 | Carbonic acid, disodium salt | drilling |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | hydraulic fracturing |
| 64-19-7 | Acetic acid | hydraulic fracturing |
| 7447-40-7 | Potassium chloride (KCI) | drilling |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing |
| 9000-30-0 | Guar gum | hydraulic fracturing |
| СВІ | Polymer with substituted alkylacrylamide salt | Drilling |

Table 3.18 Tier 3 assessment chemicals for Working Site 1 Northern Sydney Basin Bioregion Bioregion

Of the six drilling chemicals reportedly used, three chemicals have RQs < 1 and therefore are considered to present low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Three chemicals are predicted to have

RQs \geq 1 for the transport accident release scenario as shown in Table 3.19. None of the other release points had predicted RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 Point(s) of Release |
|------------|---|---------------------|-------------------------------|
| 11138-66-2 | Xanthan gum | Yes | Transport |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | No | N/A |
| 497-19-8 | Carbonic acid, disodium salt | No | N/A |
| 7447-40-7 | Potassium chloride (KCI) | Yes | Transport |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | No | N/A |
| СВІ | Polymer with substituted alkylacrylamide salt | Yes | Transport |

Table 3.19 Drilling chemicals that have $RQ \ge 1$ for Working Site 1 after Tier 3 assessment

Of the six hydraulic fracturing chemicals used, three chemicals have RQs < 1 and therefore are considered to present low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Three chemicals are predicted to have RQs \geq 1 for the transport accident release scenario as shown in Table 3.20. None of the other release points are predicting RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 Point(s) of Release |
|------------|---|---------------------|-------------------------------|
| 1310-73-2 | Sodium hydroxide (Na(OH)) | Yes | Transport |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | No | N/A |
| 64-19-7 | Acetic acid | No | N/A |
| 7647-01-0 | Hydrochloric acid | Yes | Transport |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | No | N/A |
| 9000-30-0 | Guar gum | Yes | Transport |

Table 3.20 Hydraulic fracturing chemicals that have $RQ \ge 1$ for Working Site 1 after Tier 3 assessment

Furthermore, no spills were reported for each of the release points assessed in Working Site 1.

Working Site 2 Northern Inland Catchments Bioregion

Well location and aquatic receptors

• Working Site 2 has five well sites located in the Fitzroy Basin about 158 to 275 km from the Maranoa-Balonne-Condamine subregion of the NIC Bioregion. There are two sets of wells here, including: A set of 4 B32, B33, and wells located in the Fitzroy Basin at a

distance of 0.14 km from each other. A small unnamed water body is located at a distance of 0.56 to 0.74 km from the wells.

- A set of two wells located in the Fitzroy Basin at a distance of 92 km from each other. One well has a set of two small unnamed water bodies located at a distance of 0.21 to 0.4 km from the well. The other well has an unnamed water body at a distance of 1.72 km.
- These two sets of wells are located 129 to 232 km apart

These nearby water bodies are not gauged. Therefore, the nearest gauged river or water body was used to represent the rivers near the working site. Refer to Appendix B for more detailed information on methodology for calculating PECs at aquatic receptor sites.

Ecological receptors

Many ecological receptors identified as MNES or protected areas are present in the Working Site 2 sub-region but all are located a significant distance from the well sites.

Risk estimation

The subset of chemicals used for Working Site 2 is listed in Table 3.21. No information was provided by industry on the drilling chemicals used at Working Site 2.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|-----------|--|--|
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | hydraulic fracturing |
| 64-19-7 | Acetic acid | hydraulic fracturing |

Table 3.21 Tier 3 assessment chemicals for Working Site 2 Northern Inland Catchments Bioregion

Of these two chemicals reported to be used in hydraulic fracturing, neither was predicted to have an $RQ \ge 1$ (Table 22). These chemicals are considered of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site.

Table 3.22 Hydraulic fracturing chemicals that have $RQ \ge 1$ for Working Site 2 after Tier 3 assessment

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 Point(s) of Release |
|-----------|--|---------------------|-------------------------------|
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | No | N/A |
| 64-19-7 | Acetic acid | No | N/A |

Furthermore, no spills were reported for each of the release points assessed in Working Site 2.

Working Site 3 Northern Inland Catchments Bioregion

Well location and aquatic receptors

Working Site 3 has 55 well sites grouped by area into group A, B and C. Groups A (with 24 wells) and B (with 29 wells) are located in the Fitzroy Basin about 18 to 52 km from the Maranoa-Balonne-Condamine subregion. The waterways, Scott Creek, Bluff Creek, Western Creek, Eurombah Creek Kurrajong Gully, Pear Gully, Slate Hill Creek and Scotchy Creek are located at various distances from the group A, and B wells.

Group C wells (with two wells) are located in Balonne-Condamine subregion, 0.24 km apart. Unnamed creeks are located at a distance of 0.36 to 1.3 km from the wells and the Tchanning Creek is located at the distance of 1.4 km from the wells.

These waterbodies are not gauged. Therefore, data from the nearest gauging station was collected and treated to represent the creeks near the working sites. Refer to Appendix B for more detailed information on methodology for calculating PECs at aquatic receptor sites.

Ecological receptors

Many ecological receptors identified as MNES or protected areas are present in the Working Site 3 sub-region but all are located a significant distance from the well sites. The Murray Cod is listed as a vulnerable species under the EPBC Act and could potentially be found in the NIC Bioregion and in the rivers near the wells in this working site.

Many protected sites are in the subregion but all at significant distance from the well sites. The closest is a groundwater-dependent ecosystem (spring) located 5 to 9 km away from some of the wells in this working site.

Risk estimation

The subset of chemicals used in drilling and fracturing activities for Working Site 3 are listed in Table 3.23.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|---|--|
| 111-30-8 | Pentanedial / glutaraldehyde | drilling |
| 11138-66-2 | Xanthan gum | drilling |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | hydraulic fracturing |
| 144-55-8 | Carbonic acid, monosodium salt | drilling |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing |
| 497-19-8 | Carbonic acid, disodium salt | drilling |
| 64-19-7 | Acetic acid | hydraulic fracturing |
| 7447-40-7 | Potassium chloride (KCI) | hydraulic fracturing |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing |
| 7647-14-5 | Sodium chloride (NaCl) | hydraulic fracturing |

Table 3.23 Tier 3 assessment chemicals for Working Site 3 Northern Inland Catchments Bioregion

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|-----------|---|--|
| 7786-30-3 | Magnesium chloride (MgCl ₂) | hydraulic fracturing |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing |
| 9000-30-0 | Guar gum | Hydraulic fracturing |

Five drilling chemicals were reported to be used however, no volume data were provided for transport, storage or use. Instead, the Tier 3 assessment was completed by substituting average data for the NIC Bioregion. On this basis two chemicals were predicted to have RQs < 1 and of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Three chemicals are predicted to have RQs \geq 1 for the transport accident release scenario as shown in Table 3.24. None of the other release points are predicting RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 Point(s) of Release |
|------------|---|---------------------|-------------------------------|
| 111-30-8 | Pentanedial/glutaraldehyde | Yes | Transport |
| 11138-66-2 | Xanthan gum | Yes | Transport |
| 144-55-8 | Carbonic acid, monosodium salt | No | N/A |
| 497-19-8 | Carbonic acid, disodium salt | Yes | Transport |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | No | N/A |

Table 3.24 Drilling chemicals that have RQ ≥ 1 for Working Site 3 after Tier 3 assessment

Of the 10 hydraulic fracturing chemicals used, three chemicals have RQs < 1 and therefore are considered of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Seven chemicals are predicted to have RQs \geq 1 for the transport accident release scenario as shown in Table 3.25. None of the other release points had predicted RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 for Well Group | RQ ≥ 1 Point(s) of Release |
|------------|---|------------------------|--------------------------|----------------------------------|
| 1310-73-2 | Sodium hydroxide (Na(OH)) | Yes | С | Transport |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | Yes | A | Transport |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | Yes | А | Transport |
| 64-19-7 | Acetic acid | No | N/A | N/A |
| 7447-40-7 | Potassium chloride (KCI) | Yes | С | Transport |
| 7647-01-0 | Hydrochloric acid | Yes | С | Transport |
| 7647-14-5 | Sodium chloride (NaCl) | Yes | С | Transport |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | No | N/A | N/A |

Table 3.25 Hydraulic fracturing chemicals that have RQ \ge 1 for Working Site 3 after Tier 3 assessment

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 for Well Group | RQ ≥ 1 Point(s) of Release |
|-----------|---|------------------------|--------------------------|----------------------------------|
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | No | N/A | N/A |
| 9000-30-0 | Guar gum | Yes | С | Transport |

Furthermore, no spills were reported for each of the release points assessed in Working Site 3.

Working Site 4 Northern Inland Catchments Bioregion

Well location and aquatic receptors

Working Site 4 has five well sites located in the Fitzroy Basin. These Working Site 4 wells are located at a distance of 1.4 to 1.6 Km apart. There are two sets of wells here, including:

A set of three wells are located at a distance of 0.49 to 1.1 km from each other. Creeks that are located within 2 km of these wells include Hardknock Creek, located at a distance of 0.2 to 0.38 km and Wandoan Creek, located at a distance of 1.8 to 2.0 km. Unnamed waterbodies are also located at a distance of 0.45 to 1.1 km from the wells.

A set of two wells are located at a distance of 0.011 km from each other. The Wandoan Creek is located at a distance of 0.64 km from the wells and unnamed water bodies are located at a distance of 0.22 to 0.64 km.

These creeks and waterways within close proximity to the well sites are not gauged. Therefore, the nearest gauged river or water body was used to represent the rivers near the working site. Refer to Appendix B for more detailed information on methodology for calculating PECs at aquatic receptor sites.

Ecological receptors

Many MNES and protected areas are identified in the subregion but all at significant distance from the well sites.

Risk estimation

The subset of chemicals used in drilling and fracturing activities for Working Site 4 are listed in Table 3.26.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|-------------------------------|--|
| 107-21-1 | 1,2-Ethanediol* | hydraulic fracturing |
| 11138-66-2 | Xanthan gum* | drilling, hydraulic fracturing |
| 111-76-2 | Ethanol, 2-butoxy-* | hydraulic fracturing |
| 1310-73-2 | Sodium hydroxide (Na(OH))* | hydraulic fracturing |

Table 3.26 Tier 3 assessment chemicals for Working Site 4 Northern Inland Catchments Bioregion

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|--|--|
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing |
| 497-19-8 | Carbonic acid, disodium salt* | drilling |
| 7447-40-7 | Potassium chloride (KCI) | drilling, hydraulic fracturing* |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy-* | drilling |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing |
| 7647-14-5 | Sodium chloride (NaCl)* | drilling, hydraulic fracturing |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | hydraulic fracturing |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt)* | drilling, hydraulic fracturing |
| 9000-30-0 | Guar gum | hydraulic fracturing |

* Chemical used at a "typical" well site. It is not reported for well sites identified near to an aquatic receptor

Six drilling chemicals were reported by the operating company for Working Site 4 but only one chemical was identified to be used at well sites near to an aquatic receptor. The additional chemicals reported are for a 'typical' well site that is not near to an aquatic receptor. These chemicals were included in the assessment for completeness only but they are not considered in the final conclusion.

Of the six chemicals, three chemicals were predicted to have RQs < 1 and therefore are considered of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Three chemicals are predicted to have RQs \geq 1 for the transport accident release scenario as shown in Table 3.27. None of the other release points are predicting RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 Point(s) of Release |
|------------|--|---------------------|-------------------------------|
| 11138-66-2 | Xanthan gum* | Yes | Transport |
| 497-19-8 | Carbonic acid, disodium salt* | No | N/A |
| 7447-40-7 | Potassium chloride (KCl) | Yes | Transport |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy-* | No | N/A |
| 7647-14-5 | Sodium chloride (NaCl)* | Yes | Transport |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt)* | No | N/A |

Table 3.27 Drilling chemicals that have RQ ≥ 1 for Working Site 4 after Tier 3 assessment

* Chemical used at a 'typical' well site. It is not reported for well sites identified near to an aquatic receptor

Twelve hydraulic fracturing chemicals were reported by the operating company for Working Site 4 but only six chemicals were identified to be used at well sites near to an aquatic receptor. The additional chemicals reported are for a 'typical' well site that is not near to an aquatic receptor. These chemicals were included in the assessment for completeness only but they are not considered in the final conclusion.

Of the 12 hydraulic fracturing chemicals used, seven chemicals have RQs < 1 and therefore are considered of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Five chemicals are predicted to have RQs \geq 1, as shown in Table 3.28. Four of these chemicals are for use at well sites near to an aquatic receptor. Exceedances were predicted for the transport accident release scenario only. None of the other release points had predicted RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 Point(s) of Release |
|--|---|---------------------|-------------------------------|
| 107-21-1 | 1,2-Ethanediol* | No | N/A |
| 111-76-2 | Ethanol, 2-butoxy-* | No | N/A |
| 1310-73-2 | Sodium hydroxide (Na(OH))* | No | N/A |
| 26172-55-4 3(2H)-Isothiazolone, 5- chloro-2-methyl- | | Yes | Transport |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | Yes | Transport |
| 7447-40-7 | Potassium chloride (KCI)* | Yes | Transport |
| 7647-01-0 | Hydrochloric acid | No | N/A |
| 7647-14-5 | Sodium chloride (NaCl)* | No | N/A |
| 7727-54-0 | 7727-54-0 Peroxydisulfuric acid, diammonium salt | | N/A |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | No | N/A |
| 9000-30-0 | Guar gum | Yes | Transport |
| 11138-66-2 | Xanthan gum* | No | N/A |

Table 3.28 Hydraulic fracturing chemicals that have $RQ \ge 1$ for Working Site 4 after Tier 3 assessment

* Chemical used at a 'typical' well site. It is not reported for well sites identified near to an aquatic receptor

No spills were reported for each of the release points assessed in Working Site 4.

Working Site 5 Northern Inland Catchments Bioregion

Well location and aquatic receptors

Working Site 5 has four well sites located over the Balonne-Condamine and Fitzroy Basins. Two sets of two wells each in Working Site 5 are located 133 km apart.

One set of two wells are located in the Fitzroy Basin 0.012 km apart. The nearest aquatic receptors have been identified as unnamed water bodies located at a distance of 0.055 to 0.14 km from the wells. Jacks Creek is also located about 2.9 km from the wells.

