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

#### *Technical report number 3* Literature review: Environmental risks posed by chemicals used in coal seam gas operations

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



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

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The report's authors gratefully acknowledge input from the Project Steering Committee, which comprised representatives from the Department of Health, 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.

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|---|---|--|--|
|   | 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<br>Environment and<br>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 extrac  | tion   |  |
| 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<br>Environment and<br>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   |   |  |  |

Literature review: Environmental risks posed by chemicals used in coal seam gas operations

| Technical<br>report<br>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<br>Environment and<br>Energy |  |

## Foreword

#### **Purpose of the Assessment**

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

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

This research assessed and characterised the risks to human health and the environment from surface handling of chemicals used in coal seam gas extraction during the period 2010 to 2012. This included the transport, storage and mixing of chemicals, and the storage and handling of water pumped out of coal seam gas wells (flowback or produced water) that can contain chemicals. International evidence<sup>1</sup> 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

<sup>&</sup>lt;sup>1</sup>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: Literature review: Environmental risks posed by chemicals used in coal seam gas operations

This literature review collated and considered information from published and unpublished national and international sources available up to the end of 2013, with minor updates since, as part of the first stage of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia. The objectives were to inform the environmental components of the subsequent stages of the assessment; in particular, to:

- characterise the receiving environment
- investigate the approaches and limitations of possible environmental risk assessment modelling options for coal seam gas chemicals

Key findings of the review are:

- The climate, topography, soils, hydrology, hydrogeology, and ecology of the receiving environments vary significantly across the regions in Australia where coal seam gas extraction takes place. Important receptors include the fast flowing rivers of eastern Australia that drain into the Pacific Ocean, the moderately regulated rivers of the northern Murray-Darling Basin, the ephemeral wild rivers of the Lake Eyre Basin and the Great Artesian Basin.
- Significant Australian ecological receptors include: 490 listed, threatened, migratory and marine species, 24 threatened ecological communities, 13 declared Ramsar wetlands and six listed National Heritage places, two of which are also World Heritage properties.
- Previous Australian risk assessments for chemicals used in coal seam gas extraction were mostly qualitative, with only limited quantitative exposure modelling. There were no modelling tools available for quantitative risk assessment of coal seam gas chemicals, but other surface-to-surface chemical exposure models can be adapted for this purpose.

Information about the processes used in coal seam gas extraction and the potential for intentional or unintentional release of chemicals into the environment during these operations is found in other literature reviews that are part of the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia.

## **Abbreviations**

| General<br>abbreviations | Description  |
|--------------------------|--|
| BTEX                     | Benzene, toluene, ethylbenzene, xylenes                          |
| cm                       | Centimetres  |
| СМА                      | Catchment Management Authority                                   |
| COPC                     | Chemical of potential concern                                    |
| CSG                      | Coal seam gas  |
| CSIRO                    | Commonwealth Scientific and Industrial Research Organisation     |
| DEHP                     | Department of Environment and Heritage Protection (Queensland)   |
| DERM                     | Department of Environment and Resource Management (Queensland)   |
| EPA                      | Environmental Protection Authority                               |
| EPBC Act                 | Environment Protection and Bioversity Conservation Act 1999      |
| FAO                      | Food and Agricultural Organization                               |
| GAB                      | Great Artesian Basin   |
| GL                       | Gigalitres   |
| ha                       | Hectare  |
| IBRA                     | Interim Biogeographic Regionalisation for Australia              |
| kg                       | Kilogram   |
| km                       | Kilometre  |
| L                        | Litre  |
| LNG                      | Liquefied natural gas  |
| m                        | Metre  |
| mm                       | Millimetre   |
| m²                       | Area in metres squared   |
| m <sup>3</sup>           | Volume in cubic metres   |
| MCAS-S                   | Multi-criteria analysis shell for spatial decision support       |
| mD                       | Millidarcy   |
| mg/L                     | Milligrams per litre   |
| ML                       | Megalitre  |
| NICNAS                   | National Industrial Chemicals Notification and Assessment Scheme |
| NRM                      | Natural resource management                                      |
| PNEC                     | Predicted no effect concentration                                |

#### Literature review: Environmental risks posed by chemicals used in coal seam gas operations

| General<br>abbreviations | Description                                   |
|--------------------------|---|
| RQ                       | Risk quotient                                 |
| Т                        | Tonnes  |
| TDS                      | Total dissolved solids                        |
| US EPA                   | United States Environmental Protection Agency |
| WHO                      | World Health Organization                     |

## Glossary

| Term              | Description   |
|-------------------|---|
| Alluvial          | A type of sediment deposited from flowing water into floodplains  |
| Aquatic ecosystem | Any body of water including lakes, streams, wetlands, reservoirs,<br>estuaries or marine environments and associated living organisms and<br>non-living components functioning as a natural system  |
| Aquifer           | Rock or sediment in formation, group of formations or part of a formation,<br>which is saturated and sufficiently permeable to transmit quantities of<br>water to wells and springs   |
| Arid              | Areas of Australia that receive annual average rainfall corresponding to less than 250 mm in southern parts of Australia and 350 mm in the northern parts of Australia  |
| Biocide           | An additive intended to destroy, deter, render harmless, prevent the action or otherwise exert a controlling effect on microorganisms. Commonly used in drilling and hydraulic fracturing fluids  |
| Biodiversity      | Variety of life forms including different plants, animals and microorganisms, the genes they contain and the ecosystems they form. Biodiversity is usually considered at three levels: genetic, species and ecosystem   |
| Bioregion         | Based on an Interim Biogeographic Regionalisation for Australia (IBRA).<br>A complex land area composed of a cluster of interacting ecosystems that<br>are repeated in similar form. Region descriptions seek to describe the<br>dominant landscape scale attributes of climate, lithology, geology,<br>landforms and vegetation. Biogeographic regions vary in size with larger<br>regions found where areas have more subdued terrain and arid and semi-<br>arid climates |
| Bituminous coal   | A form of black coal representing an intermediate stage of formation<br>between sub-bituminous coal and anthracite (the highest rank of coal).<br>Coal is ranked based on stage of formation, fixed carbon content, and<br>energy content   |
| Blowout           | A sudden and uncontrolled escape of fluids to the surface from the wellbore   |
| Bore              | Refers to a groundwater bore including the wellhead and all subsurface components (such as the drilled bore hole, annulus, and casing)  |
| Borehole          | A hole drilled for purposes other than production of oil, gas or water (e.g. a mineral exploration borehole)  |
| Bunding           | A physical form of site containment to prevent breaches or losses of chemicals from the well site   |
| Casing            | Steel or fibreglass pipe used to line a well and support the rock. Casing   |