The other set of two wells are located in the Balonne-Condamine Basin at a distance of 0.53 km from each other. Cottage Creek is located at a distance of 0.44 to 0.89 km from the wells and Six Mile Creek is located at a distance of 2.0 to 2.45 km.

These creeks and waterways within close proximity to the well sites are not gauged. Therefore, the nearest gauged river or water body was used to represent the rivers near the working site. Refer to Appendix B for more detailed information on the methodology for calculating PECs at aquatic receptor sites.

Ecological receptors

Many MNES and protected areas are identified in the subregion but all are distant from the well sites. The Murray Cod is listed as a vulnerable species under the EPBC Act and could potentially be found in the NIC Bioregion and in the rivers near one of the set of two wells.

Risk estimation

The subset of chemicals used in drilling and fracturing activities for Working Site 5 are listed in Table 3.29.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|---|--|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | hydraulic fracturing |
| 11138-66-2 | Xanthan gum | drilling |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | hydraulic fracturing |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | hydraulic fracturing |
| 497-19-8 | Carbonic acid, disodium salt | hydraulic fracturing |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | drilling, hydraulic fracturing |
| 7447-40-7 | Potassium chloride (KCI) | drilling |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | drilling, hydraulic fracturing |
| 7778-80-5 | Sulfuric acid, dipotassium salt | drilling |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | hydraulic fracturing |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling |
| 9000-30-0 | Guar gum | hydraulic fracturing |
| CBI | Polymer with substituted alkylacrylamide salt | drilling |

Table 3.29 Tier 3 assessment chemicals for Working Site 5 Northern Inland Catchments Bioregion

Of the seven drilling chemicals reported to be used, one chemical was predicted to have an RQ < 1 and therefore considered of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Six chemicals are predicted to have RQs \geq 1 for the transport accident release scenario as shown in Table 3.30. None of the other release points are predicting RQs \geq 1.

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 for Well Group | RQ ≥ 1 Point(s) of Release |
|------------|---|------------------------|--------------------------|----------------------------------|
| 11138-66-2 | Xanthan gum | Yes | G3-4, G7-8 | Transport |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | Yes | G3-4, G7-8 | Transport |
| 7447-40-7 | Potassium chloride (KCI) | Yes | G7-8 | Transport |
| 7778-80-5 | 78-80-5 Sulfuric acid, dipotassium salt | | G3-4 | Transport |
| 77-92-9 | 92-9 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | | N/A | N/A |
| СВІ | BI Polymer with substituted alkylacrylamide salt | | G3-4 | Transport |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | Yes | G3-4 | Transport |

Table 3.30 Drilling chemicals that have $RQ \ge 1$ for Working Site 5 after Tier 3 assessment

Of the eight hydraulic fracturing chemicals used, two chemicals have RQs < 1 and therefore are considered of low concern to aquatic receptors at all points of release under the Tier 3 assessment conditions for this working site. Six chemicals are predicted to have RQs \geq 1 for the transport accident release scenario as shown in Table 3.31. None of the other release points had predicted RQs \geq 1.

Table 3.31 Hydraulic fracturing chemicals that have $RQ \ge 1$ for Working Site 5 after Tier 3 assessment

| CAS RN | Chemical Name | RQ ≥ 1 after Tier 3 | RQ ≥ 1 for Well Group | RQ ≥ 1 Point(s) of Release |
|------------|--|------------------------|--------------------------|----------------------------------|
| 10043-35-3 | Boric acid (H ₃ BO ₃) | Yes | G3-4, G7-8 | Transport |
| 26172-55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | Yes | G3-4, G7-8 | Transport |
| 2682-20-4 | 3-Isothiazolone, 2-methyl- | No | G3-4, G7-8 | Transport |
| 497-19-8 | Carbonic acid, disodium salt | Yes | G3-4, G7-8 | Transport |
| 7647-01-0 | Hydrochloric acid | Yes | G3-4, G7-8 | Transport |
| 7727-54-0 | Peroxydisulfuric acid, diammonium salt | Yes | G3-4, G7-8 | Transport |
| 7786-30-3 | Magnesium chloride (MgCl ₂) | No | N/A | N/A |
| 9000-30-0 | Guar gum | Yes | G3-4, G7-8 | Transport |

No spills were reported for each of the release points assessed in Working Site 5.

Storage Area 6 Northern Inland Catchments Bioregion

Intermediate Storage location and aquatic receptors

An intermediate chemical storage is located in the Balonne-Condamine Basin. The nearest aquatic receptors are unnamed creeks located at a distance of 0.26 to 0.77 km from the site. These creeks are not gauged. Therefore, the nearest gauged river or water body was used to represent the rivers near the intermediate storage facility. Refer to Appendix C for more detailed information on methodology for calculating PECs at aquatic receptor sites.

Ecological receptors

Many MNES and protected areas are identified in the subregion but all at significant distance from intermediate storage facility. The Murray Cod is listed as a vulnerable species under the EPBC Act and could potentially be found in the NIC Bioregion.

Risk estimation

The subset of chemicals used in drilling and fracturing activities for Storage Area 6 are listed in Table 3.32.

| CAS RN | Chemical Name | Associated with drilling or hydraulic fracturing |
|------------|---|--|
| 111-30-8 | Pentanedial / glutaraldehyde | drilling |
| 11138-66-2 | Xanthan gum | drilling |
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | drilling |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | drilling, hydraulic fracturing |
| 497-19-8 | Carbonic acid, monosodium salt | drilling |
| 497-19-8 | Carbonic acid, disodium salt | drilling |
| 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | hydraulic fracturing |
| 64-19-7 | Acetic acid | hydraulic fracturing |
| 7447-40-7 | Potassium chloride (KCl) | drilling, hydraulic fracturing |
| 7647-01-0 | Hydrochloric acid | hydraulic fracturing |
| 7647-14-5 | Sodium chloride (NaCl) | hydraulic fracturing |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | drilling, hydraulic fracturing |
| 9000-30-0 | Guar gum | hydraulic fracturing |

| Table 3.32 | Tier 3 assess | ment chemicals fo | r Storage Si | ite 6 Northern | Inland Catchment | s Bioregion |
|------------|---------------|-------------------|--------------|----------------|------------------|-------------|
| | 101 0 000000 | | n oloruge or | | | |

All eight drilling and hydraulic fracturing chemicals stored at the intermediate storage facility were predicted to have an RQ < 1 and therefore are considered of low concern to aquatic receptors at all points of release considered under the Tier 3 assessment conditions for this storage site. Chemical transport is not considered for the storage site, because it is considered under each Working Site.

No spills were reported in Storage Site 6.

3.3.4 Risk estimation

3.3.4.1 Drilling chemicals

Of the 12 drilling chemicals analysed at the Tier 3 level, 12 chemicals were predicted to have an RQ < 1 under seven of the eight release points assessed during single and multiple releases across the six sites. This indicates that these drilling chemicals, when used in current coal seam gas operations under the specified conditions of each site, are unlikely to have adverse environmental impacts if used in accordance with the assessment scenarios.

However, this assessment also found that eight chemicals (Table 3.33), when directly released to an aquatic environment because of a transport accident, across four sites represent either a potential concern (RQ values \geq 1 and < 10) or potentially high concern (RQ values \geq 10) to the environment. Working Site 2 showed RQ < 1 for all the release points assessed. Transport release points were not considered for Storage Area 6.

Detailed descriptions of the resulting Tier 3 RQs for each chemical are provided at Appendix E.

Table 3.33 Drilling chemicals

| CAS RN | Chemical Name | Working Site 1 | Working Site 2 | Working Site 3 | Working Site 4 | Working Site 5 (RQs) | |
|----------------|---|------------------------|----------------|-------------------------|-----------------------|-------------------------|-------------------------|
| | | (RQs) | (RQs) | (RQs) | (RQs) | Well G3-4 | Well G7-8 |
| Transport a | accident – Direct release to an | aquatic environme | nt | | | | |
| RQs ≥ 1 | | | | | | | |
| 111-30-8 | Pentanedial / glutaraldehyde | | | 5.64 5.90 6.18 | | | |
| 11138-66- 2 | Xanthan gum | 1.93 2.11 2.27 | | 45.29 47.35 49.60 | | 23.56 26.93 32.31 | 18.60 21.26 25.51 |
| 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | | | | | | |
| 1310-73-2 | Sodium hydroxide (Na(OH)) | | | | | 2.02 2.31 2.77 | 1.17 |
| 144-55-8 | Carbonic acid, monosodium salt | | | | | | |
| 497-19-8 | Carbonic acid, disodium salt | | | 2.82 2.95 3.09 | | | |
| 55566-30- 8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | | | | | 1.27 1.45 1.75 | |
| 7447-40-7 | Potassium chloride (KCI) | 9.87 10.79 11.60 | | | 6.46 8.64 12.07 | 26.12 29.86 35.83 | |
| 7647-14-5 | Sodium chloride (NaCl) | | | | | | |
| 7778-80-5 | Sulfuric acid, dipotassium salt | | | | | 184.24 210.55 | |

| CAS RN Che | Chemical Name | Working Site 1 | Working Site 2 | Working Site 3 | Working Site 4 (RQs) | Working Site 5 (RQs) | |
|------------|---|----------------------|----------------|----------------|-------------------------|-------------------------|-----------|
| | | (RQs) | (RQs) | (RQs) | | Well G3-4 | Well G7-8 |
| | | | | | | 252.66 | |
| 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | | | | | | |
| СВІ | Polymer with substituted alkylacrylamide salt | 6.00 6.56 7.05 | | | | 12.92 14.77 17.72 | |

Blank cell = chemical not in use at the particular working site or well

As indicated in Section 2.5.1.7, chemicals with $RQ \ge 1$ and < 10 are considered chemicals of potential concern, and risk mitigation measures may be required if the chemical is used. Chemicals with $RQ \ge 10$ are considered chemicals of potentially high concern, and specific risk mitigation measures are likely to be required if the chemical is used.

On this basis, the following chemicals, with RQs in the range of 1 to 10, are considered of potentially concern and therefore risk mitigation measures may be required if the chemical is used:

- Pentanedial / glutaraldehyde (111-30-8) in Working Site 3
- Xanthan gum (11138-66-2) in Working Site 1
- Sodium hydroxide (Na(OH)) (1310-73-2) in Working Site 5
- Carbonic acid, disodium salt (497-19-8) in Working Site 3
- Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) (55566-30-8) in well groups in Working Site 5
- Polymer with substituted alkylacrylamide salt (CBI) in Working Site 1
- Potassium chloride (KCl) (7447-40-7) in Working Sites 1 and 4.

The following chemicals, with RQs greater than 10, are considered of potentially high concern and therefore specific risk mitigation measures are likely to be required if the chemical is used:

- Xanthan gum (11138-66-2) in Working Sites 3 and 5
- Sulfuric acid, dipotassium salt (7778-80-5) in Working Site 5
- Polymer with substituted alkylacrylamide salt (CBI) in Working Site 5
- Potassium chloride (KCI) (7447-40-7) in Working Sites 1, 4 and 5.

3.3.4.2 Hydraulic fracturing chemicals

A similar analysis of the 15 hydraulic fracturing chemicals was also conducted (Table 3.34). Of the 15 hydraulic fracturing chemicals analysed at the Tier 3 level, 15 chemicals were predicted to have an RQ < 1 under seven release points assessed during single and multiple releases across the six sites. Again, this indicates that these hydraulic fracturing chemicals, when used in current coal seam gas operations under the specified conditions, are unlikely to have adverse environmental impacts.

This assessment also found that 10 chemicals (Table 3.34) when directly released to an aquatic environment from a transport accident across the four sites represent a potential concern (RQ values \geq 1 and < 10) or potentially high concern (RQ values \geq 10) to the environment. Working Site 2 showed RQ < 1 in all the release points assessed and Storage area 6 did not considered a transport release point.

Detailed descriptions of the resulting Tier 3 RQs for each chemical are provided at Appendix E.

Table 3.34 Hydraulic fracturing chemical

| CAS RN | Chemical Name | Working site 1 (RQs) | Working site 2 (RQs) | Working site 3 (RQs) | Working site 4 (RQs) | Working site5 (RQs) | |
|--|--|----------------------------|----------------------------|----------------------------|----------------------------|---------------------------|--|
| Transport accident – Direct release to an aquatic environment RQs ≥ 1 | | | | | | | |
| 10043- 35-3 | Boric acid (H ₃ BO ₃) | | | | | 46.92 53.62 64.35 | |
| 107-21-1 | 1,2-Ethanediol | | | | | | |
| 11138- 66-2 | Xanthan Gum | | | | | | |
| 1310-73- 2 | Sodium hydroxide (Na(OH)) | 2.22 2.43 2.61 | | 3.44 3.60 3.77 | | | |
| 26172- 55-4 | 3(2H)-Isothiazolone, 5- chloro-2-methyl- | | | 31.21 32.62 34.18 | 5.80 7.76 10.83 | 1.66 1.90 2.28 | |
| 2682-20- 4 | 3-Isothiazolone, 2- methyl- | | | 6.96 7.28 7.63 | 1.29 1.73 2.42 | | |
| 497-19-8 | Carbonic acid, disodium salt | | | | | 1.57 1.80 2.16 | |
| 55566- 30-8 | Phosphonium, tetrakis(hydroxymethyl)- , sulfate (2:1) (salt) | | | | | | |
| 64-19-7 | Acetic acid | | | | | | |
| 7447-40- 7 | Potassium chloride (KCI) | | | 131.07 137.02 143.55 | | | |
| 7647-01- 0 | Hydrochloric acid | 1.37 1.50 1.61 | | 2.24 2.35 2.46 | | 1.08 1.23 1.47 | |
| 7647-14- 5 | Sodium chloride (NaCl) | | | 6.92 7.24 7.58 | | | |
| 7727-54- 0 | Peroxydisulfuric acid, diammonium salt | | | | 4.22 5.64 7.88 | 22.28 25.47 30.56 | |
| 77-92-9 | 1,2,3- Propanetricarboxylic acid, 2-hydroxy- | | | | | | |
| 9000-30- 0 | Guar gum | 23.06 25.20 27.09 | | 72.43 75.72 79.33 | 10.78 14.42 20.13 | 16.67 19.06 22.87 | |

Blank cell = chemical not in use at the particular work-site or well

As with drilling, on the basis that the RQ is in the range of 1 to 10, these chemicals are considered of potentially concern and therefore further risk mitigation measures may be required if the chemical is used:

- Sodium hydroxide (Na(OH)) (1310-73-2) in Working Sites 1 and 3
- 3(2H)-Isothiazolone, 5-chloro-2-methyl- (26172-55-4) in Working Sites 4 and 5
- 3-Isothiazolone, 2-methyl- (2682-20-4) in Working Sites 3 and 4
- Carbonic acid, disodium salt (497-19-8) in Working Site 5
- Hydrochloric acid (7647-01-0) in Working Sites 1, 3 and 5
- Sodium chloride (7647-14-5) in Working Site 3
- Peroxydisulfuric acid, diammonium salt (7727-54-0) in Working Site 4.

On the basis that the RQ is greater than 10, these chemicals are considered of potentially high concern and therefore specific risk mitigation measures are likely to be required if the chemical is used:

- Boric acid (H₃BO₃) (10043-35-3) in Working Site 5
- 3(2H)-Isothiazolone, 5-chloro-2-methyl- (26172-55-4) in Working Site 3
- Potassium chloride (KCI) (7447-40-7) in Working Site 3
- Peroxydisulfuric acid, diammonium salt (7727-54-0) in Working Site 5
- Guar gum (9000-30-0) in Working Sites 1, 3, 4 and Working Site 5.

3.3.4.3 Findings of the deterministic risk assessments

The chemicals that were identified as being of low concern, using the deterministic risk assessment approach are listed in Table 3.35.

| | CAS RN | Chemical Name | Alternative name |
|----|------------|---|-----------------------------|
| 1 | 10043-52-4 | Calcium chloride (CaCl ₂) | Calcium chloride |
| 2 | 107-22-2 | Ethanedial | Glyoxal |
| 3 | 67-56-1 | Methanol | |
| 4 | 107-21-1 | 1,2-Ethanediol | Ethylene glycol |
| 5 | 111-76-2 | Ethanol, 2-butoxy- | Ethylene glycol butyl ether |
| 6 | 1305-62-0 | Calcium hydroxide (Ca(OH) ₂) | Slaked lime |
| 7 | 144-55-8 | Carbonic acid, monosodium salt | Sodium bicarbonate |
| 8 | 64-19-7 | Acetic acid | |
| 9 | 7786-30-3 | Magnesium chloride (MgCl ₂) | Magnesium chloride |
| 10 | 77-92-9 | 1,2,3-Propanetricarboxylic acid, 2-hydroxy- | Citric acid |

Table 3.35 Coal seam gas chemicals assessed to be of low concern

The chemicals that were found to be of potential concern or high concern after Tier 3 assessment in the event of direct release to an aquatic ecosystem from a transport accidents are listed in Table 3.36.

| | CAS RN | Chemical Name | Alternative name |
|----|------------|---|--|
| 1 | 10043-35-3 | Boric acid (H ₃ BO ₃) | Boric acid |
| 2 | 111-30-8 | Pentanedial | Glutaradehyde |
| 3 | 11138-66-2 | Xanthan gum | |
| 4 | 1310-73-2 | Sodium hydroxide (Na(OH)) | Caustic soda |
| 5 | 26172-55-4 | 3 <i>(2H)</i> -Isothiazolone, 5- chloro-2-methyl- | Methylchloroisothiazolinone |
| 6 | 2682-20-4 | 3-Isothiazolone, 2-methyl- | Methylisothiazolinone |
| 7 | 497-19-8 | Carbonic acid, disodium salt | Sodium carbonate |
| 8 | 55566-30-8 | Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) | Tetrakis(hydroxymethyl)- phosphonium sulfate |
| 9 | 7447-40-7 | Potassium chloride (KCI) | Potassium chloride |
| 10 | 7647-01-0 | Hydrochloric acid | Muriatic acid |
| 11 | 7647-14-5 | Sodium chloride (NaCl) | Table salt |
| 12 | 7727-54-0 | Peroxydisulfuric acid, diammonium salt | Ammonium persulfate |
| 13 | 7778-80-5 | Sulfuric acid, dipotassium salt | Potassium sulfate |
| 14 | 9000-30-0 | Guar gum | |
| 15 | СВІ | Polymer with substituted alkylacrylamide salt | |

Table 3.36 Coal seam gas chemicals assessed to be of potential concern

3.3.4.4 Chemical fate and effects

A search for physico-chemical and ecotoxicological data for the chemicals considered during the assessment found limited information, which is used here to discuss the chemicals fate and behavior in the receiving aquatic environment. Most modelled values found were categorised as of low or unknown quality and were not used during the assessment¹¹. In this section, these values are used only to infer the chemical fate and behavior in the receiving aquatic environment (see DoEE 2017b and Appendix A).

The physico-chemical characteristics and the environmental fate and effects of the 15 chemicals with $RQ \ge 1$ during transport accidents directly releasing to an aquatic ecosystem are summarised below. None of the other release points had predicted $RQs \ge 1$.

Sodium chloride and potassium chloride

In the coal seam gas industry, sodium chloride (7647-14-5) and potassium chloride (7447-40-7) are used as stabilisers or preservatives (DoE 2014). Potassium chloride is a solid

¹¹ Values categorised as of high quality were only used during the calculation of PECs. The values categorised as reliable are reported in the physic-chemical section (chapter 3).

inorganic salt that is highly soluble in water (342 g/L at 20°C) and fully dissociates in aqueous solutions to K⁺ and Cl⁻ ions (OECD 2001). Potassium chloride is ubiquitous in the environment, existing either as an inorganic salt or as potassium and chloride ions. Potassium and chloride ions are essential to all living organisms. As the intracellular and extracellular concentrations of potassium and chloride ions are regulated by organisms, there is low potential for bioaccumulation (OECD 2001). Information on the physico-chemical properties for sodium chloride was not available, but the environmental behaviour of this chemical is expected to be similar to that described for potassium chloride.

Sodium chloride and potassium chloride have very low toxicity to fish (LC50 1 290 mg/L and 880 mg/L respectively) and *Daphnia* (chronic NOEC 314 mg/L and 373 mg/L respectively; ECHA 2013b). Furthermore, these chemicals are amongst the major constituents of salinity in surface waters in Australia (Dunlop et al. 2008). For such chemicals the use of safety (assessment) factors in predicting the PNEC for ecosystems from short-term laboratory studies is limited (Kefford and Nugegoda 2004). This is due to salt tolerance or acquisition of salt tolerance due to previous exposure to saline environments in some species, a non-monotonic response to increasing salinity, and indirect effects of salinity such as changes in nutrient cycling, and die-back of adjacent riparian areas which provide shelter or shade (Dunlop et al. 2008; Kefford et al. 2005; Rutherford and Kefford 2005; Schafer et al. 2011).

Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects as these salts are ubiquitous and are present in most water, soil and sediment, therefore organisms are adapted to a level of exposure. The magnitude of the acute effect for a receiving aquatic environment would depend on the released concentrations as well as the degree of adaptation of species present to these naturally occurring ions and salts.

Tetrakis(hydroxymethyl)phosphonium sulfate

In the coal seam gas industry, phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) (55566-30-8) is used for its biocide properties (DoE 2014).

Tetrakis(hydroxymethyl)phosphonium sulfate is fully miscible in water. However, it is not persistent in the aquatic system as it undergoes rapid mineralisation (Health Canada 2010). Tetrakis(hydroxymethyl)phosphonium sulfate has limited potential to partition into sediment or organic matter (Health Canada 2010) and is not expected to be present in air as indicated by its negligible Henry's Law constant (K_H).

Phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) has low toxicity to fish (LC50 for 94 mg/L, ECHA 2013b). Release to surface waters under the assessed circumstances is not expected to have long-term environmental effects due to its rapid mineralisation. The acute effect for the receiving aquatic environment would depend on the released concentrations and the rate of removal of the chemical through degradation, and dilution.

Polymer with substituted alkylacrylamide salt

Modelling results indicate that polymer with substituted alkylacrylamide salt (CBI) is highly water soluble, and has a negligible octanol-water coefficient, which indicate that it has low potential to accumulate in living organisms and that it could be easily dissipated (under the appropriate flow conditions) in natural waters. Also, studies showed that it is readily biodegraded and therefore not persistent (ECHA 2015).

Polymer with substituted alkylacrylamide salt has very low toxicity to fish (LC50 is 680 to 3 550 mg/L, ECHA 2013b). The acute effect for the receiving aquatic environment could depend on the released concentrations and rate it is removed through degradation, and dissipation (dilution).

Sulfuric acid, dipotassium salt

Sulfuric acid, dipotassium salt (7778-80-5) is highly water soluble, suggesting that it could be dissipated (under the appropriate flow conditions) in natural waters.

Sulfuric acid, dipotassium salt has low toxicity to fish (LC50 is 34 to 162 mg/L, ECHA 2013b and QSAR) but is very toxic to algae (EC50 is 0.397 mg/L QSAR). Release to surface waters under the assessed circumstances may have limited long-term environmental effects because it is readily biodegraded and therefore not considered to be persistent. The acute effect for the receiving aquatic environment would depend on the released concentrations and the rate it is removed through degradation, and dissipated (dilution).

Boric acid

In the coal seam gas industry, boric acid (10043-35-3) is used as cross-linker to increase the viscosity of gelling agents and can also be used for its biocide properties (DoE 2014).

In natural waters, boron forms a stable species and exists primarily as undissociated boric acid (B(OH)₃) and complex polyanions (e.g., B(OH)₄⁻). These forms of boron are highly soluble and are not easily removed from solution by natural mechanisms (i.e. persistent molecule, not subject to hydrolysis, photodegradation or biodegradation) with low potential to adsorb to particulate matter and surfaces. Borate and boric acid are in equilibrium depending on the pH of the water. At acidic pH, boron exists in solution mainly as undissociated boric acid, whereas at alkaline pH it is present as borate ions (Canadian Council of Ministers of the Environment 2009, European Union 2007). Also, based on its properties, boric acid is not expected to significantly partition to sediment (Canadian Council of Ministers of the Environment 2009, European Union 2007).

Boric acid has very low toxicity to fish (LC50 for fish is 447 mg/L) but it is toxic to *Daphnia* (chronic NOEC is 2.1 – 6 mg/L, ECHA 2013b). Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects as boric acid has relatively low chronic aquatic toxicity to aquatic organisms and because boric acid is ubiquitous in most water, soil and sediment, and organisms are adapted to a level of exposure. The acute effect for the receiving aquatic environment would depend on the released concentrations, the pH of the natural water and the rate it is dissipated (dilution).

Hydrochloric acid

In the coal seam gas industry, hydrochloric acid is used to dissolve calcite in the coal prior to fracturing (DoE 2014). Hydrochloric acid is a very strong acid and it is formed when hydrogen chloride gas is dissolved in water. When this happens the hydrogen chloride reacts with the water and dissociates completely to give hydronium cations and chloride anions. (The water solubility of hydrogen chloride is 823 g/L at 0°C; 637 g/L at 30°C; OECD 2002b).

Biodegradation is not applicable to hydrochloric acid because both the hydronium and chloride ions are ubiquitous inorganic ions that are present in most water, soil and sediment (OECD 2002a, OECD 2002d).

Hydrochloric acid in water decreases the pH in the aquatic ecosystem. The degree to which pH is decreased depends on the buffer capacity of the aquatic ecosystem, which is described by the following equilibrium equations between CO_2 , HCO_3 - and CO_3^{2-} :

 $CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$ (pKa1 = 6.35) [Equilibrium Equation 1]

 $HCO_{3} \leftrightarrow CO_{3}^{2} + H^{+} (pKa2 = 10.33)$ [Equilibrium Equation 2]

Hydrochloric acid is toxic to fish (LC50 4.92 mg/L) and has low toxicity to *Daphnia* (LC50 62 mg/L, ECHA 2013b). Release to surface waters under the assessed circumstances will have limited long-term environmental effects because hydronium and chloride ions are ubiquitous in most water, soil and sediment systems and most aquatic organisms are adapted to a level of exposure. The acute effect to the receiving aquatic environment would depend on the released concentrations, the pH and buffer capacity of the natural waters, and the rate it is diluted through the water column.

Carbonic acid, disodium salt

In the coal seam gas industry, carbonic acid, disodium salt (CAS RN 497-19-8) is normally used to keep the pH of the fluid in a specified range (DoE 2014). Carbonic acid, disodium salt has high water solubility and very low vapour pressure so it will be distributed to the aquatic environment on release (OECD 2002e). In natural waters, sodium carbonate dissociates and exists as sodium and carbonate ions. Carbonic acid, disodium salt naturally occurs widely, existing in the environment as sodium and carbonate ions (OECD 2002e, UNEP 1995). The hazard of sodium carbonate for the environment is mainly caused by the pH effect of the carbonate ion. For this reason the effect of sodium carbonate on the organisms depends on the buffer capacity of the aquatic system to which it is released.

The acute toxicity of sodium carbonate for aquatic organisms depends to a significant extent on the buffer capacity of the test medium (OECD 2002e, OECD 2002f). Carbonic acid, disodium salt has very low toxicity to fish (LC50 300 - 320 mg/L) and *Daphnia* (chronic LC50 424 mg/L, ECHA 2013b). Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects because sodium and carbonate ions are ubiquitous in the environment and most aquatic organisms are adapted to a level of exposure. The acute effect to the receiving aquatic environment would depend on the released concentrations, the pH, buffer capacity, and chemical composition of the natural waters and on the rate it is diluted through the water column.

Sodium hydroxide

In the coal seam gas industry, sodium hydroxide (CAS RN 1310-73-2) is used to keep the pH of the fluid in a specified range (DoE 2014). Sodium hydroxide is a strongly alkaline substance that dissociates fully in water. The concentration of hydroxide ion (OH⁻) is regulated by the equilibrium between CO_2 , HCO_3^{-1} and $CO_3^{2^-}$. The buffer capacity is in turn determined by the relative concentrations of these substances. Sodium hydroxide solidifies at 20°C when its concentration in water is higher than 52% by weight (this can be considered the maximum water solubility at 20°C). An exothermic reaction occurs when NaOH is added to water and if the amount of NaOH that is added is close to the limit of its solubility the reaction can be very vigorous. Sodium hydroxide is very mobile in soil (OECD 2002g, OECD 2002h).

In natural waters, sodium hydroxide will dissociate and exist in the form of sodium and hydroxide ions. Both sodium and hydroxide ions are ubiquitous in the natural environment. Atmospheric emissions of sodium hydroxide are rapidly neutralised by CO₂ (or other gaseous acids) and the resultant salts (e.g. sodium carbonate) are washed out by rain. Therefore, potential atmospheric emissions of sodium hydroxide are not considered to be of concern. Small terrestrial emissions of sodium hydroxide will be neutralised by the buffer capacity of the soil (OECD 2002g, OECD 2002h).