| Term                                | Description  |
|-------------------------------------|--|
|                                     | extends to the surface and is sealed by a cement sheath between the casing and the rock  |
| Catchment                           | A topographic area that collects all the precipitation that falls on it  |
| 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 <sub>4</sub> ) typically extracted from permeable coal seams at depths of 300 to 1000 m. Also called coal seam methane (CSM) or coal bed methane (CBM).  |
| Conservative<br>approach/assessment | An assessment aimed at deliberately overestimating the potential risks to humans and the environment (after US EPA 1992)   |
| Contaminants                        | For the coal seam gas industry, contaminants refer to drilling chemicals,<br>hydraulic fracturing chemicals, geogenic chemicals, methane gas and by-<br>products from the production zone of gas reservoirs that have migrated to<br>the surrounding environment |
| Drainage division                   | Drainage divisions are broad regions of the Australian continent defined<br>by aggregation of adjoining river basins with comparable climate or<br>geography or shared discharge points (equivalent to catchment divisions)                                      |
| Ecological indicator                | A measure, an index of measures, or a model that characterises an ecosystem or one of its critical components. An indicator may reflect biological, chemical or physical attributes of an ecological condition   |
| Ecological receptor                 | Includes any living organisms other than humans, the habitat which<br>supports such organisms or natural resources which could be adversely<br>affected by environmental contaminations resulting by a release at or<br>migration from a site                    |
| Ecoregion                           | A large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions  |
| Ecosystem                           | Community of organisms, which may include humans, interacting with one<br>another. Incorporating the physical, chemical and biological processes<br>inherent in that interaction and the environment in which they live  |
| Ecosystem health                    | A term used to describe desired ecosystem conditions. The perception of health will vary depending on goals (e.g. production versus biodiversity)  |
| Endemic                             | A species that is unique or confined to a specific locality  |
| Fairway                             | The trend along which a particular geological feature, such as a coal seam, is likely to occur. (See also – 'Play')  |
| Flowback water                      | The initial flow of water returned to a well after fracture stimulation and prior to production  |

| Term                           | Description  |
|--------------------------------|--|
| Formation water                | Naturally occurring water that is within or surrounding the coal, rock or other formations underground   |
| Geogenic chemical              | A naturally occurring chemical originating, for example, from geological formations  |
| Groundwater                    | Water occurring naturally below ground level (whether in an aquifer or<br>other low-permeability material), or water occurring at a place below<br>ground that has been pumped, diverted or released to that place for<br>storage there. This does not include water held in underground tanks,<br>pipes or other works  |
| Groundwater<br>management unit | A hydraulically connected groundwater system that is defined and<br>recognised by State and Territory agencies. This definition allows for<br>management of the groundwater resource at an appropriate scale at<br>which resource issues and intensity of use can be incorporated into local<br>groundwater management practices   |
| Groundwater province           | An area that has a broad uniformity of hydro-geological and geological conditions, being identified as either predominantly sedimentary or fractured rock (as defined by the former Australian Water Resources Council)  |
| Habitat                        | A specific type of place within an ecosystem that is occupied by an organism, population or community that contains both living and non-living components with specific biological, chemical and physical characteristics, including life requirements (e.g. food, shelter and water)  |
| Hazard                         | Inherent property of an agent or situation having the potential to cause adverse effects when an organism, system, or sub(population) is exposed to that agent   |
| Hydraulic fracture             | The fracture created in coal seams through the process of hydraulic fracturing   |
| Hydraulic fracturing           | Also known as 'fracking' or 'fracture stimulation', is a process by which<br>hydrocarbon (oil and gas) bearing geological formations are 'stimulated' to<br>enhance the flow of hydrocarbons and other fluids towards the well. In<br>most cases is only undertaken where the permeability of the formation is<br>initially insufficient to support sustained flow of gas. The hydraulic<br>fracturing process involves the injection of fluids, gas, proppant and other<br>additives under high pressure into a geological formation to create a<br>conductive fracture. The fracture extends from the well into the coal<br>reservoir, creating a large surface area through which gas and water are<br>produced and then transported to the well via the conductive propped<br>fracture channel |
| Hydrogeology                   | The geology of groundwater, especially concerning the physical, biological and chemical properties of its occurrence and movement  |
| Hyporheic zone                 | The saturated zone of subsurface sediment and porous spaces adjacent to and below a stream, through which stream water readily exchanges with groundwater  |

| Term                              | Description   |
|-----------------------------------|---|
| Infiltration                      | Passage of water through the soil surface and into the soil   |
| Permeability                      | A measure of the ability of a geological formation to transmit fluid through pore spaces  |
| рН                                | A measure of the acidity/alkalinity of a solution, expressed on a logarithmic scale from 1 (most acidic) to 14 (most alkaline); 7 is neutral  |
| Play                              | A particular structural geological setting or group of coal seam gas<br>prospects in the same region that is controlled by the same set of<br>geological circumstances  |
| Probabilistic modelling           | Values calculated using multiple inputs as a probability distribution to describe model variables   |
| Produced water                    | Water that is pumped out of the coal seams to release the natural gas<br>during the production phase. Some of this water is returned fracturing fluid<br>and some is natural 'formation water' (often salty water that is naturally<br>present in the coal seam). This produced water moves through the coal<br>formation to the well along with the gas, and is pumped out via the<br>wellhead |
| Production zone                   | The treated (e.g. drilled and sometimes hydraulic fractured) volume of coal seam  |
| 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   |
| Psammolittoral zone               | The sandy, sarurated zone at the stream's edge  |
| Recharge                          | Groundwater recharge is the process whereby surface water (such as from rainfall runoff) percolates through the ground to the water table   |
| Recharge area                     | The area where water can enter and move downward to the groundwater.<br>Recharge areas are usually permeable in the upper slopes and are often<br>on shallow soils  |
| Riparian / riverine<br>vegetation | Frequenting river banks; growing by rivers or streams   |
| Risk                              | The likelihood that a hazard will actually cause its adverse effects, together with a measure of the effect   |
| Runoff                            | The proportion of precipitation that is not immediately absorbed by the soil and thus flows across the surface  |
| Salinity of water                 | Measure of total dissolved solids (TDS) in a water sample. Four quality classifications are used: fresh (TDS < 500 mg/L); marginal (TDS 500 to 1 500 mg/L); brackish (TDS 1 500 to 5 000 mg/L); and saline (TDS > 5 000 mg/L)   |
| Sclerophyll                       | Species that have adapted to lengthy seasonal drought by producing  |

| Term                             | Description  |
|----------------------------------|--|
|                                  | tough leathery leaves to cut down moisture loss by transpiration   |
| Semi-arid                        | Areas where rainfall is too low and unreliable for crops to be grown with certainty  |
| Strain                           | Changes in the length or volume associated with deformation from applied stress  |
| Stress                           | The force per unit area acting on a plane within a body  |
| Sub-bituminous coal              | An intermediate stage of formation between lignite (brown coal) and bituminous coal  |
| Subregion                        | A subdivision of a bioregion which contains distinctive geomorphic units that closely aligns with land capability and development potential  |
| Surface water<br>management area | Areas defined by the State and Territory water management agencies for<br>the purposes of reporting on surface water resources. The boundaries of<br>the reporting units commonly coincide with the Australian Water<br>Resources Council river basins. In a number of cases the reporting units<br>represent subdivisions of these river basins |
| Surfactant                       | Used during the hydraulic fracturing process to decrease liquid surface tension and improve fluid movements  |
| Unconventional gas               | Natural gas found in a very low permeability rock, such as shale gas and coal seam gas   |
| Vadose zone                      | The unsaturated zone that extends from the top of the ground surface<br>down to the water table. In the vadose zone, the water in the soil's pores<br>is at atmospheric pressure   |
| Well                             | A human-made hole in the ground, generally created by drilling, to obtain<br>water. As used in this report: a coal seam gas well including the wellhead<br>and all subsurface components (such as the drilled borehole, annulus,<br>and casings)   |
| Well integrity                   | A measure of the ability of the well and wellbore system to allow access to<br>the reservoir while controlling fluid movement along the well or from the<br>well into or out of the surrounding rock   |
| Well pad                         | The area of land on which the surface infrastructure for drilling and<br>hydraulic fracturing operations are placed. The size of a well pad varies<br>depending on the type of operation (e.g. well pads are larger at<br>exploration than production)   |
| Wellbore                         | The hole produced by drilling, with the final intended purpose being for production of oil, gas or water   |
| Wellhead                         | The above-ground part of a well placed on top of the wellbore. Wellheads manage the movement of gas and water to the surface   |
| Xeric                            | Characterised by or adapted to an extremely dry habitat  |

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## **1** Introduction

#### 1.1 This literature review

A literature review informed the environmental risk assessment. The aims of the review were to:

- inform the environmental conceptualisation for the risk modelling
- inform the environmental risk assessment
- understand approaches and limitations (data gaps) of possible environmental risk assessment modelling options.