Sodium hydroxide has very low toxicity to fish (LC50 196 mg/L) and *Daphnia* (chronic LC50 240 mg/L ECHA 2013b). Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects because sodium and hydroxide ions are ubiquitous in nature and most aquatic organisms are adapted to a level of exposure. The acute effect to the receiving aquatic environment would depend on the released

concentrations, the pH and buffer capacity of the natural waters, and on the rate it is diluted through the water column.

Peroxydisulfuric acid, Diammonium salt

In the coal seam gas industry, peroxydisulfuric acid, diammonium salt (CAS RN 7727-54-0) is used to break the bonds of the gel in order to reduce the viscosity back to that of water (DoE 2014). Ammonium persulfate is soluble in water and has a negligible vapour pressure. On release into the environment, ammonium persulfate will be distributed into the water compartment in the form of ammonium and persulfate ions. Aqueous ammonium persulfate is expected to degrade in the environment mainly through hydrolysis, but metal catalysed decomposition and reactions with organic chemicals present in the soil or water are also possible (OECD 2005d, OECD 2005e). Ammonium persulfate is not expected to adsorb to soil due to its dissociation properties, instability (hydrolysis) and high water solubility (OECD 2005d, OECD 2005e).

Peroxydisulfuric acid, diammonium salt is of low toxicity to *Daphnia* (EC50 140 mg/L, and chronic NOEC *Daphnia* is 10 mg/L (OECD 2005a)). Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects due to the low chronic toxicity to aquatic organisms and because it is expected to readily degrade in water. The acute effect to the receiving aquatic environment would depend on the released concentrations, and the rate it is removed through degradation, and dissipation (diluted) through the natural waters.

(2H)-Isothiazolone, 5-chloro-2-methyl-, 3-Isothiazolone, 2-methyl-, and Pentanedial/Glutaraldehyde

In the coal seam gas industry, (2H)-Isothiazolone, 5-chloro-2-methyl-, 3-Isothiazolone, 2methyl-, and Pentanedial / glutaraldehyde (CAS RNs 26172-55-4, 2682-20-4 and 111-30-8, respectively) are used for their biocide properties (DoE 2014). The available modelling results they are highly soluble in water and have lower affinity for organic matter, suggesting they will be primarily distributed to the water column on release with low potential to adsorb to particulate matter and surfaces. The negligible octanol-water coefficients of these chemicals suggests that they have low potential to bioaccumulate.

Furthermore, biodegradability tests and their modelled half life in water (ECHA 2015) suggest that pentanedial / gluteraldehyde and 3-lsothiazolone, 2-methyl- will readily degrade in the aquatic environment and will not be persistent. However, 3(2H)-isothiazolone, 5-chloro-2-methyl- is expected to be more resistant to biodegradation than its non-chlorinated congener.

3(2H)-Isothiazolone, 5-chloro-2-methyl-, and 3-Isothiazolone, 2-methyl-, are toxic to highly toxic to aquatic organisms (LC50 for fish is 0.19 to 2.13 mg/L, EC50 for algae is 3.49 mg/L and EC50 for Daphnia is 0.062 mg/L; and LC50 for fish is 0.07 to 0.19 mg/L, EC50 for algae is 4.48 mg/L and EC50 for *Daphnia* is 6.7, respectively, ECHA 2013b). Pentanedial / Glutaraldehyde in general has low toxicity to aquatic organism (LC50 for fish is 3.5 to 23.9 mg/L, EC50 for algae is 2.87 mg/L EC50 for *Daphnia* is 16.3 mg/L, and, the NOEC for *Daphnia* is 2.1 mg/L, Pereira et al. 2014; ECHA 2013b). Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects. The acute effect to the receiving aquatic environment would depend on the released concentrations, and the rate that they are removed through degradation, and dissipation (dilution) through the water column.

Guar gum and Xanthan gum

Guar gum (CAS RN 9000-30-0) and xanthan gum (CAS RN 11138-66-2) are used for controlling the viscosity of drilling fluids (DoE 2014). Xanthan gum is a high molecular weight

anionic polysaccharide secreted by the bacteria *Xanthomonas compestris* (TDS Xanthan Gum). Guar gum is a high molecular weight carbohydrate derived from the seed of the guar plant (*Cyanopsis tetragonolobus*) (US EPA 2005).

Guar gum adsorbs strongly to soil and sediment and there is limited potential for guar gum to reach surface waters via dissolved runoff and / or to leach into ground water. Volatilisation from soils and water is not considered to be a likely transport process in the environment (US EPA 2005). Guar gum is expected to readily undergo microbial biodegradation in the environment (on the bases that is polysaccharide and expected to be readily biodegradable), and the potential to bioaccumulate in organisms is considered to be low (US EPA 2005). There is no information available for xanthan gum to enable prediction of the fate and behaviour in the receiving environment. However, xanthan gum is expected to exhibit similar behaviour to that of guar gum because the two compounds are chemically similar.

Guar gum and xanthan gum have very low toxicity to fish (LC50 for fish is 218 mg/L and 420 mg/L, respectively ECHA 2013b). Release to surface waters under the assessed circumstances is unlikely to have long-term environmental effects because these carbohydrate chemicals are expected to be readily biodegradable. The acute effect to the receiving aquatic environment would depend on the released concentrations and on the rate that they are removed through sorption, settling and degradation in the sediment.

3.3.5 Summary

For the salts (e.g. sodium chloride), acids (e.g. hydrochloric acid) and alkaline chemicals (e.g., sodium hydroxide) the risk may be overestimated by the deterministic model as these chemicals are highly water soluble and are readily dissipated in water flowing through an aquatic system. Additionally, the magnitude of the effects caused by these chemicals will be affected by the conditions of the receiving aquatic ecosystems (e.g. pH, buffering capacity, etc). Ecotoxicity studies and modeling results indicate that most of these chemicals have low to very low toxicity to aquatic organisms. Release to surface waters under the assessed circumstances is expected to have limited long-term environmental effects because the dissociation products of these chemicals are ubiquitous in most water, soils and sediments. These chemicals typically have low chronic aquatic toxicity to aquatic organisms and most organisms are adapted to some level of continuous exposure. The acute effect to the receiving aquatic environment, for the acids and alkaline substances, would depend on the released concentrations, the pH, buffer capacity of the receiving environment, chemical composition of the receiving natural waters, and the rate of dissipation through the water column. For the salts, the toxicity to the receiving aquatic environment would depend on the released concentrations as well as existing concentrations of these salts in the receiving environment, and the level of adaptation that species have to them.

The predicted risk for organic chemicals may be overestimated because their degradation in the water column was not considered as a component of the estimation of PECs due to the lack of reliable data. Available ecotoxicity and modelling studies indicate that most chemicals have low to very low toxicity to aquatic organisms although there are some exceptions¹². Some of the assessed organic chemicals¹³ are highly soluble in water and have low affinity for organic matter, suggesting that they will be primarily distributed to the water column on release and that they will have low potential to accumulate in living organisms provided that they are not persistent in the aquatic environment. Other assessed organic chemicals¹⁴ may adsorb strongly to soil and sediment particles and settle to sediment in aquatic ecosystems, but the expected bioaccumulation potential is low. Release to surface waters under the

¹² e.g. 5-chloro-2-methyl-, and 3-Isothiazolone, 2-methyl-

¹³ e.g. 3-Isothiazolone, 2-methyl.

¹⁴ e.g. guar gum

assessed circumstances is expected to have limited long-term environmental effects because these chemicals can degrade in aquatic environment. The magnitude of the acute effect for the receiving aquatic environment would depend on the released concentrations, the rate they are removed through degradation, and dissipation (dilution) through the water column or on the rate that they are removed through sorption, settling and degradation in the sediment.

Furthermore, although reuse for irrigation and dust suppression showed RQ < 1 for aquatic ecosystems for each of the assessed chemicals, there are some chemicals that may accumulate in soils due to their physico-chemical properties and the ongoing applications of waste fluids to terrestrial compartments. Chemicals that may accumulate in soils include salts (such as sodium and potassium chloride), boron-containing chemicals and mineral acid and alkaline substances.

3.4 Risk management

3.4.1 Existing regulatory measurements

Australia has a robust regulatory framework for environmental management of industrial chemicals. Regulation by agencies in the states and territories is applicable to the coal seam gas industry. In general, regulation mandates responsible management and use of chemicals and requires users to take all reasonable measures to avoid unnecessary release of chemicals to the environment resulting from handling, transport, use or waste disposal.

Details of various codes and regulations used in NSW and Queensland to manage the risks associated with transport, storage, handling, use and waste disposal of industrial chemicals, including coal seam gas chemicals, are described in Appendix F.

Below is a summary of several NSW, Queensland and national codes and regulations that apply to transport and storage of chemicals used in coal seam gas operations:

- Australian Dangerous Goods Code (DIRD 2015): Sets out a range of requirements for workers and organisations including training, routes, goods too dangerous to be transported by road, packaging, incompatibility etc. Also places specific duties on consignors, packers, loaders and drivers to comply. <u>http://www.ntc.gov.au/heavyvehicles/safety/australian-dangerous-goods-code/</u>
- Dangerous Goods Driver Licence (Qld): Ensures drivers are trained to act appropriately when driving vehicles that carry dangerous goods including chemicals. <u>http://www.qld.gov.au/transport/licensing/driver-</u> <u>licensing/applying/dangerous/driver/index.html</u>
- Dangerous Goods Driver Licence (NSW): Ensures drivers are trained to act appropriately when driving vehicles that carry dangerous goods including chemicals. <u>http://www.epa.nsw.gov.au/dangerousgoods/training.htm</u>
- Work Health and Safety Act 2011 (Qld): Chemical transport companies and officers or persons conducting a business are required to have systems in place to ensure staff are protected from risks caused by crashes and spills. These are in combination with the specific requirements and duties set out in the Dangerous Goods Code. https://www.legislation.gld.gov.au/LEGISLTN/CURRENT/W/WorkHSA11.pdf
- Work Health and Safety Act 2011 (NSW): Chemical transport companies and officers or persons conducting a business are required to have systems in place to ensure staff are protected from risks caused by crashes and spills. These are in combination with

the specific requirements and duties set out in the Dangerous Goods Code.<u>http://www.legislation.nsw.gov.au/maintop/view/inforce/act+10+2011+cd+0+N</u>

- Protection of the Environment Operations Act 1997 (NSW): Chemical transporters are required to ensure that risks of spilling chemicals (both during transit and transfer operations) are mitigated. These could include transferring chemicals in contained hard-stand areas, and having spill response procedures etc.) http://www.epa.nsw.gov.au/legislation/aboutpoeo.htm#P90_6221
- Environmental Protection Act 1994; Environmental Protection Regulation 2008 ERA 8 (Qld): Seeks to ensure that the environmental risks of chemical storage and handling activities is adequately controlled. It would be unlikely facilities would be approved in close proximity to aquatic ecosystems or other environmentally sensitive areas. https://www.legislation.qld.gov.au/LEGISLTN/CURRENT/E/EnvProtR08.pdf
- Environmental Protection Licence Chemical Storage (NSW): Seeks to ensure that environmental risk of the chemical storage and handling activities is adequately controlled. It would be unlikely that a facility would be approved in close proximity to aquatic ecosystems or other environmentally sensitive areas. <u>http://www.legislation.nsw.gov.au/fragview/inforce/subordleg+211+2009+sch.1+0+N?S</u> <u>RTITLE=%22Protection%20of%20the%20Environment%20Operations%20(General)%</u> <u>20Regulation%202009%22&nohits=y&tocnav=y</u>

3.4.2 Discussion

The conditions hypothesised for the models used in deterministic risk assessments of chemicals have a significant effect on the predicted RQs. In this study, the release scenario and the site-specific conditions were the main determinants of the predicted RQs and the resulting risk assessment. For example, depending on site-specific conditions, carbonic acid disodium salt may be assessed as either of potential concern or of low concern. Differences in the predictions of these deterministic assessments reflect the magnitude of the adverse effects that may result from accidental release of a chemical where the characteristics of the local environment where the release occurs differ.

Of the 20 chemicals analysed at Tier 3 (over four work-sites), there were 15 chemicals assessed to be of potential concern ($RQ \ge 1$ and < 10) or potentially high concern ($RQ \ge 10$) for scenarios involving direct release to an aquatic ecosystem from a transport accident. None of the other release scenarios resulted in predicted $RQs \ge 1$ for any chemical.

On the basis of this study, the drilling chemicals that are assessed to be of potentially high concern are: sulfuric acid potassium salt (1:2) (CAS RN 7778-80-5), xanthan gum (CAS RN 11138-66-2), polymer with substituted alkylacrylamide salt (CBI), and potassium chloride (CAS RN 7447-40-7).

The hydraulic fracturing chemicals that are assessed to be of potentially high concern chemicals are: potassium chloride (CAS RN 7447-40-7), guar gum (CAS RN 9000-30-0), boric acid (CAS RN 10043-35-3), 3(2H)-Isothiazolone, 5-chloro-2-methyl- (CAS RN 26172-55-4), and peroxydisulfuric acid ([(HO)S(O)₂]₂O₂), ammonium salt (1:2) (CAS RN 7727-54-0).

The drilling chemicals assessed to be of potential concern are: potassium chloride (CAS RN 7447-40-7), polymer with substituted alkylacrylamide salt (CBI), pentanedial (CAS RN 111-30-8), xanthan gum (CAS RN 11138-66-2), phosphonium, tetrakis(hydroxymethyl)-, sulfate (2:1) (salt) (CAS RN 55566-30-8), Carbonic acid sodium salt (1:2) (CAS RN 497-19-8) and sodium hydroxide (CAS RN 1310-73-2).

The hydraulic fracturing chemicals that are assessed to be of potentially concern are: 3(2H)-Isothiazolone, 5-chloro-2-methyl- (CAS RN 26172-55-4), sodium chloride (CAS RN 7647-14-5), peroxydisulfuric acid ([(HO)S(O)₂]₂O₂) ammonium salt (1:2) (CAS RN 7727-54-0), 3(2H)-Isothiazolone, 2-methyl- (CAS RN 2682-20-4), sodium hydroxide (CAS RN 1310-73-2), Carbonic acid sodium salt (1:2) (CAS RN 497-19-8) and hydrochloric acid (CAS RN 7647-01-0).

The Tier 3 results apply to the release scenarios and specific work-site conditions hypothesised in this study. If one of these chemicals was released into an aquatic ecosystem by a transport accident, under these conditions, then it is expected that adverse environmental effects would have occurred in that ecosystem.

However, industry reported that there were no spills of any of the chemicals assessed in this study, within 2 km of an aquatic receptor, during the period 2013 to 2015. Additionally, there were no reported transport accidents involving any of these chemicals at any of the worksites assessed in this study, during the period 2013 to 2015.

4 The qualitative risk assessment approach

Of the 113 chemicals¹⁵ reported to be in use by the Australian coal seam gas industry in the period between 2010 and 2012, there were 54 that did not have sufficient data to be assessed using a deterministic risk assessment.

This section summarises the results of the qualitative risk assessments for these 54 chemicals when they are used in coal seam gas extraction operations in Australia.

4.1 Introduction

The physico-chemical data available for most of the 54 chemicals in this group was limited and none of them had aquatic ecotoxicity data that was appropriate for quantitative calculations. These chemicals were subjected to an intensive process to compile, analyse and interpret the available scientific literature and were assessed using qualitative risk assessment approach based on weight of evidence and expert judgement. The methodology that was used for these qualitative risk assessments is described in Sections 4.2 to 4.11.

The assessments were focused on the potential environmental impact of the chemicals to surface waters, soils, and shallow groundwater, in accordance with the National Assessment. The potential impacts were considered in the context of release of chemicals arising from storage, handling, coal seam gas mining operations (drilling, fracking etc.), and disposal, during, subsequent to, and preceding coal seam gas extraction operations.

Of the 54 chemicals assessed using the qualitative approach, three were identified as being of potential environmental concern. These were: Boric acid, compound with 2-aminoethanol (CAS RN 26038-87-9); Boric acid, disodium salt ($H_2B_8O_{13}$) (CAS RN 12008-41-2); and Borax (CAS RN 1303-96-4) based on their potential to cause localised toxicity in plants under certain environmental conditions.

The remaining 51 chemicals were assessed as being of low concern to the environment, based on the assessments and associated assumptions outlined in this report.

4.2 Qualitative risk assessments

The Department of the Environment and Energy used the *Environmental Risk Assessment Guidance Manual for Industrial Chemicals* (EPHC 2009a) as its primary reference for conducting the qualitative risk assessments. The methods for environmental risk assessment described in this guidance manual are based on international best practice for conducting environmental risk assessment of chemicals (e.g. SETAC 2004, US EPA 2014b, US NRC 1983, US NRC 1994, US NRC 2009, Environment Canada 2003).

The manual provides the Department and other risk assessors with guidance to assist them to assess the environmental risks of industrial chemicals, including using qualitative assessments when quantitative assessments cannot be performed.

¹⁵ For ease of discussion, the term 'chemicals' will be used to refer to the all chemicals, substances and / or materials identified in NICNAS 2016a.

The manual recommends that qualitative assessments, based on expert judgement, should be used when no data or analogue data are available for a chemical and modelling predictions are not possible. The manual recommends the approach developed by Environment Canada and described in Environment Canada (2003). This document provides guidance for applying expert judgement to matters including:

- Creating a weight of evidence to support the selection of pivotal information
- Qualitative analysis of degradation and persistence of chemicals
- Qualitative analysis of bioaccumulation
- Qualitative analysis of inherent ecotoxicity.

The Canadian approach to qualitative assessment of chemicals with limited data informed the methodology that is used in Australia for assessment of existing industrial chemicals under the Inventory Multi-tiered Assessment and Prioritisation Framework (IMAP). This Framework operates under the National Industrial Chemicals Notification and Assessment Scheme (NICNAS 2015a). The qualitative assessments of the 54 chemicals with limited data (Appendix G) were conducted in accordance with the IMAP Framework and the Canadian approach.

4.3 **Problem formulation**

Relevant factors such as the natural occurrence of the chemical or components of the chemical in the environment and their typical background levels together with abiotic and / or biotransformation of chemicals or materials into other species were considered when planning the focus of the assessment for each chemical or group of chemicals.

A default exposure scenario was used to characterise exposure in all cases: it was assumed that all of these chemicals and materials may come to be present in surface soil, surface water or shallow groundwater as a result of coal seam gas operations. Accidental releases were assumed to be mitigated by emergency management procedures such as those required under the National Standard for the Storage and Handling of Workplace Dangerous Goods (NOHSC: 1015 (2001)) and the *Queensland Work Health and Safety Act 2011* (Qld WHS 2011).

4.4 Pre-assessment profile

International regulatory information was reviewed for each assessment to identify any existing controls or concerns, including whether the substances in question were listed in international treaties to which Australia is a signatory. The international treaties reviewed were:

- The Stockholm Convention on Persistent Organic Pollutants (FAO UNEP 2009). This treaty aims to protect human health and the environment from persistent organic pollutants. Parties to the treaty take measures to eliminate the production, import and export of certain persistent organic pollutants and restrict the production of certain others.
- The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. The objective of this Convention is 'to promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm and to contribute to their environmentally sound use, by facilitating information exchange about their

characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to Parties'. (FAO UNEP 1998).

• The Montreal Protocol on Substances that Deplete the Ozone Layer (UNEP 1987). This treaty is aimed at protecting the ozone layer by phasing out substances that deplete it, including chlorofluorocarbons and hydrochlorofluorocarbons.

Also reviewed were:

- The Candidate List of Substances of Very High Concern (SVHC) for Authorisation (ECHA 2013a). This list identifies SVHCs under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation in the European Union (European Commission 2015).
- The Priority List of Substances for Further Evaluation of their Role in Endocrine Disruption under the European Union Community Strategy for Endocrine Disruptors (European Commission 2001).
- The List of Chemicals for Initial Tier 1 Screening (US EPA 2009) and the Draft Second List of Chemicals for Tier 1 Screening (US EPA 2014d) under the United States Environmental Protection Agency Endocrine Disruptor Screening Program.

If the chemical under consideration was identified as being subject to one of these international treaties or listed as an SVHC or for screening for endocrine activity, this was recorded. It should be noted that being subject to one of these international treaties, or listed as an SVHC or for screening for endocrine activity, does not necessarily mean that the substance has previously been assessed using a process analogous to that presented here.

4.5 Grouping

Information about the 54 chemicals and materials considered in this assessment was gathered and reviewed. Information was from scientific literature and included data from experiments on chemical solubility, toxicity, and use, and literature on chemical and / or material behaviour and occurrence in the environment.

The information gathered was used to group chemicals and materials together. The process for establishing groupings was based on that developed for the Inventory Multi-tiered Assessment and Prioritisation Framework being conducted for NICNAS (2015a).

Grouping increased the efficiency of the assessment process. Silica (SiO₂), quartz (SiO₂), and cristobalite (SiO₂) were all grouped together, for example, on the basis of these materials being different forms of silica and having similar predicted behaviour in the aquatic environment. The basis for chemical and material groupings and their predicted behaviour in the environment is presented in Appendix G.

4.6 Sources of information

A wide range of resources were consulted during the assessment process. Physico-chemical and toxicological data were obtained from the databases in the OECD QSAR Toolbox (LMC 2013), textbooks and the peer-reviewed literature. Other sources of information include reports published by regulatory peers such as the United States Environmental Protection Agency and the United Nations Environment Programme, publically available industry data, and information provided as a result of an industry survey (NICNAS 2017a). Data obtained using these sources were evaluated using the principles of reliability, relevance, adequacy, and weight of evidence, as outlined below.

4.7 Analogue and modelled data

Where certain information relating to a chemical or material was not available, appropriate analogues for the chemical or material were identified wherever possible. Additional data were not necessary if the potential for a particular environmental hazard was expected to be low based on information about other relevant properties. For example, a lack of suitable toxicity endpoints was not critical if information was available to suggest that the substance was not bioavailable.

The use of modelling was typically limited to characterisation of physico-chemical properties for a small number of simple organic substances. More widespread use was inappropriate due to the nature of the chemicals being assessed. The chemical modelling tools used during the assessment of these substances have been designed for organic substances, and are recommended for use only with certain substances which meet domain criteria. For example, inorganic substances are outside of the domain of these models.

Through the identification of data for the substances under assessment, and the use of data for analogue chemicals or modelled data, where necessary, it was possible to compile sufficient information to allow for robust assessments of all 54 chemicals using a qualitative approach.

As for available empirical information, data obtained for analogues or by modelling were evaluated using the principles of reliability, relevance, adequacy, and weight of evidence.

4.8 Reliability, relevance, and adequacy of data

The data presented in scientific literature differs in quality. For example, some data may have been collected using methods and tests that are now recognised to be unreliable; or without appropriate checks to ensure the data are reproducible. For this reason, the potential for data to provide an accurate indication of the behaviour of chemicals or materials in the environment must be evaluated. This concept is termed reliability. All of the data presented in Appendix G were assessed to be suitably reliable for the purposes of this report.

All of the chemicals assessed in this report are common industrial chemicals that are used for many purposes other than coal seam gas extraction. Consequently, much of the information and data that is available for these chemicals is not relevant to their use by the coal seam gas industry or for environmental risk assessments. For instance, the boiling point of enzymes is not relevant to environmental risk assessments; instead, it is the temperature range within which they are reactive that is relevant. Similarly, molecular formulae and molecular weights are only relevant to discrete chemicals and are not relevant to the environmental risk assessment of materials such as wood fibres. The capacity for data to provide information appropriate to the aim of a study is termed relevance and only data relevant to the fate and behaviour of chemicals and materials in the environment was used in this report. All data were checked for reliability, relevance, and adequacy, as described in EPHC (2009a).

Only the properties, behaviour, and characteristics relevant to the potential for each chemical and material to be of environmental concern are presented. For this reason, the types of information presented within Appendix G differ from assessment to assessment.

4.9 Weight of evidence

A weight of evidence approach, considering available information, was central to the assessment method. The weight of evidence approach is a means of evaluating data through consideration of its strengths and weaknesses. In the context of this assessment, the weight

of evidence process involved using expert judgement to assess scientific literature, relevant studies by current users of the chemical or previous assessments undertaken by other regulators on a case-by-case basis. Further detail on the weight of evidence approach and its use in assessments can be found in EPHC (2009a).

4.10 Peer review

All assessments conducted using this qualitative method were peer-reviewed by senior scientists of the Chemical and Biological Assessments Section of the Department of the Environment and Energy and by experts in the field of environmental chemical risk assessment from the CSIRO. Peer review of assessments establishes whether an assessment has reached a scientifically reasonable conclusion based on the available information. Peer review also establishes whether the recommendations for each assessment are commensurate with the risks identified.

4.11 Limitations

The qualitative risk assessment methodology used for the 54 chemicals with limited data addressed the toxic effects of each chemical in the environment. These assessments do not consider the concerns associated with combinations of chemicals, mixtures, or contaminants. The assessments also do not consider the potential for these substances to impact the behaviour of other substances that may exist in the natural environment.

Even the least toxic chemicals are capable of causing temporary environmental stress, due to physico-chemical effects, if they are released to the environment in sufficiently large quantities. However, under the exposure assumptions outlined for this qualitative assessment it was not expected that large quantities (tonnes) of chemicals would be released. Therefore, those chemicals that were assessed as having very low toxicity to environmental organisms, and that were only expected to cause temporary physico-chemical effects if they are released in large quantities, were assessed as being of low concern.

5 Key findings of the qualitative risk assessment approach

Section 4 presented the qualitative risk assessment method used to assess the 54 chemicals which did not have sufficient information for a deterministic risk assessment. The findings of these assessments are summarised here. Detailed assessments are presented in Appendix G.

5.1 Findings

Of the 54 chemicals that have limited available ecotoxicological and / or physico-chemical data and which were identified as being used in the period 2010 to 2012, within the hydraulic fracturing fluids and drilling muds used in coal seam gas operations, 51 were considered to be of low concern to the environment (Table 5.1) and three were found to be of potential concern (Table 5.2).

The 51 chemicals identified to be of low concern to the environment when used in coal seam gas operations are expected to have low potential to cause adverse effects if they are used in accordance with existing government regulations (see Section 2.5.1.6). Many of these chemicals may cause physico-chemical stress if released to the environment in high volumes, where the sheer volume of the chemical can perturb natural processes. For example, degradation of large amounts of nutritional substances through microbial action can reduce dissolved oxygen levels. This can cause direct physico-chemical stress on other organisms by limiting available oxygen, and also cause indirect physico-chemical stress by altering parameters such as the reduction-oxidation potential of water bodies (ANZECC and ARMCANZ 2000). Under the exposure assumptions outlined for this assessment, significant adverse effects due to such physico-chemical effects are not expected. Further assessment of such effects may be considered on a case-by-case basis, using the information in this report, if a detailed analysis of a particular coal seam gas operation indicates that it is needed.

Further information on the potential for physico-chemical effects is provided in individual assessments. Readers are referred to the *Australia and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000) for additional guidance on the appropriate assessment of physico-chemical stressors.

Chemicals and materials can pose different risks to different organisms under different circumstances, and the assessments presented here have been tailored as outlined under the problem formulation heading. Therefore, while these 51 chemicals and materials were identified to be of low concern to the environment when used in coal seam gas operations, alternative conclusions may be reached in assessments which have a different scope (for example, corresponding human health assessments).