This review involved collation and review of information available to the end of 2013, with minor updates made to the report since, from published and unpublished national and international sources including:

- journal articles
- conference proceedings
- websites
- industry and consulting reports
- non-governmental organisation and community reports
- media reports
- university and government research organisation reports
- scientific text books
- government reports.

The available published and unpublished national and international information was reviewed to:

- provide an understanding of the receiving environment to provide information for modelling and to identify key ecological receptors to assess the risks (see Section 2)
- understand the focus and extent of previous exposure modelling, and possible approaches and likely data gaps, for predicting the potential risks of chemicals associated with coal seam gas operations in Australia (see Section 3).

#### 1.2 Background

Coal seam gas has attracted worldwide attention as a source of unconventional natural gas supply, in part because of the abundance of the coal seam gas resource, and the competitive cost of producing this type of methane (Miyazaki 2005; Freij-Ayoub 2012).

In Australia, coal seam gas reserves occur in high- to medium-volatile bituminous Permian coals of the Sydney and Bowen basins and sub-bituminous to high-volatile bituminous Jurassic coals of the Surat Basin (Day 2009). Most of the production related to Jurassic coals is from the Walloon Coal Measures of the Surat Basin. Production from Permian coals occurs at the Fairview / Spring Gully, Peat / Scotia and Moranbah projects in the Bowen Basin and the Camden project in the Sydney Basin.

#### **1.3** History of coal seam gas development in Australia

Exploration drilling for coal seam gas started in 1976 and the first commercial production was achieved in 1996 from the Late Permian Baralaba Coal Measures of the eastern Bowen Basin in Queensland (Miyazaki 2005; Day 2009). During the 1980s and early 1990s major companies explored the Bowen Basin, the Galilee Basin and the Sydney Basin (Day 2009). Minor exploration of the Clarence-Moreton Basin was also undertaken. However, these activities were unsuccessful due to poor appreciation of the local and regional geology, the effect of stress regimes on coal permeability, inappropriate well completion methods and high costs (Day 2009).

During the 1990s, modest success was achieved in the Moura-Dawson Valley area of the eastern Bowen Basin with improvements in: understanding the local geological setting and stress regime; drilling; well completion; and cost control. The main factor limiting production of coal seam gas in the Moura-Dawson Valley region was low coal permeability. This effect continues to limit coal seam gas production in the Gunnedah and Sydney basins in New South Wales (Day 2009).

By 2000, the local industry had addressed earlier shortcomings in its exploration strategy and methodology, and significant coal seam gas production was established in the Bowen Basin. Attention then turned to the Middle Jurassic Walloon Coal Measures of the Surat Basin. The first coal seam gas well in the Surat Basin was drilled in 1995, but further exploration did not occur until 2000. Kogan North Field achieved the first commercial coal seam gas production in January 2006. This was soon followed by Berwyndale South Field, which delivered its first gas sales in May 2006. Exploration of the Surat Basin outlined a fairway favourable for coal seam gas production from the Walloon Coal Measures. The fairway was defined by depth and gas content and extended from north-west of Roma to south of Dalby. Numerous coal seam gas fields have been discovered within this fairway (Day 2009).

#### **1.4 Current activities**

Coal seam gas production in Australia is focused on Queensland, as existing fields expand and new projects are brought into production. The major producing fields in the Bowen Basin are Moranbah, Fairview, Spring Gully, Peat, Scotia and the Dawson Valley near Moura. The major producing fields in the Surat Basin are Berwyndale South, Argyle-Kenya, Kogan North, Daandine and Tipton West (Day 2009; Freij-Ayoub 2012). Australia Pacific LNG (a joint venture between Origin Energy and ConocoPhillips) was the leading producer in 2011, with plans to export some of its coal seam gas production via a liquefied natural gas (LNG) plant at Gladstone (Roarty 2011). This company is also planning to drill and establish 10 000 gas wells in the Bowen and Surat basins over the next 30 years, construct a gas transmission pipeline of about 530 km, and is building an LNG plant on Curtis Island, off the coast near Gladstone (Australia Pacific LNG 2012).

In New South Wales, coal seam gas exploration and production was an emerging industry at the time of this review. Exploration, pre-development, or pilot testing has occurred in the Hunter region, Gloucester Basin, Gunnedah Basin, Southern Coalfield Sydney Basin (near Camden) and Clarence-Moreton Basin in north-eastern New South Wales. The Camden Gas Project in the Sydney Basin is New South Wales's only operating coal seam gas production project.

In South Australia, coal seams in the Cooper Basin have been confirmed to contain significant quantities of gas (Yeo 2012).

In the Northern Territory, there are no known coal seam gas prospects. Hydraulic fracturing on a number of wells has stimulated gas production in shale (DME 2012); however, shale gas production is outside the scope of this review.

In Tasmania, the gas content of various coal deposits has been deemed insufficient for pilot production (Day 2009).

At present there is no coal seam gas production in Victoria and there are no applications to begin production. Although the location of Victoria's coal resources is well known, the amount of associated gas and the feasibility of extraction are uncertain. A number of companies have been granted exploration licences for coal seam gas in these areas (DPI 2012a).

## 2 Characterisation of the receiving environment

#### 2.1 Introduction

The initial receiving environments for chemicals associated with coal seam gas extraction include terrestrial, surface and subsurface aquatic ecosystems. The majority of fracturing chemicals associated with coal seam gas extraction are expected to either be present in aqueous waste streams (extracted solids, flowback and produced water) that return to the surface, or remain in subsurface aquatic ecosystems. Wastewater (flowback and produced water), potentially containing chemicals, may enter the terrestrial compartment, surface waters or subsurface waters as a result of re-use or disposal. Chemicals may also enter the environment through unintentional releases, e.g. chemicals may be spilt on-site or seep from wastewater storage areas into the terrestrial compartment. Surface and subsurface water resources may also become exposed to chemicals released into the terrestrial compartment following subsequent runoff or soil infiltration respectively.

Chemicals may be transported or degraded within the environment. The movement of a chemical in the receiving environment and its ultimate fate are determined by the physical, biological and chemical characteristics of that environment. This section aims to identify the relevant characteristics of the receiving environment, to inform the environmental risk assessment of chemicals associated with coal seam gas extraction. The receiving environment is described by identifying:

- the extent of the priority areas to be considered in the environmental risk assessment
- ecosystem characteristics that influence chemical transport and fate
- the availability of data on ecosystem characteristics that may be used in surface exposure modelling
- generic characteristics of potential ecological receptors of chemicals.

#### 2.2 Extent of the receiving environment

#### 2.2.1 Location of coal resources in Australia

Australia has significant unconventional gas resources. Unconventional gas includes coal seam gas, tight gas and shale gas. This report is focused on coal seam gas.