Three boron compounds (Boric acid (H_3BO_3), compound with 2-aminoethanol, CAS RN 26038-87-9; Boric acid, ($H_2B_8O_{13}$), disodium salt, CAS RN 12008-41-2; and Borax ($Na_2(B_4O_7).10H_2O$), CAS RN 1303-96-4) were assessed as being of potential concern (Table 5.2). These chemicals generally have low aquatic toxicity, but potential concerns highlighted in this report arise from their toxicity to plants. Release of large volumes of these chemicals under certain environmental conditions may cause localised toxic effects, especially in the terrestrial environment.

| | Assessment Name | Chemical Name | CAS RN |
|----|---|---|---|
| 1 | Hydrogen peroxide | Hydrogen peroxide (H ₂ O ₂) | 7722-84-1 |
| 2 | Sodium acetate | Acetic acid, sodium salt | 127-09-3 |
| 3 | Choline chloride | Ethanaminium, 2-hydroxy- <i>N,N,N-</i> trimethyl-, chloride | 67-48-1 |
| 4 | Triethanolamine | Ethanol, 2,2',2"-nitrilotris- | 102-71-6 |
| 5 | Tetrasodium EDTA | Glycine, <i>N</i> , <i>N</i> -1,2-ethanediylbis[<i>N</i> - (carboxymethyl)-, tetrasodium salt | 64-02-8 |
| 6 | Water | Water | 7732-18-5 |
| 7 | Terpenes | Terpenes and terpenoids | СВІ |
| 8 | Alkanes, C _{12⁻26} branched and linear | Alkanes, C12-26 branched and linear | 90622-53-0 |
| 9 | Fatty acid esters | Fatty acids ester | СВІ |
| 10 | Nitrogen | Nitrogen | 7727-37-9 |
| 11 | Bauxite (Al ₂ O ₃ .xH ₂ O), sintered | Sintered bauxite | 1318-16-7 (assessed as 144588-68-1) |
| 12 | Modified guar gum | Guar gum, carboxymethyl 2- hydroxypropyl ether, sodium salt | 68130-15-4 |
| 13 | Gelatins | Gelatins | 9000-70-8 |
| 14 | Group assessment - | Nitric acid, magnesium salt | 10377-60-3 |
| 15 | Simple inorganic salts | Sulfuric acid, barium salt (1:1) | 7727-43-7 |
| 16 | | Thiosulfuric acid ($H_2S_2O_3$), disodium salt | 7772-98-7 |
| 17 | Group assessment - | Carbonic acid | 463-79-6 |
| 18 | Soluble carbonates | Carbonic acid, dipotassium salt | 584-08-7 |
| 19 | | Carbonic acid, sodium salt (2:3) | 533-96-0 |
| 20 | | Carbon dioxide | 124-38-9 |
| 21 | Group assessment – | Limestone | 1317-65-3 |
| 22 | derivatives | Calcium oxide | 1305-78-8 |
| 23 | Group assessment - Silica | Silica | 7631-86-9 |
| 24 | | Silica gel, precipitated, crystalline free | 112926-00-8 |
| 25 | | Kieselguhr, calcined | 91053-39-3 |
| 26 |] | Quartz (SiO ₂) | 14808-60-7 |
| 27 | | Cristobalite (SiO ₂) | 14464-46-1 |
| 28 | | Crystalline silica, tridymite | 15468-32-3 |
| 29 | Group assessment – | Talc (Mg ₃ H ₂ (SiO ₃) ₄) | 14807-96-6 |
| 30 | Phyllosilicate rocks and minerals | Bentonite | 1302-78-9 |
| 31 | Group assessment – Non- | 2-Propenoic acid, methyl ester, polymer | 25038-72-6 |

| | Table 5.1. | The 51 | chemicals and | materials | considered | to be of | low | concern t | to the | environment |
|--|------------|--------|---------------|-----------|------------|----------|-----|-----------|--------|-------------|
|--|------------|--------|---------------|-----------|------------|----------|-----|-----------|--------|-------------|

| | Assessment Name | Chemical Name | CAS RN |
|----|---|--|--------------|
| | ionic polymers | with 1,1-dichloroethene | |
| 32 | | 2-Propenamide, homopolymer | 9003-05-8 |
| 33 | Group assessment – Anionic polymers | 2-Propenoic acid, polymer with 2- propenamide | 9003-06-9 |
| 34 | | Polymer I | СВІ |
| 35 | | Polyacrylamide/polyacrylate copolymer | СВІ |
| 36 | Group assessment – | Polyamine | СВІ |
| 37 | Cationic polymers 2-Propen-1-aminium, <i>N</i> , <i>N</i> -dimethyl- <i>N</i> -2- propenyl-, chloride, homopolymer | | 26062-79-3 |
| 38 | Group assessment – | Polysaccharide | СВІ |
| 39 | Modified celluloses | Cellulose, 2-hydroxyethyl ether | 9004-62-0 |
| 40 | | Polyanionic cellulose PAC | Not supplied |
| 41 | Group assessment – | Cellulase | 9012-54-8 |
| 42 | Enzymes | Hemicellulase | 9025-56-3 |
| 43 | | Enzyme | СВІ |
| 44 | Group assessment – | Wood dust | Not supplied |
| 45 | Wood products | Wood fibre | Not supplied |
| 46 | | Walnut hulls | Not supplied |
| 47 | | Nut hulls | Not supplied |
| 48 | | Natural fibres I | Not supplied |
| 49 | | Natural fibres II | Not supplied |
| 50 | | Natural fibres III | СВІ |
| 51 | Polyesters | Polyesters | Not supplied |

Table 5.2. Three chemicals assessed to be of potential concern.

| | Assessment Name | Chemical Name | CAS RN |
|----|---------------------------------------|---|------------|
| 51 | Group assessment – Boron compounds | Boric acid (H_3BO_3), compound with 2- aminoethanol | 26038-87-9 |
| 52 | | Boric acid, $(H_2B_8O_{13})$, disodium salt | 12008-41-2 |
| 53 | | Borax (Na ₂ (B ₄ O ₇).10H ₂ O) | 1303-96-4 |
6 Conclusions

The environmental risk assessments described in this report considered the potential risks to the environment (surface and near surface water environments) of the 113 chemicals identified as being used for coal seam gas extraction in Australia in the period 2010 to 2012.

The approaches used for these assessments are described in detail in Sections 2, 3 and 4 of this report. In summary:

- A deterministic (quantitative) approach was developed to assess 59 chemicals for which sufficient physico-chemical data were available to allow for modelling and calculations of the predicted environmental concentrations that might occur as a result of release of the chemical under a variety of scenarios.
- A qualitative assessment approach, based on expert judgement and weight of evidence, was used for the risk assessment of the remaining 54 chemicals for which insufficient data were available for quantitative calculations.

The environmental risk classification for each chemical was determined in accordance with the principles outlined by EPHC (2009a) and the ARMCANZ and ANZECC (2000) guidelines. There are three risk categories:

- Chemicals of 'low concern' (RQ < 1). These chemicals are assessed to be unlikely to have adverse environmental effects if they are released to the environment from coal seam gas operations. Chemicals of low concern do not require specific risk management measures.
- Chemicals of 'potential concern' (RQ ≥ 1: and < 10). These chemicals have the potential to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures may be necessary to ensure that chemicals of potential concern do not harm the environment.
- Chemicals of 'potentially high concern' (RQ ≥ 10). These chemicals are likely to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures are likely to be required to ensure that chemicals of potentially high concern do not harm the environment.

The findings of this study are described in detail in Sections 3 and 5 of this report.

None of the 113 chemicals identified as being used for coal seam gas extraction in Australia in the period 2010 to 2012 are categorised as PBT chemicals (persistent, bioaccumulative, toxic).

6.1 Chemicals of low concern

All of the chemicals reported to be used for coal seam gas extraction in Australia are common industrial chemicals that have a variety of uses outside the coal seam gas extraction industry. Some of them are ubiquitous in the environment and several are used in the production of foodstuffs. Many others are used in common household items including cleaning agents and personal care products. However, even the least toxic chemicals, such as those that are used in foods, are capable of causing temporary environmental stress, due to physico-chemical effects, if they are released to the environment in sufficiently large quantities.

Under the exposure assumptions outlined for the qualitative assessments, 51 chemicals were assessed as being of low concern because they have low toxicity to environmental organisms, and are only expected to cause temporary physico-chemical effects if they are released in very large quantities.

Additionally, there were 10 chemicals assessed to be of low concern (RQ < 1) using the deterministic approach.

In total, 61 chemicals were assessed to be of low concern (Tables 3.35 and 5.1). These chemicals are unlikely to have adverse environmental effects if they are released to the environment from coal seam gas operations. These low concern chemicals do not require specific risk management measures.

6.2 Chemicals of potential concern

Of the 113 chemicals identified as being used for coal seam gas extraction in Australia in the period 2010 to 2012, there were 52 that were assessed to be of potential concern. These chemicals have the potential to cause adverse environmental effects if they are released to the environment from coal seam gas operations. Specific risk management measures may be necessary to ensure that chemicals of potential concern do not harm the environment.

Deterministic assessments identified 15 chemicals at Tier 3 (Table 3.36) as being of potential concern in the event of direct release of the chemical to an aquatic ecosystem through accidental releases from transport accidents, such as a truck roll-over, at specific coal seam gas work-sites. The chemicals in this group include mineral salts, alkaline salts, mineral acids, oxidisers, carbohydrates and synthetic organic chemicals including polymers and biocides.

There were also 34 chemicals identified at Tier 1, using the deterministic approach, as being of potential concern. These chemicals would normally have been assessed at higher tiers. However, industry advised that they were not in use as of July 2015. Consequently, there was no site-specific data available to assess these 34 chemicals at Tiers 2 and 3. The categorisation of these 34 chemicals as 'of potential concern' might change if the data required became available and these chemicals were assessed at higher tiers.

Additionally, qualitative assessments of three boron-containing chemicals indicated that these are of potential concern (Table 5.2). This is because the use of coal seam gas wastewater for agricultural irrigation or road dust suppression may lead to accumulation of boron in soils at levels that are toxic to plants. This consideration is also relevant to boric acid, which was identified, using deterministic methods, as one of the 15 chemicals of concern in the event of direct release to an aquatic ecosystem.

6.2.1 Chemicals of potential concern if they are directly released to an aquatic ecosystem

Fifteen chemicals were assessed at Tier 3 of the deterministic approach, to be of concern if they are directly released to an aquatic ecosystem due to transport accidents. These chemicals are only expected to cause limited short-term effects in the event of direct release to an aquatic ecosystem due to a transport accident. Under the assumptions of this study, there are no other circumstances that are expected to allow these chemicals to accumulate in surface water at either chronic or acutely toxic concentrations.

Some of these chemicals, such as sodium chloride, boric acid and xanthan gum have low toxicity to aquatic organisms and were assessed to be of potential concern only if a large quantity (several tonnes) is released to the environment. Others, including the isothiazolone biocides, are of potential concern because they are highly to very highly toxic to aquatic organisms and may cause short-term harmful effects at relatively low quantities if they are released to the environment.

The aquatic toxicity of the alkaline salts in this group (sodium carbonate and sodium hydroxide) is largely due to their capacity to affect the pH of an aquatic ecosystem. This is also the case for hydrochloric acid. Consequently, the potential of these chemicals to cause adverse effects to the aquatic environment depends on both the volume of chemical that is released and the pH buffering capacity of the aquatic system to which they are released. However, the risk assessments for these chemicals indicate that short-term adverse environmental effects are only expected in the event of direct release to an aquatic system.

All of the organic chemicals identified as being of potential concern are soluble in water and are readily degraded in aquatic ecosystems. Therefore, although some of these chemicals are toxic to certain environmental organisms, none of them will be persistent in the environment and none are expected to bioaccumulate. The inorganic chemicals identified as being of potential concern are all highly soluble in water and can be readily diluted to subtoxic concentrations and be dissipated if there is there is sufficient water-flow in the system.

Australia has a robust regulatory framework to manage and mitigate the risks of handling and transporting chemicals and dangerous goods (DIRD 2015). Transport accidents involving significant quantities of chemicals are rare in Australia and it is unlikely that the hypothetical transport accident scenarios envisaged in this study will eventuate. Industry reported that there were no spills of any of the chemicals assessed in this study within 2 km of an aquatic receptor during the period 2013 to 2015. There were no reported transport accidents involving coal seam gas chemicals at any of the working sites assessed in this study during the period 2013 to 2015.

The findings of this study underscore the importance of handling and transporting all coal seam gas chemicals in accordance with the relevant state and territory regulations and industry codes of practice.

6.2.2 Boron-containing chemicals of potential concern

In total, four boron-containing chemicals were assessed to be of potential risk to the environment. These were: borax, boric acid, disodium borate and boric acid, compound with 2-aminoethanol. These chemicals are used in large quantities in drilling and hydraulic fracturing operations as cross-linking agents in gel-treated hydraulic fracturing fluids.

Boron is an essential trace element for all life and the four boron-containing chemicals used for coal seam gas extraction have low toxicity to aquatic organisms. However, moderate soil concentrations can cause toxic effects in terrestrial plants (phytotoxicity).

The use of coal seam gas wastewater containing residues of boron chemicals for agricultural irrigation and road dust suppression on heavy textured sodic soils that receive low rainfall is expected to result in local soil accumulation of boron. This may cause toxic effects in agricultural crops cultivated on irrigated land or immediately adjacent to roads, but wider environmental effects are expected to be limited by the low mobility of boron under these conditions. If coal seam gas wastewater is repeatedly applied to acidic sandy soils that receive high rainfall, the boron present in the wastewater is expected to be relatively more mobile. Stunted or reduced growth of exposed plants in the terrestrial environment may be caused as the boron moves off agricultural land or roads that have been treated with wastewater. Therefore, wastewater containing residues of boron chemicals used for coal

seam gas extraction processes should only be used for irrigation and road dust suppression after careful consideration of the potential for such use to lead to toxic accumulation of boron in soils.

6.3 Summary of Conclusions

When the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia was commissioned by the Australian Government in 2012 there was no methodology available for the deterministic (quantitative) risk assessment of coal seam gas chemicals.

Therefore, an important component of this study was the development of a suitable deterministic risk assessment approach for analysis of coal seam gas chemicals used in Australia. The resulting deterministic risk assessment approach was used to analyse 59 of the 113 chemicals identified as being used for coal seam gas extraction in Australia in the period 2010 to 2012.

Fifteen of these chemicals were identified as being of potential concern in the event of direct release of the chemical to an aquatic ecosystem as the result of transport accidents at specific coal seam gas work-sites. These were the only circumstances that were identified by the deterministic risk assessment, at Tier 3, that would allow coal seam gas chemicals to occur in surface water at toxic concentrations.

Thirty-four chemicals were identified at Tier 1 of the deterministic approach as being of potential concern. These chemicals would normally have been assessed at higher tiers. However, the site-specific data required to assess these 34 chemicals at Tiers 2 and 3 was not available. The categorisation of these 34 chemicals as 'of potential concern' might change if the data required to assess these chemicals at higher tiers became available.

Australia has a robust and effective regulatory framework to manage and mitigate the risks of handling and transporting chemicals, so the hypothetical transport accident scenarios envisaged in this study are unlikely. Nevertheless, the findings of this study demonstrate the capacity of deterministic models to identify coal seam gas chemicals that are of potential risk to the environment and the circumstances in which adverse environmental effects might be expected to occur.