Australia has substantial resources of both black and brown coal. The most significant black coal resources are located in eastern Australia in the Bowen and Surat basins in Queensland and the Sydney Basin in New South Wales. Resources in the east also include the Gunnedah, Gloucester, Clarence-Moreton and Maryborough basins (Geoscience Australia and ABARE 2010). These eastern basins are located on both sides of the Great Dividing Range and extend from south of Wollongong in New South Wales to north of Mackay in Queensland. However, black coal basins also occur (Jalreth and Huleatt 2012):

• on the continental west coast, with the Perth Basin reaching from Cape Leeuwin in the south to several hundred kilometres north of Geraldton

- on the continental north coast, with the Canning Basin extending inland from Broome in Western Australia, and the Laura Basin located to the north-west of Cooktown in Queensland
- in the continental interior, including the Arckaringa Basin near Coober Pedy in South Australia, the Pedirka Basin to the north straddling the South Australian and Northern Territory border, and the Galilee, Cooper and Eromanga basins, which extend from the south-west Queensland border eastward to the Bowen Basin
- underlying much of eastern Tasmania.

Recoverable brown coal resources are predominantly those in the Gippsland basin in Victoria (Geoscience Australia and ABARE 2010). However, brown coal basins are present along much of the continental southern coast, with the Eucla Basin stretching from west of Esperance in Western Australia to the Eyre Peninsula in South Australia, the Murray Basin underlying a large portion of the southern reaches of the Murray River, and the Otway and Gippsland basins lining the Victorian south coast (Jalreth and Huleatt 2012).

Substantial resources of coal seam gas are associated with the major coal basins of eastern Australia. Exploration in Queensland continues to concentrate in the Bowen, Galilee and Surat basins. In New South Wales exploration continues in the Sydney, Gunnedah, Gloucester and Clarence-Moreton basins. Other prospective basins include the Pedirka, Murray, Perth, Ipswich, Maryborough and Otway basins (Geoscience Australia and ABARE 2010).

#### 2.2.2 Priority areas for bioregional assessment

Bioregional assessments provide a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and coal mining development on water resources (Barrett et al. 2013).

The Australian Government is undertaking a program of bioregional assessments to better understand the potential impacts of coal seam gas and large coal mining developments on water resources and water-dependent assets. The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) provides oversight of the Australian Government's Bioregional Assessment Program, which is targeting regions with significant coal deposits and initially focusing on those regions subject to significant existing or anticipated mining pressure. Bioregional assessments are being progressed for the following regions:

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions within the Northern Sydney Basin bioregion
- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

The priority areas are described by natural resource management (NRM) regions or catchments. There are 56 NRM regions in Australia and these are based on catchments or bioregions (Caring for our Country, 2011). The main NRM regions in each priority area and

their management units are listed in Appendix A, the main catchments and bioregions in the priority areas are listed in Appendix B and Appendix C, respectively. Further information on surface water and the bioregional framework in Australia is provided in the following section.

The six priority areas are shown in Figure 2.1. For the purposes of characterising the receiving environment, the Lake Eyre Basin priority area is taken to include the full Galilee Basin data collection area as shown in Figure 2.1 but to exclude areas that are not underlain by an identified coal resource.



Source: © Copyright, Commonwealth of Australia (2014)

Figure 2.1 The current bioregions of the Bioregional Assessment Program

#### 2.2.3 Comments on the extent of the receiving environment

It is not known if all coal resources in Australia contain recoverable coal seam gas. The location of coal resources suggests that the possible extent of the coal seam gas industry could reach across the country. However, for the purposes of this review, and the subsequent environmental risk assessment, the consideration of the receiving environment only extends to the six priority areas for bioregional assessment identified here.

#### 2.3 Ecological characteristics of the receiving environment

A definition of ecology provided by Attiwill and Wilson (2006) is:

*...the study of relationships between organisms and their environment, and the interaction between organisms*?

An understanding of the biological, physical, climatic and chemical attributes is required to describe the ecological characteristics of the receiving environment. These ecological characteristics are therefore important for understanding the fate and behaviour of chemicals in the receiving environment. For example, the movement of chemicals that may be transported in runoff waters will be influenced by the amount and timing of runoff from a catchment which is determined by climate, topography, soil type, geology, and vegetation (NLWRA 2002).

Other characteristics of the receiving environment may assist prediction of the environmental concentrations of chemicals. For example, the characteristics of hydrological features in the priority areas will influence the dilution and final concentrations of chemicals in environmental waters.

Characterisation of the receiving environment in this section includes:

- features and broad-scale patterns across the Australian landscape
- the range of ecological characteristics within each priority area
- sources of further data that may be used during the risk assessment.

#### 2.3.1 The Australian context

#### 2.3.1.1 Topography

Topography influences land slope, climate, water movement, and thus chemical transport, in the environment. Australia is typified by low elevations, with an average elevation of 330 m and less than 1% of the total area reaching over 1000 m in elevation (Geoscience Australia 2010). Wolfe (2009) describes the main topographic features as:

- an eastern highlands area, called the Great Dividing Range, which runs north-south from the northern tip of the continent (Cape York Peninsula) down through Queensland, New South Wales and eastern Victoria to the southern island state of Tasmania. This eastern range is relatively low (less than 2228 m)
- a central lowland area, which at its lowest point (Lake Eyre) is 15 m below sea level
- a large, low plateau (a peneplain) occurs in the western half of the continent.

#### 2.3.1.1.1 Further data sources

The National Elevation Data Framework portal (Geoscience Australia 2013) provides a central repository of digital elevation data that describes Australia's landforms and seabed. National datasets are available for a hydrologically enforced digital elevation model (DEM-H) down to a resolution of 1 second (approximately 30 m) (Gallant 2011).

The Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS-S) is a software tool (ABARES 2012a) with Australian national map layers available. The map layers include environmental and economic parameters relating to land surface characteristics of the priority areas including climate, elevation, slope percentage and length, soil, physiographic regions, land use, vegetation, and land cover.

#### 2.3.1.2 Soils

Soils in Australia are classified using the *Australian soil classification* (Isbell 2002). The classification is based on attributes that have significance for land use and soil management. The classification describes general characteristics of soils that may influence chemical fate and transport such as organic matter content, pH and soil texture.

Australian soils tend to be old, salty, clayey (except in the west of the continent, where they tend to be sandy), acidic, nutritionally and organically impoverished and structurally challenging (ANRA 2009a). Compared with soils in the northern hemisphere, Australian soils have less organic matter, poorer structure and tend to be quite clayey just below the surface, which restricts drainage and impedes root growth. Australian soils mirror the continent's great age and consequently are products of environmental conditions throughout history (climate, organisms, topography, parent material and time). This means that large areas are affected by salt and have various nutrient and physical limitations for plant growth and agriculture (ANRA 2009a).

#### 2.3.1.2.1 Further data sources

The MCAS-S (ABARES 2012a) map layers include soil type under the Australian soil classification.

The Australian Soil Resource Information System (ASRIS) is a national database of soil information, suitable for use at national to large regional scale (ASRIS 2013). ASRIS provides digital maps of key soil properties and a national database of existing primary data relating to soil and land resources. Key soil properties include pH, organic carbon, total phosphorus, extractable phosphorus (New South Wales and Victoria), total nitrogen, texture, clay per cent, silt per cent, sand per cent, layer (horizon) thickness, solum thickness, bulk density, available water capacity, and saturated hydraulic conductivity. The national database of existing primary data comprises a soil profile database, a soil and land resources map database, and other datasets relevant to modelling soil properties.

The Geochemical Atlas of Australia (Geoscience Australia 2012) contains a recently generated national dataset of 68 mineral elements and bulk properties of soils, including loss on ignition, pH, electrical conductivity and grain size (percentage composition of clay/silt/sand). Soil samples were gathered from 1315 sites in 1186 catchments across Australia at two depths (approximately 10 cm and 80 cm) as part of Geoscience Australia's National Geochemical Survey of Australia project.

#### 2.3.1.3 Climate

Climatic factors such as rainfall, temperature and evaporation rates can influence the availability of water, the permanence of surface water receiving environments, and distribution of fauna and flora across Australia. The rate of chemical degradation may vary, depending on the effects of these variables on transport of chemicals through the environment. Continental-scale patterns for these parameters are briefly described below.

Australia is the driest inhabited continent and, according to Wolfe (2009), over 70% of the land area is classed as either semi-arid or arid. Rainfall in very arid areas is highly variable and falls on very few days of the year. Rainfall generally increases towards the coast as proximity to both moisture sources and reliable rain-producing weather systems improves. Elevation also has an important influence on rainfall, with the mountain areas of north-eastern Queensland, south-eastern Australia and western Tasmania receiving higher rainfall totals (BOM 2011a). Long-term average annual rainfall is less than 150 mm in a large region centred in the north of South Australia, and only slightly greater (up to 250 mm) for much of the rest of central Australia and a large portion of Western Australia. Rainfall is typically greater than 750 mm for much of the eastern seaboard, much of the continent north of 15°S, Tasmania and the south-west of Western Australia. Rainfall isohyets (lines joining points of equal precipitation on a map) are regularly spaced in the north and west as a consequence of the flat terrain (Adams et al. 2006).

Australia's seasonal pattern of rainfall is characterised by (ANRA 2009b):

- a humid, monsoonal wet season (October to March) followed by a hot, dry season (April to September) in the north
- Mediterranean climate in the south-west with hot, dry summers and cool, wet winters, watered by frontal rain from the Southern Ocean
- a more uniform distribution of rainfall through the year in the south-east.

Latitude, topography and proximity to the coast influence temperature as described by Adams et al. (2006) and BOM (2011b). In particular, average maximum temperatures generally increase with decreasing latitude and increasing distance from the coast. Temperatures also decrease with increasing elevation, although the effect of topography is not as pronounced. Proximity to the coast moderates temperature ranges with coastal areas receiving cooling afternoon sea breezes in summer and milder nights in winter. In contrast, inland areas have colder temperatures at night due to reduced cloud cover and humidity, and generally lighter wind speeds.

Areas in central Australia are very dry and therefore have a high rate of evaporation, which can exceed 4000 mm annually in north-western Australia. In contrast, coastal areas tend to have a lower evaporation rate, for example less than 1600 mm annually along the NSW coast, as a result of their proximity to a large water source. Areas with low rainfall and low humidity tend to have a high evaporation rate, whilst areas with high rainfall and high humidity tend to have a low evaporation rate (BOM 2006).

#### 2.3.1.3.1 Further data sources

The MCAS-S (ABARES 2012a) map layers include temperature, evaporation and rainfall data. A range of climate data can also be obtained from the Bureau of Meteorology (BOM) at Climate Data Online (BOM 2012) or through BOM data services (BOM 2013a). An example of the type of data that may be useful in modelling runoff is the Rainfall IFD Data System (BOM 2013b), which describes rainfall intensity-frequency-duration (IFD). The current IFD dataset was published in 1987 based on data available up to 1983. A revision incorporating an expanded rainfall database is expected to be available in the first quarter of 2013. A pilot study revision is already available for south-east Queensland and north-east New South Wales.

#### 2.3.1.4 Surface water

The Great Dividing Range separates the long, slow rivers flowing towards inland Australia from the short, faster rivers flowing into the Pacific Ocean. In central Australia lakes and river systems became drier and more reliant on flows from the wetter margins of the continent. The priority areas occur on both sides of the divide.

Australian rivers are characterised by relatively low and variable flows, as noted by Whittington and Liston (2003). One reason for variability is that rainfall is distributed unevenly both geographically and seasonally. On average, only 12% (less than 3% in the drier areas and up to 24% in the wetter areas) of rainfall enters the rivers. The remaining rainfall is accounted for by evaporation, used by vegetation or stored in lakes, wetlands and groundwater aquifers.

The *Australian catchment, river and estuary assessment 2002* (NLWRA 2002) also relates the differing characteristics of Australian rivers to climate. Notably, rivers differ between:

 northern Australia, where monsoonal rains are common during the wet season (almost 50% of Australia's average annual runoff is from the Timor Sea and Gulf of Carpentaria drainage divisions)

- the arid interior, where tropical cyclones may occasionally dump heavy rain, causing spectacular flooding
- south-eastern Australia, where rainfall is more evenly distributed and the climate is temperate.

The result is that Australia has a mix of a few perennial and mainly intermittent and episodic rivers, fed by groundwater sources and surface rainfall.

Australian Water Resources 2005 (NWC 2006) divides surface water resources into 12 drainage divisions, 246 river basins, and 340 surface water management areas. The drainage division and main river basins in the six priority areas are provided in Appendix B.

#### 2.3.1.5 Groundwater

Australian groundwater resources can be relatively high in salt, compared with continents such as North America and Europe, a consequence of periods of inundation of the Australian continent by the sea, and a low rate of recharge with rainfall or fresh groundwater (Wolfe 2009). Groundwater ranges from fresh to saline and can vary within an aquifer. For example, Moran and Vink (2010) report salinity (as total dissolved solids) ranging from 103 mg/L to 24 473 mg/L within the Condamine River alluvium.

Groundwater resources are extensively developed across Australia, particularly in semi-arid to arid zones with unreliable access to surface waters. Groundwater in Australia is divided into 69 groundwater provinces and 367 groundwater management units (NWC 2006).

The most significant groundwater feature in Australia is the Great Artesian Basin (GAB). It underlies an area of over 1.7 million km<sup>2</sup> (Booth and Tubman 2011) beneath the arid and semi-arid parts of Queensland, New South Wales, South Australia and the Northern Territory. The GAB is comprised of sedimentary rock layers that form aquifers and aquitards (confining layers), containing groundwater that is mostly under artesian conditions, and encompasses several geological basins ranging from 200 to 65 million years old (Smerdon et al. 2012). The major recharge areas around its eastern margins coincide with the western slopes of the Great Dividing Range in Queensland and New South Wales (Miles et al. 2012). Other recharge areas exist along the margins in the Flinders, Gawler and Stuart ranges to the west, and Carpenteria to the north. Recent work has identified overlying geological formations in the Carpentaria and Central Eromonga regions to be important for groundwater recharge (Smerdon et al. 2012). The GAB underlies much of the Lake Eyre Basin and Northern Inland Catchments priority areas.

Recharge of groundwater occurs by diffuse (infiltration of precipitation or irrigation) or by localised (from rivers, lakes or surface depressions) mechanisms. Factors influencing groundwater recharge include characteristics of the recharge beds such as topography, land use and vegetation cover, existing soil moisture and the ability of the recharge beds and aquifer materials to capture and transmit water (BRS 2007).

Groundwater and surface water are usually interconnected and interchangeable resources. Groundwater pumping within a catchment has the effect of reducing baseflow in a gaining stream, and in some cases it can turn a gaining stream into a losing stream, causing induced recharge. However, there may be a time lag that hampers recognition of the interconnection of these resources (Harris 2006).

One of the objectives of the National Water Initiative is to recognise connectivity between surface and groundwater resources and manage connected systems as a single resource. Research to establish areas of rivers with net gains or losses (NWC 2011), has resulted in published studies (Parsons et al. 2008; Baskaran et al. 2009; SKM 2012a).