The remaining 54 of the 113 chemicals were assessed using a qualitative approach. The methods used in this qualitative approach were based on those that have been developed for the high-throughput assessment of industrial chemicals (NICNAS 2015a).

The qualitative risk assessments identified boron chemicals as being of potential concern to the environment. In particular, residues of these chemicals may be present in coal seam gas wastewater and, if this wastewater is repeatedly used for irrigation and dust suppression, boron may accumulate in soils at levels that are toxic to plants.

The purpose of chemical risk assessments is to inform the risk management and mitigation procedures that ensure the safe use of chemicals. The findings of this study underscore the importance of handling and transporting all coal seam gas chemicals in accordance with the relevant regulations and codes of practice. Additionally, the findings for boron chemicals provide information for the responsible management of wastes that contain residues of these chemicals. In particular, wastewater containing residues of boron chemicals should only be used for irrigation and road dust suppression after careful consideration of the potential for such use to lead to toxic accumulation of boron in soils.

7 References

- ACS 2015, Chemistry abstracts service. Accessed: 1 Sep 15 at https://www.cas.org
- ACS 2014, CAS REGISTRY and CAS RN FAQs, CAS® A Division of the American Chemical Society. Accessed: 8 January 2014 at http://www.cas.org/content/chemical-substances/faqs
- Adgate, JL, Goldstein, BD, and McKenzie, LM 2014, 'Potential public health hazards, exposures and health effects from unconventional gas development', *Environmental Science and Technology*, 48(15), pp. 8307-8320.
- ANRA 2001, Australian Agriculture Assessment, *National Land and Water Resources Audit Appendix 2*, Australian Natural Resources Atlas, Land and Water Australia, Commonwealth of Australia, Canberra. ISBN: 0 642 37121 0. Accessed: http://www.anra.gov.au/topics/agriculture/pubs/national/agriculture_asris.html
- ANZECC and ARMCANZ 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resources Management Council of Australia and New Zealand (ARMCANZ), Canberra. Accessed: http://www.environment.gov.au/water/policy-programs/nwqms/index.html
- Apte SC, Kookana RS, Batley GE, and Williams M 2017, *Literature review: Geogenic contaminants associated with coal seam gas operations*, Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- Atkins, PW 1986, *Physical Chemistry* (3rd ed), Oxford University Press, Oxford.
- Aylward, G and Findlay, T 1974, *SI Chemical Data* (2nd ed.), John Wiley and Sons, Chichester.
- Caldwell, DJ, Mastrocco, F, Hutchinson, TH, Lange, R, Heijerick, D, Janssen, C, Anderson, PD and Sumpter, JP 2008, 'Derivation of an aquatic predicted no-effect concentration for the synthetic hormone, 17α-ethinyl estradiol', *Environmental Science and Technology*, 42, pp. 7046-7054.
- Caldwell, DJ, Mastrocco, F, Nowak, E, Johnston, J, Yekel, H, Pfeiffer, D, Hoyt, M, DuPlessie, BM, Anderson, PD 2010, 'An Assessment of Potential Exposure and Risk from Estrogens in Drinking Water', *Environ Health Perspectives*, 118, pp. 338-344. Accessed: http://dx.doi.org/10.1289/ehp.0900654
- DEHP 2014, Coal Seam Gas / Liquid Natural Gas Compliance Plan, 2012-13 End of year report, Report prepared by the Department of the Environment and Heritage Protection (DEHP), Queensland Government, Brisbane.
- DIRD 2015, *The Australian dangerous goods code edition 7.4*. Department of Infrastructure and Regional Development. Accessed: 5 April 2016 at https://infrastructure.gov.au/transport/australia/dangerous/dg_code_7e.aspx
- DoE 2014, *Hydraulic fracturing ('fraccing') techniques, including reporting requirements and governance arrangements*, undertaken by URS Australia Pty Ltd and revised by the Department of the Environment following peer review. Accessed: http://iesc.environment.gov.au/resource/background-review-hydraulic-fracturing-%E2%80%98fraccing%E2%80%99-techniques-including-reporting

- DoEE 2017a, Literature review: Environmental risks posed by chemicals used in coal seam gas operations, Project report prepared by the Chemicals and Biotechnology Assessments Section (CBAS) in the Department of the Environment and Energy as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- DoEE 2017b, Environmental exposure conceptualisation: Surface to surface water pathways, Project report prepared by the Chemicals and Biotechnology Assessments Section (CBAS) of the Department of the Environment and Energy as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- Dunlop, JE, Kefford, BJ, McNeil, VH, McGregor, GB, Choy, S and Nugegoda, D 2008, 'A review of guideline development for suspended solids and salinity in tropical rivers of Queensland, Australia', *Australasian Journal of Ecotoxicology*, vol. 14, 129-142.
- Dunlop, J, McGregor, G and Horrigan, N 2005, Potential impacts of salinity and turbidity in riverine ecosystems, Characterisation of impacts and a discussion of regional target setting for riverine ecosystems in Queensland, The State of Queensland. ISBN 1 74172 078 8.
- EC 2003, Technical Guidance Document on Risk Assessment in support of Commission Directive 93/67/EEC on Risk Assessment for new notified substances, Commission Regulation (EC) No 1488/94 on Risk Assessment for existing substances, Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market, Part II.
- EC 1996, Technical Guidance Document in Support of Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances and Commission Regulation (EC) No 1488/94 on Risk Assessment For Existing Substances, Part II, European Communities (EC).
- ECHA 2015, European Chemical Agency Database. Accessed: 18 August 2015 at http://echa.europa.eu/information-on-chemicals/registered-substances
- ECHA 2013a, Candidate List of Substances of Very High Concern for Authorisation, European Chemicals Agency, Helsinki, Finland.
- ECHA 2013b, *Registered Substances*, European Chemicals Agency (ECHA). Accessed 8 January 2014 at http://echa.europa.eu/web/guest/information-onchemicals/registered-substances
- ECHA 2008, Guidance on information requirements and chemical safety assessment Chapter R.6: QSARs and grouping of chemicals, Guidance for the implementation of REACH, European Chemicals Agency (ECHA). Accessed: 8 January 2014 at http://echa.europa.eu/documents/10162/13632/information_requirements_r6_en.pdf
- Environment Canada 2003, Guidance Manual for the Categorisation of Organic and Inorganic Substances on Canada's Domestic Substances List, Determining Persistence, Bioaccumulation Potential and Inherent Toxicity to Non-Human Organisms, Existing Substances Branch, Environment Canada, June 2003.
- EPBC Act 1999, *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth). Accessed: http://www.comlaw.gov.au/Series/C2004A00485
- EPHC 2009a, *Environmental Risk Assessment Guidance Manual for Industrial Chemicals*, Prepared by Australian Environment Agency Pty Ltd for DoEE, formerly Environment Protection Branch, Department of the Environment, Water, Heritage and the Arts, Environment Protection and Heritage Council. Accessed: http://www.scew.gov.au/resource/chemical-risk-assessment-guidance-manuals

- EPHC 2009b, Environmental Risk Assessment Guidance Manual for Agricultural and Veterinary Chemicals, Prepared by Australian Environment Agency Pty Ltd for DoEE, formerly Environment Protection Branch, Department of the Environment, Water, Heritage and the Arts, Environment Protection and Heritage Council. Accessed: http://www.scew.gov.au/resource/chemical-risk-assessment-guidance-manuals
- ERIN 2013, *Coal Seam Gas: Status, Available or Granted coal seam gas Permits*, Encom Petroleum Information, Environmental Resources Information Network (ERIN), Department of the Environment and Energy.
- European Commission 2015, *REACH Registration, Evaluation, Authorisation and Restriction of Chemicals. Enterprise and Industry.* Accessed: September 1, 2015 at http://ec.europa.eu/enterprise/sectors/chemicals/reach/index_en.htm
- European Commission 2001, Communication from the Commission to the Council and the European Parliament on the implementation of the Community Strategy for Endocrine Disruptors: a range of substances suspected of interfering with the hormone systems of humans and wildlife. Accessed: 16 September 2015 at http://eurlex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52001DC0262
- FAO UNEP 2009, *Stockholm Convention on Persistent Organic Pollutants (POPs)*, Food and Agriculture Organization of the United Nations Environment Programme, Châtelaine, Switzerland.
- FAO UNEP 1998, Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, Food and Agriculture Organization of the United Nations Environment Programme, Châtelaine, Switzerland.
- Flewelling SA and Sharma M 2014, 'Constraints on upward migration of hydraulic fracturing fluid and brine', *Groundwater*, 52(1), pp 9-19.
- Groat, CG and Grimshaw, TW 2012, Fact-Based Regulation for Environmental Protection in Shale Gas Development, Report prepared by the The Energy Institute, University of Texas, Austin, USA.
- Health Canada 2010, *Tetrakis (Hydroxymethyl) Phosphonium Sulfate, Evaluation Report,* ERC 2010-02, Pest Management Regulatory Agency, Health Canada. Accessed: http://publications.gc.ca/collections/collection_2010/arla-pmra/H113-26-2010-2eng.pdf
- ICNA Act 1989, Industrial Chemicals Notification and Assessment Act 1989 (Commonwealth). Accessed: https://www.legislation.gov.au/Details/C2016C00816
- Jeffrey, R, Wu, B, Bunger, A, Zhang, X, Chen, Z, Kear, J and Kasperczyk, D 2017, *Literature review: Hydraulic fracture growth and well integrity*, Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- Kefford, BJ and Nugegoda, D 2004, 'No evidence for a critical salinity threshold for growth and reproduction in the freshwater snail Physa acuta', *Environmental Pollution*, vol. 134, pp. 377–383.
- Kefford BJ, Palmer B, Nugegoda D 2005, Relative salinity tolerances of freshwater macroinvertebrates from the south-east Easter Cape, South Africa compared with the Barwon catchment, Victoria, Australia, *Marine and Freshwater Research*, 56, pp 163-171.
- LMC 2013, *The OECD Toolbox for Grouping Chemicals into Categories*, Laboratory of Mathematical Chemistry, University "Prof. Dr. Assen Zlatarov", Bourgas, Bulgaria.

- LMC 2012, *The OECD QSAR toolbox for grouping chemicals in categories v. 3.1*, Laboratory of Mathematical Chemistry, Bourgas University, Bourgas, Bulgaria.
- LMC 2011a, *The OECD QSAR toolbox for grouping chemicals in categories v. 2.2*, Laboratory of Mathematical Chemistry, Bourgas University, Bourgas, Bulgaria.
- LMC 2011b, *Oasis Catalogic v. 3.10.9,* Laboratory of Mathematical Chemistry, Bourgas University, Bourgas, Bulgaria.
- Madsen, T, Boyd, HB, Nylen, D, Pedersen, AR, Pedersen, GI and Simonsen, F 2001, Environmental and Health Assessment of Substances in Household Detergents and Cosmetic Detergent Products, Centre for Integrated Environment and Toxicology, Environmental Project No. 615.
- Mallants D, Bekele E, Schmid W, Miotlinski K and Bristow K 2017a, *Literature review: Identification of potential pathways to shallow groundwater of fluids associated with hydraulic fracturing*, Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- Mallants, D, Bekele, E, Schmid, W, Miolinski, K and Gerke, K 2017b, *Human and environmental exposure conceptualisation: Soil to shallow groundwater pathways*, Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- Mallants D, Bekele E, Schmid W, Miotlinski K, Taylor A, Gerke K 2017c, *Human and environmental exposure assessment: Soil to shallow groundwater pathways – A study of predicted environmental concentrations*, Project report prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra
- Mayo-Bean, K, Moran, K, Meylan, B and Ranslow, P 2012a, Methodology Document for the Ecological Structure-Activity Relationship Model (ECOSAR) Class Program Estimating Toxicity of Industrial Chemicals to Aquatic Organisms Using the Ecosar (Ecological Structure Activity Relationship) Class Program, MS-Windows Version 1.1, Office of Pollution Prevention and Toxics U.S. Environmental Protection Agency Syracuse Research Corporation Consortium for Environmental Risk Management, LLC, May.
- Mayo-Bean, K, Moran-Bruce, K, Nabholz, JV, Meylan, WM and Howard, PH 2012b, OPERATION MANUAL for the Ecological Structure-Activity Relationship Model (ECOSAR) Class Program Estimating Toxicity of Industrial Chemicals to Aquatic Organisms Using the Ecosar (Ecological Structure Activity Relationship) Class Program, MS-Windows Version 1.11, Office of Pollution Prevention and Toxics US Environmental Protection Agency Syracuse Research Corporation Consortium for Environmental Risk Management, LLC, March.
- Myers, T 2012, 'Potential contaminant pathways from hydraulically fractured shale to aquifers', *Groundwater*, 50(6), pp. 872-882.
- Myers, JP, Zoeller, RT, and vom Saal, FS 2011, A clash of old and new scientific concepts in toxicity, with important implications for public health, Environmental Health Perspectives 2011, 117: 1652-1655.
- NICNAS 2015a, Inventory Multi-tiered Assessment and Prioritisation Framework, National Industrial Chemicals Notification and Assessment Scheme (NICNAS). Accessed:

16 September 2015 at http://www.nicnas.gov.au/chemical-information/imapassessments/the-imap-framework

- NICNAS 2015b, Australian Inventory of Chemical Substances (AICS). Available at: http://www.nicnas.gov.au/regulation-and-compliance/aics [Accessed September 1, 2015].
- NICNAS 2017a, Identification of chemicals associated with coal seam gas extraction in Australia, Project report, report prepared by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- NICNAS 2017b, *Literature review: Summary report*, Project report, report prepared by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- NICNAS 2017c, Human health risks associated with surface handling of chemicals used in coal seam gas extraction, Project report prepared by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) as part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia, Commonwealth of Australia, Canberra.
- NOHSC: 1015 (2001), National Standard for the Storage and Handling of Workplace Dangerous Goods, National Occupational Health and Safety Commission. Accessed: http://www.safeworkaustralia.gov.au/sites/swa/about/publications/pages/ns200103sto rageandhandling
- OECD 2014, The OECD Environmental Risk Assessment Toolkit: Tools for Environmental Risk Assessment and Management. Accessed: http://www.oecd.org/chemicalsafety/riskassessment/theoecdenvironmentalriskassessmenttoolkittoolsforenvironmentalriskass essmentandmanagement.htm
- OECD 2013a, OECD QSAR Toolbox. OECD QSAR Toolbox version 2.2. Organisation for Economic Co-operation and Development.
- OECD 2013b, Test No. 210: Fish, Early-life Stage Toxicity Test, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264203785-en
- OECD 2012, Test No. 211: Daphnia magna Reproduction Test, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264185203-en
- OECD 2011a, Test No. 201: Freshwater Alga and Cyanobacteria, Growth Inhibition Test, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264069923-en
- OECD 2011b, SIDS Initial Assessment Report on 2-Pentanone, 4-methyl- for SIAM 5, 28-30 October 1996, published March 2011. Accessed: 6 Jan 14 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=366b433d-d3f0-4687-8334dbf9165e225b&idx=0
- OECD 2009a, SIDS Initial Assessment Report on1,2-Ethanediol for SIAM 18, 20-23 April 2004, published June 2009. Accessed: http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=615607ee-9fd5-464d-b09e-a3d6d71ea88d&idx=0