SKM (2012b) reported that, other than monitoring for salinity, very little monitoring of groundwater quality occurs across Australia. Water quality monitoring activities are generally undertaken on a project-by-project basis. Gaps also exist in the monitoring network, either due to funding arrangements or because monitoring networks are not keeping pace with recent increases in groundwater development.

#### 2.3.1.5.1 Further data sources

MCAS-S (ABARES 2012a) map layers include evaporation, runoff, soil moisture and distance to surface water features.

The Australian water resources assessment 2000 (NLWRA 2000) identified that datasets on surface water quality parameters such as salinity, pH and nutrients were incomplete. Data were primarily limited to the more developed areas, often in basins where water quality had already been an issue. The Bureau of Meteorology (BOM) now has responsibility for compiling and disseminating comprehensive water information across Australia. BOM receives information about river flows and groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades. BOM is in the process of developing the Australian Water Resources Information System (AWRIS) (BOM 2013c), an information system capable of receiving, standardising, organising and interpreting water data from across the nation.

The Environmental Information Explorer (BOM 2013d) provides access to information about monitoring sites that measure the quality and quantity of water in surface water features, particularly rivers and water storages, and rainfall and evaporation at meteorological stations. Site information is available for sites owned and operated by over 90 organisations across Australia. The portal allows identification of environmental monitoring site locations, observations and measurements. The distribution of water monitoring sites is not uniform across the Australian landscape. Water quantity information such as watercourse level (2158 active monitoring sites) is more frequently recorded than water quality parameters such as pH (696 active monitoring sites). Data from these monitoring sites may be obtained from the site owner.

The Australian Hydrological Geospatial Fabric (BOM 2013e), also known as the Geofabric, identifies the spatial relationships of important hydrological features such as rivers, lakes, reservoirs, dams, canals and catchments. Surface water features include both natural features and anthropogenic infrastructure including dams, pipes and road crossings. In addition connectivity, flow direction and system boundaries for surface water modelling are inferred for streams and catchments. Geofabric also includes a national groundwater (aquifer) dataset which, although not suitable for regional or local modelling, identifies aquifer boundaries and the uppermost unconfined aquifer, and contains information on salinity, lithology and hydraulic connectivity.

In Victoria, data for water quality and quantity parameters are available through the Victorian Water Resources Data Warehouse (DSE 2013). In New South Wales, water monitoring information may be accessed through the Office of Water website (Office of Water 2011). Information on Queensland's water quality, water quantity and aquatic ecosystem monitoring programs may be found through the Queensland Waterways Monitoring Portal (DERM 2012). Queensland's surface water and groundwater monitoring data may be accessed through the Water Monitoring Data Portal (DNRM 2012).

#### 2.3.2 Ecoregions

The World Wildlife Fund (WWF) has identified ecoregions, or biomes, globally that are representative of the most outstanding examples of the 26 major habitat types in the terrestrial, freshwater and marine environment. The major habitat types describe different

areas that share similar environmental conditions, habitat structure and patterns of biological complexity, and that contain similar communities and species adaptations (WWF 2013a).

Australia has eight of these 14 terrestrial habitats. Under the *Interim Biogeographic Regionalisation for Australia* (IBRA), these terrestrial habitats are divided into 89 bioregions and 419 subregions (DEHP 2012). Subregions may be further divided into regional ecosystems, although at present there is no consistent identification and mapping of ecosystems at a regional scale. Regional mapping has been completed in some areas, such as Queensland (DEHP 2012).

The biomes associated with the four main terrestrial habitats that occur across the six priority areas are briefly described below. The Australian ecoregions for terrestrial, freshwater and marine habitats in the priority areas are also identified.

#### 2.3.2.1 Deserts and xeric shrublands

The amount of annual rainfall in deserts and xeric shrublands can vary greatly, however evaporation generally exceeds rainfall. Temperature extremes are a characteristic of most deserts. Searing daytime heat gives way to cold nights, as there is no insulation provided by humidity and cloud cover. The diversity of climatic conditions supports a rich array of habitats. Many of these habitats are ephemeral in nature, reflecting the paucity and seasonality of available water (DSEWPAC 2013a). The eastern portion of the Australian biome for this terrestrial habitat is overlain by the Central Australian Freshwater ecoregion— a xeric basin (freshwater) habitat type that is defined primarily by the interior-draining Lake Eyre and Bulloo-Bancannia drainage basins (WWF 2013b).

#### 2.3.2.2 Temperate broadleaf and mixed forests

Temperate forests experience a wide range of variability in temperature and precipitation. In Australia, the temperate forests stretching from south-east Queensland to southern Australia enjoy a moderate climate and high rainfall, that give rise to unique eucalyptus forests and open woodlands (DSEWPAC 2013a). Much of this area is included in the Eastern Australia Temperate Forests ecoregion (WWF 2013c). Genera such as Eucalyptus and Acacia typify the composition of the temperate broadleaf and mixed forests in Australia. This biome in Australia has served as a refuge for numerous plant and animal species when drier conditions prevailed over most of the continent. This has resulted in a remarkably diverse spectrum of organisms with high levels of regional and local endemism (DSEWPAC 2013a).

#### 2.3.2.3 Temperate grasslands, savannas and shrublands

Temperate grasslands, savannas and shrublands differ largely from tropical grasslands due to the cooler and wider annual temperatures, as well as the types of species found there. Generally speaking, these regions are devoid of trees, except for riparian or gallery forests associated with streams and rivers. Positioned between temperate forests and the arid interior of Australia, the south-east Australian temperate savannas span a broad north-south area across Queensland, New South Wales and Victoria. However, most of this habitat has been converted to sheep rearing and wheat cropping, and only small fragments of the original eucalypt vegetation remain (DSEWPAC 2013a).

#### 2.3.2.4 Tropical and subtropical grassland savannas and shrublands

Large expanses of land in the tropics do not receive enough rainfall to support extensive tree cover. The tropical and subtropical grasslands, savannas, and shrublands are characterised by rainfall levels between 900 mm and 1500 mm per year. While much of Australia is covered by grassland, savanna ecosystems are far more restricted — these ecosystems are limited to moister areas along the coast with the Kimberley, Top End and Cape York

savannas. Patches of dry rainforest with high species diversity also occur throughout the ecoregion (DSEWPAC 2013a).

#### 2.3.2.4.1 Other Australian ecoregions

The WWF describes a further two ecoregions in the priority areas. The Eastern Australia Rivers and Streams ecoregion is a small rivers ecoregion of freshwater habitat type that includes the rivers and streams of the Great Dividing Range (WWF 2013d). The Southern Australian Marine ecoregion is a temperate shelf and seas ecoregion of marine habitat type along the southern coast of Australia, including the area offshore of the Gippsland Basin (WWF 2013e).

#### 2.3.3 Flora and fauna

The present distribution of many species and genera in Australia is linked to broad-scale climatic patterns. The deserts of Australia are barriers to migration and there are many species in eastern and western Australian that are not found on the other side of the divide (Adams et al. 2006). Current vegetation species diversity and distribution across Australia is strongly influenced by the onset of aridity (low rainfall and high variability over much of the continent) and old soils (which have lost much of their original nutrient supply). Forests only cover about a fifth of the continent. Taller forests are confined to Tasmania, the Great Dividing Range and south-west Western Australia. The limit of woodlands is defined by annual rainfall of greater than 500 mm. Australian flora also has a long history of evolution influenced by fire (Hill and Brodribb 2006).

Hill and Brodribb (2006) indicate that, in general, Australia's flora is typified by Gondwanan elements that have become geographically isolated and have evolved through differentiation and speciation. Gondwanan sub-elements include the following:

- *relict*, which show little diversification from the original flora and are confined to more humid habitats such as cool-temperate rainforests in Tasmania and Victoria, and subtropical and tropical rainforests in northern New South Wales and Queensland
- *autochthonous*, which is derived from the original Gondwanan flora to produce typically Australian taxa with high levels of endemism, such as *Eucalyptus* and *Banksia*.

The autochthonous sub-element of Australian flora has an unparalleled degree of scleromorphy (sclero meaning hard) typified by small, rigid leaves, short internodes and small plant size. It is recognised that sclerophylly may be a response to the limited availability of water or nutrients. The result of geographic isolation of the Australian continent is that many of the species in the *Acacia, Eucalyptus* and *Banksia* genera are endemic (Hill and Brodribb 2006).

Australia has over 18 000 species of described vascular plants, which are the most conspicuous components of the living environment. More than 3200 species of lichens are known to occur in Australia and its territories, representing about 400 genera in about 100 families (DSEWPAC 2013b). Lichens are especially diverse in tropical and temperate regions — that is, near the east coast from north Queensland to Tasmania. At least 1800 bryophyte species (mainly mosses and liverworts) are known in Australia, these comprise significant endemic, southern-temperate, pantropical and cosmopolitan elements. Australia is estimated to have 160 000 to 250 000 fungal species, of which fewer than 5% have been described. At least 12 000 marine, freshwater and terrestrial algal species are thought to occur in Australia, but many are yet to be described or fully documented (DSEWPAC 2013b).

Hill and Brodribb (2006) indicate that Australian vertebrate fauna are unique in that:

- there are many unusual forms and many endemic forms at both species and higher taxonomic levels
- many groups, such as placental mammals, that have high diversity in the world have low diversity in Australia
- certain functional elements seen on other continents are lacking in the modern fauna, such as open-country carnivores including lions, wolves, etc.

The mammalian fauna of Australia is distinctive. Only the continental island of Australia and the smaller island of New Guinea have representatives of all three extant major groups of mammals — placental, monotremes and marsupials. The usual perception of the mammalian fauna of Australia emphasises the monotremes and marsupials, however Australia also has an abundance of other mammals such as rodents, bats and marine mammals (DSEWPAC 2013b).

The rich and diverse Australian fauna is estimated to include well over 250 000 species. At present over 120 000 species (just under half of the total) have been documented and described. Of the described fauna, the relatively well-known vertebrates represent about 7 550 species. The abundant invertebrates are represented by around 114 000 species, half of which are yet to be described (DSEWPAC 2013b).

#### 2.3.3.1 Further data sources

The Atlas of Living Australia (Australian Government 2013) contains information on all the known species in Australia aggregated from a wide range of data providers, including museums, herbaria, community groups, government departments, individuals and universities.

#### 2.3.4 Biodiversity

Australia is one of 17 countries described as being megadiverse (DEWHA 2009a). This group of countries has less than 10% of the global surface, but supports more than 70% of the biological diversity on Earth. Australia is home to between 600 000 and 700 000 species, many of which are endemic — that is, they are found nowhere else in the world (DEWHA 2009a). Approximately 80% of Australia's terrestrial and aquatic flora and fauna occur nowhere else in the world. Endemism is particularly high in some groups. For example, 41.3% of the chordates (including 87% of mammals, 45% of birds, 93% of reptiles, 94% of frogs) and some 92% of the vascular plants are endemic (Chapman 2009).

Biodiversity hotspots are areas with a high diversity of locally endemic species, which are species that are not found or are rarely found outside of the hotspot (DEWHA 2009a). The Australian Government announced 15 national biodiversity hotspots in October 2003. Of these, three coincide with the six priority areas and are described briefly below.

#### 2.3.4.1 Einasleigh and Desert Uplands (Queensland)

Above the Galilee coal basin in north Queensland the high ranges and plateaus of Einasleigh contrast sharply with the plains and low ranges of the Desert Uplands. Einasleigh basalt lava flows and lava tunnels provide habitat for threatened and geographically restricted plants and animals. Water enters the GAB aquifers here and important artesian spring complexes contain endemic plants, snails and fish, including the Edgbaston goby and the salt pipewort (*Eriocaulon carsonii*). Ecologically and geologically important wetlands include Lake Buchanan and Lake Galilee. In the Desert Uplands alone there are 22 rare or threatened animals, including the masked owl and the Julia Creek dunnart, and 29 rare or threatened plants (DEWHA 2009b).

#### 2.3.4.2 Brigalow North and South (Queensland and New South Wales)

The inland plains of the Brigalow Belt, which occur in the Northern Inland Catchment priority area, originally supported vast vegetation communities dominated by brigalow (*Acacia harpophylla*). On the western slopes of the Great Dividing Range there are large tracts of eucalypt woodlands, and the hotspot is also a stronghold for large numbers of endemic invertebrates. This hotspot includes populations of the endangered bridled nail-tail wallaby and the only remaining wild population of the endangered northern hairy-nosed wombat, now limited to around 110 individuals in the wild. The area contains important habitat for rare and threatened species including the bulloak, the jewel butterfly, brigalow scaly-foot, glossy black-cockatoo, greater long-eared bat, large pied bat, eastern long-eared bat and the threatened community of semi-evergreen vine thickets. The hotspot provides important habitat for star finches and golden-tailed geckos (DEWHA 2009b).

#### 2.3.4.3 Border Ranges North and South (Queensland and New South Wales)

This subtropical and temperate hotspot is one of Australia's most diverse areas — and it is the most biologically diverse area in New South Wales and southern Queensland. It has a variety of significant habitats: subtropical rainforest, wet sclerophyll forest, mountain headlands, rocky outcrops and transition zones between forests. These habitats support a variety of bird and macropod species (DEWHA 2009b).

#### 2.3.4.3.1 Further data sources

MCAS-S (ABARES 2012a) map layers include information on vegetation types and protected matters under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The Species Profile and Threats Database (DSEWPAC 2012a) provides information about species and ecological communities listed under the EPBC Act. It includes information on species populations, distribution, habitat, movements, feeding and reproduction, and taxonomy.

Biodiversity assessment information for bioregions is available in the Australian Natural Resources Atlas (ANRA 2009c). The Assessment of Terrestrial Biodiversity 2002 Database, the underlying national dataset compiled from state and territory data, is available though the Australian Natural Resources Data Library (ABARES 2012b).

#### 2.3.4.4 Groundwater-dependent ecosystems

There has been growing recognition that many Australian ecosystems are dependent on groundwater, since the first national assessment by Hatton and Evans (1998). Groundwater-dependent ecosystems can be located in marine, coastal, riparian, in-stream, terrestrial and in cave and aquifer environments (Eamus et al. 2006). The following three simple primary classes of groundwater-dependent ecosystems were described in Eamus et al. (2006), and since endorsed by an inter-jurisdictional reference group on groundwater-dependent ecosystems, and used in the Atlas of Groundwater Dependent Ecosystems (BOM 2013a):

 aquifer and cave ecosystems, where stygofauna (i.e. groundwater-inhabiting organisms) reside within the groundwater resource. These ecosystems include karstic, fractured rock and alluvial aquifers. The hyporheic zones of rivers and floodplains (region where there is mixing of shallow groundwater and surface water) are included in this category because these ecotones often support stygobites (obligate groundwater inhabitants)

- 2. All ecosystems dependent on the surface expression of groundwater. This therefore includes base-flow rivers and streams, wetlands, some floodplains and mound springs and estuarine seagrass beds. While it is acknowledged that plant roots are generally below ground, this class of groundwater-dependent ecosystem requires a surface expression of groundwater, which may, in many cases, then soak below the soil surface and thereby become available to plant roots
- 3. All ecosystems dependent on the subsurface presence of groundwater, often accessed via the capillary fringe (i.e. non-saturated zone above the saturated zone of the water table) when roots penetrate this zone. This class includes communities such as river red gum (*Eucalyptus camuldulensis*) forests on the Murray-Darling Basin, and Banksia woodland on the Gnangara mound of Western Australia. No surface expression of groundwater is required in this class of groundwater-dependent ecosystem.