- OECD 2009b, SIDS Initial Assessment Report on Sodium sulphite (Sulfurous acid, disodium salt) for SIAM 26, 16-18 April 2008, published August 2009, accessed 7 January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=fbc94dc8-2987-487c-adce-f7812fe34cb8&idx=0
- OECD 2009c, SIDS Initial Assessment Report on Sodium chlorite and chlorine dioxide for SIAM 23, 17-20 October 2006, accessed 7 January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=4b607feb-86ee-4775-81c8-373b341f2d5e&idx=0
- OECD 2009d, Test No. 302C: Inherent Biodegradability: Modified MITI Test (II), OECD Guidelines for the Testing of Chemicals, Section 3, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264070400-en
- OECD 2007a, Guidance Document on the Validation of (Quantitative) Structure-Activity Relationships [(Q)SAR] Models, Environment Directorate Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology ENV/JM/MONO(2007)2 30-Mar-2007. Accessed: http://search.oecd.org/officialdocuments/displaydocumentpdf/?cote=env/jm/mono(200 7)2&doclanguage=en
- OECD 2007b, SIDS Initial Assessment Report on Ethanol, 2-butoxy- for SIAM 23, 17-20 October 2006, published February 2007. Accessed: 6 January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=4245c759-1cf3-4aed-8569b57afaa0ec9a&idx=0
- OECD 2007c, SIDS Initial Assessment Report on Ethanol, 2-butoxy- for SIAM 21, 18-20 October 2005, published March 2007. Accessed 6 January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=3e7222c3-f296-4d3e-a9f2-833ebc6b14d6&idx=0
- OECD 2007d, SIDS Initial Assessment Report on Methanol OECD SIAM 19, 19-22 October 2004, published July 2007. Accessed 7 January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=29efcabd-ddba-4ae7-bc6da1686fed5105&idx=0
- OECD 2007e, Manual for Investigation of HPV Chemicals, Section 4.2.
- OECD 2006a, SIDS Initial Assessment Report on Peroxydisulfuric acid, diammonium salt for SIAM 20, Paris, France, 19-21 April, 2005. Accessed: 07 Jan14 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=955aee27-245f-4461-a566-0a4b58729ca4&idx=0
- OECD 2006b, SIDS Initial Assessment Report on Sulfuric acid, disodium salt for SIAM 20, Paris, France, 19-21 April, 2005. Accessed: 07 Jan 14 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=1cb7fa7a-56a8-4872-bb26-13cd7f73fc57&idx=0
- OECD 2006c, SIDS Initial Assessment Report on Sulfuric acid, diammonium salt for SIAM 19, Berlin, Germany, 19–22 October 2004. Accessed: 07 Jan 14 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=59503a7d-9652-4bd3-8d0c-851ae2be08f4&idx=0
- OECD 2006d, SIDS Initial Assessment Report on Sulfuric acid, diammonium salt for SIAM 19, Berlin, Germany, 19–22 October 2004. Accessed: 07 Jan 14 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=59503a7d-9652-4bd3-8d0c-851ae2be08f4&idx=0
- OECD 2006e, Test No. 310: Ready Biodegradability CO2 in sealed vessels (Headspace Test), OECD Guidelines for the Testing of Chemicals, Section 3, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264016316-en

- OECD 2005a, SIDS Initial Assessment Report on Glycerol For SIAM 14 Paris, France, 26-28 March 2002. Accessed 7 January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=64c80f80-a7cf-41a0-8de9-1cdd0d357462&idx=0
- OECD 2005d, IUCLID Data Set for Ammonium persulfate (CAS No. 7727-54-0); Potassium persulfate (CAS No. 7727- 27-1); Sodium persulfate (CAS No. 7775-27-1), UNEP Publications.
- OECD 2005e, Screening Information Dataset (SIDS) Initial Assessment Report for Ammonium persulfate (CAS No. 7727-54-0); Potassium persulfate (CAS No. 7727-27-1); Sodium persulfate (CAS No. 7775-27-1), UNEP Publications. Accessed: http://www.chem.unep.ch/irptc/sids/OECDSIDS/persulfates.pdf
- OECD 2004a, Test No. 117: Partition Coefficient (n-octanol/water), HPLC Method, OECD Guidelines for the Testing of Chemicals, Section 1, OECD Publishing. Accessed: http://www.oecd-ilibrary.org/environment/test-no-117-partition-coefficient-n-octanolwater-hplc-method_9789264069824-en
- OECD 2004b, Test No. 202: Daphnia sp. Acute Immobilisation Test, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing. Accessed: http://www.oecdilibrary.org/environment/test-no-202-daphnia-sp-acute-immobilisationtest_9789264069947-en
- OECD 2002a, IUCLID data set for hydrogen chloride (CAS no. 7647-01-0), UNEP Publications, Paris, France
- OECD 2002b, SIDS initial assessment report on 2-propanol for SIAM 6, 9-11 June 1997. Accessed: January 2014 at http://webnet.oecd.org/HPV/UI/SIDS_Details.aspx?key=987952ea-6aa8-4601-833ac2c124e618d2&idx=0
- OECD 2002c, Manual for investigation of HPV chemicals, Chapter 4: Calculation of PNEC assessment factors. Accessed: http://www.oecd.org/chemicalsafety/riskassessment/2483645.pdf
- OECD 2002d, Screening information dataset (SIDS) initial assessment report for hydrogen chloride (CAS no. 7647-01-0), UNEP Publications. Accessed: http://www.chem.unep.ch/irptc/sids/OECDSIDS/7647010.pdf
- OECD 2002e, *IUCLID data set for sodium carbonate (CAS no. 497-*19-8), UNEP Publications. Accessed: http://www.chem.unep.ch/irptc/sids/OECDSIDS/Naco.pdf
- OECD 2002f, Screening information dataset (SIDS) initial assessment report for sodium carbonate (CAS no. 497-19-8), UNEP Publications. Accessed: http://www.chem.unep.ch/irptc/sids/OECDSIDS/Naco.pdf
- OECD 2002g, IUCLID data set for sodium hydroxide (CAS no. 1310-73-2), UNEP Publications, Geneva.
- OECD 2002h, Screening information dataset (SIDS) initial assessment report for sodium hydroxide (CAS no. 1310-73-2), UNEP Publications, Geneva.
- OECD 2001, IUCLID *data set for potassium chloride (CAS no. 7447-40-7),* OECD-SIDS program UNEP Publications, Geneva.
- OECD 2000b, Test No. 215: Fish, Juvenile Growth Test, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264070202-en
- OECD 1995a, Guidance Document on Aquatic Effects Assessment.

- OECD 1995b, Test No. 107: Partition Coefficient (n-octanol/water): Shake Flask Method, OECD Guidelines for the Testing of Chemicals, Section 1, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264069626-en
- OECD 1992a, Test No. 203: Fish, Acute Toxicity Test, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264069961-en
- OECD 1992b, Test No. 301: Ready Biodegradability, OECD Guidelines for the Testing of Chemicals, Section 3, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264070349-en
- OECD 1992c, Test No. 302B: Inherent Biodegradability: Zahn-Wellens/ EVPA Test, OECD Guidelines for the Testing of Chemicals, Section 3, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264070387-en
- OECD 1981, Test No. 302A: Inherent Biodegradability: Modified SCAS Test, OECD Guidelines for the Testing of Chemicals, Section 3, OECD Publishing. Accessed: http://dx.doi.org/10.1787/9789264070363-en
- Pereira SPP, Oliveira R, Coelho S, Musso C, Soares AMVM, Domingues I, Nogueira AJA 2014, 'From sub cellular to community level: Toxicity of glutaraldehyde to several aquatic organisms', *Science of the Total Environment*, 470-471 (2014), pp. 147-158.
- Qld WHS 2011, Queensland Work Health and Safety Act 2011, Work Health and Safety Regulation 2011. Accessed at: https://www.legislation.qld.gov.au/LEGISLTN/CURRENT/W/WorkHSR11.pdf
- Rozell DJ and Reaven, SJ 2012, 'Water pollution risk associated with natural gas extraction from the Marcellus Shale', *Risk Analysis*, 32(8), pp. 1382-1393.
- Rutherford, JC and Kefford, BJ 2005, *Effects of salinity on stream ecosystems: improving models for macroinvertebrates*, CSIRO Land and Water Technical Report 22/05. CSIRO Land and Water, Canberra.
- Rutovitz J, Harris SM, Kuruppu N and Dunstan C 2011, *Drilling down: Coal seam gas a background paper*, Report prepared by the Institute for Sustainable Futures, University of Technology Sydney, pp. 1-83. Accessed: 13 Jun 14 at http://cfsites1.uts.edu.au/find/isf/publications/rutovitzetal2011sydneycoalseamgasbkg d.pdf
- Schafer RB, Kefford BJ, Metzeling L, Liess M, Burgert S, Marchant R, Pettigrove V, Goonan P, and Nugegoda D 2011, A trait database of stream invertebrates for the ecological risk assessment of single and combined effects of salinity and pesticides in South-East Australia, A trait database of stream invertebrates for the ecological risk assessment of single and combined effects of salinity and pesticides in South-East Australia, A trait database of stream invertebrates for the ecological risk assessment of single and combined effects of salinity and pesticides in South-East Australia
- Schwarzenbach, P, Gschwend, P and Imboden, D 2003, *Environmental Organic Chemistry*, Second Edition. John Wiley and Sons, New Jersey USA, pp. 216-237.
- SETAC 2004, Ecological Risk Assessment, Society of Environmental Toxicology and Chemistry, Brussels, Belgium.
- Spain, AV, Isbell, RF and Probert, ME 1983, 'Soil organic matter', *Soils: an Australian viewpoint*, CSIRO Academic Press, pp 551-563.
- Stringfellow, WT, Domen, JK, Camarillo, MK, Sandelin, WL and Borglin, S 2014, 'Physical, chemical, and biological characteristics of compounds used in hydraulic fracturing', *Journal of Hazardous Materials*, 275, pp. 37-54. Accessed: http://dx.doi.org/10.1016/j.jhazmat.2014.04.040

- TDS Xanthan Gum, Technical datasheet of xanthan gum. http://pruebas.publicar.com/bogota/sandragonzalez/sesan/files/goma-xhantan.pdf
- The Royal Society and The Royal Academy of Engineering 2012, *Shale gas extraction in the UK: a review of hydraulic fracturing,* Report prepared by The Royal Society and The Royal Academy of Engineering, UK. Accessed: 12 June 2014 at http://www.raeng.org.uk/shale
- UNEP 1995. Water quality of world river basins, United Nations Environment Programme Environment Library No.14.
- UNEP 1987, Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi, Kenya.
- US EPA 2014a, Nonmonotonic dose-response curves, US Environmental Protection Agency. Accessed: http://epa.gov/ncct/edr/non-monotonic.html
- US EPA 2014b, Framework for Ecological Risk Assessment, US Environmental Protection Agency. Accessed: http://www.epa.gov/oppefed1/ecorisk_ders/index.htm#framework
- US EPA 2014c, EPA-Expo-Box (A Toolbox for Exposure Assessors), US Environmental Protection Agency.
- US EPA 2014d, Revised Second List of Chemicals for Tier 1 Screening, US Environmental Protection Agency, Washington DC.
- US EPA 2014e, Technical Overview of Ecological Risk Assessment, US Environmental Protection Agency. Accessed: http://www.epa.gov/oppefed1/ecorisk_ders/toera_risk.htm
- US EPA 2009, Final List of Chemicals for Initial Tier 1 Screening, US Environmental Protection Agency, Washington DC.
- US EPA 2005, Science Assessment for Hydroxypropyl Guar Gum, Lower Risk Pesticide Chemical Focus Group, Office of Prevention, Pesticides and Toxic Substances, US Environmental Protection Agency. Accessed: http://www.epa.gov/opprd001/inerts/hydroxypropyl.pdf
- US EPA 2000-2012, The ECOSAR (Ecological Structure Activity Relationship) Class Program for Microsoft Windows, v 1.11, 19 June.
- US EPA 1998, Guideline for Ecological Risk Assessment. Federal Register 63(93):26846-26924, 1998EPA/630/R-95/002F, April 1998. Accessed: http://www.epa.gov/raf/publications/pdfs/ECOTXTBX.PDF
- US EPA 1996, Soil Screening Guidance: Technical Background Document, 2nd Ed., EPA/540/R95/128, Office of Solid Waste and Emergency Response, May.
- US EPA 1992, Guidelines for Exposure Assessment, Federal Register 57(104):22888-22938, EPA/600/Z-92/001, May 1992. Accessed: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=15263#Download
- US NRC 2009, Science and Decisions: Advancing Risk Assessment, Committee on Improving Risk Analysis Approaches Used by the US EPA, National Research Council, National Academy Press, Washington DC, 1983. Accessed: http://www.nap.edu/catalog/12209/science-and-decisions-advancing-riskassessment.
- US NRC 1994, Science and Judgment in Risk Assessment. Committee on Risk Assessment of Hazardous Air Pollutants, National Research Council, National Academy Press, Washington DC, 1983. Accessed: http://www.nap.edu/catalog/2125/science-andjudgment-in-risk-assessment

- US NRC 1983, Risk Assessment in the Federal Government: Managing the Process, Committee on the Institutional Means for Assessment of Risks to Public Health, National Research Council, National Academy Press, Washington DC, 1983. Accessed: http://www.nap.edu/catalog/366/risk-assessment-in-the-federalgovernment-managing-the-process
- Vidic, RD, Brantley, SL, Vandenbossche, JM, Yoxtheimer, D and Abad, JD 2013, 'Impact of shale gas development on regional water quality', *Science*, 340(6134). Accessed: http://science.sciencemag.org/content/340/6134/1235009