#### 2.3.4.4.1 Further data sources

The Atlas of Groundwater Dependent Ecosystems (BOM 2013a) shows ecosystems including springs, wetlands, rivers and vegetation that interact with the subsurface presence of groundwater or the surface expression of groundwater. Groundwater-dependent marine and estuarine ecosystems are not mapped in the atlas. Subsurface groundwater-dependent ecosystems including cave and aquifer ecosystems are only available for Tasmania. The atlas displays ecological and hydrogeological information on known groundwater-dependent ecosystems and ecosystems that potentially use groundwater. The physical characteristics that describe each ecosystem are also shown.

#### 2.3.4.5 Subsurface groundwater-dependent ecosystems

In surface ecosystems, although we do not yet fully understand the causal links and relationships, we understand key drivers of ecosystem function and dysfunction, e.g. processes such as water flow, sediment movement, nutrient cycling and fire regime (NLWRA 2002). The same cannot be said for subsurface ecosystems. Tomlinson and Boulton (2008) suggested that the sequestered location of subsurface groundwater-dependent ecosystems has not only led to these habitats being overlooked in favour of more accessible groundwater-dependent ecosystems but also masked their diversity, ecosystem services and close interconnections with other ecosystems. Characteristics of subterranean ecosystems and their biological communities are briefly described below, particularly those facets that differ, or are perceived to differ from the surface environment.

Subterranean terrestrial and aquatic habitats are characteristically devoid of light, nutrient poor, experience limited temperature variability and have high physical fragmentation (Gibert and Deharveng 2002). Aquifer ecosystems have relatively stable environmental conditions compared to surface aquatic environments (Tomlinson and Boulton 2008). Historically there has been a perceived rarity of subsurface habitat, although underlying streams (hyporheic zone) that form part of the interstitial habitat for groundwater ecosystems are neither rare nor discontinuous (Culver et al. 2009).

Hatton and Evans (1998) indicate that groundwater ecology in its full complexity considers both the ecology of the karst groundwaters and that of the porous media of unconsolidated rocks and the interaction zones between surface and groundwater environments. It also considers the influence of groundwater on aquifer microbiology and geochemistry, and deep subsurface microbiology. Tomlinson and Boulton (2008) suggest an ecologically relevant definition of groundwater to be water that has been present in pores and cracks of the saturated zone of soil or rock for sufficient time to undergo physical and chemical changes resulting from interactions with the aquifer environment. It is now recognised that groundwater ecosystems support diverse microbial communities and a wide range of invertebrate and vertebrate species (National Research Council 2004). Groundwater fauna (stygofauna) are largely invertebrates, with vertebrates restricted to larger voids such as caves found in karst areas. Stygofauna include:

- stygoxenes, which occur in groundwater accidently but have no affinity with groundwater habitats
- stygophiles, animals that spend part of their life cycle in groundwater
- *stygobites*, aquatic animals that complete their life cycle in groundwater and are obligate inhabitants of groundwater.

The composition of subterranean fauna assemblages depends on the connectivity with surface water systems. For example, stygobites comprised 60% of the subterranean community in a pristine karst aquifer of the Lez Basin in France, but can range from 80 to 100% in deep aquifers without direct contact with surface waters to less than 20% in the upper parts of riverine aquifers (Gibert and Deharveng 2002).

Tomlinson and Boulton (2008) list the following adaptations as characteristic of groundwater invertebrates: eye loss or reduction, small size, loss of pigmentation, attenuated body shape, development of sensory setae, production of fewer but larger eggs, longer time for egg development, longer life cycles, lower metabolic rates, and reduced locomotory and physiological activity in response to environmental stress. These adaptations confer greater tolerance of starvation and low oxygen levels on stygobites compared with surface water fauna. With the exception of large taxa such as fish, stygofauna from the Pilbara and adjacent areas are found wherever groundwater environments provide suitable habitat, including in porous, karstic and fractured-rock aquifers as well as the hyporheic zone and springs. This suggests that stygofauna frequently occur where there is suitable habitat.

Gibert and Deharveng (2002) describe subterranean biodiversity as characterised by:

- few lineages, characteristic of any extreme environment
- a high proportion of endemic species and evidence of allopatric vicariant speciation
- a high level of relic taxa due to the relative stability and antiquity of the habitat
- food webs that are truncated at the bottom and top.

Subterranean ecosystems have truncated and redundant functionality and are limited by nutrient availability (Gibert and Deharveng 2002). While chemoautotrophic primary production in the subsurface does occur and may be significant in particular systems (Tomlinson and Boulton 2008), there is limited evidence of diversified and productive communities that can function independently of external resources (Baker et al. 2000; Culver et al. 2006). Microbial decomposers rather than plants are the basis of the food chain and therefore have key roles in supporting biodiversity and ecosystem function. Subterranean food chains may also be truncated at the top, with few or no strict predators (Tomlinson and Boulton 2008).

The truncated functionality at the base of the food chain requires that resources be imported into subterranean ecosystems from the surface environment. Resources enter subterranean ecosystems as organic matter that seeps into fissures and channels, is buried in sediment and incorporated into decomposer food chains (Gibert and Deharveng 2002). The resources are unevenly distributed due to the heterogeneity of the habitat (Griebler and Lueders 2009). Nutrients and dissolved oxygen content in groundwater decreases with path length from point of origin. Therefore, linkages between the surface and subterranean environment are a critical dynamic in describing subterranean ecosystems.

Tomlinson and Boulton (2008) demonstrate that subsurface groundwater-dependent ecosystems are connected to terrestrial and aquatic surface ecosystems through transition zones including the hyporheic zone (the saturated zone below the water table), the vadose zone (the unsaturated zone from the surface down to the top of the water table), marine upwelling, intrusion zones, and the psammolittoral (the sandy, saturated zone at the waters' edge).

Tomlinson and Boulton (2008) identified several groundwater ecosystem services including provision of water, bioremediation, nutrient cycling, ecosystem engineering, refugia, flood control, and cultural services such as ecological indicators and tourism.

With respect to serving as ecological indicators, Tomlinson and Boulton (2008) suggested that stygofauna have the potential to offer a service as indicators of ecosystem condition and the integrity of some of the fundamental ecological processes occurring in groundwaters. However, the relative sensitivity of surface and subsurface fauna has not been established and the lower metabolic rates of stygobites could mean that longer exposures might be required before toxic effects are evident. Boulton et al. (2008) identified that the stygofaunal species *Phreatoicus* fulfilled a keystone role within one alluvial groundwater ecosystem because its increased population densities played a significant role in processing microbes. However, little was known of individual species range, general biology and tolerances, which is indicative of the general state of knowledge on stygofauna.

Knowledge of groundwater ecosystems in Australia is limited. Humphreys (2006) concluded that the available data show that Australia has a diverse groundwater fauna but the focus of knowledge is in the rangelands, particularly in Western Australia, where subterranean fauna are routinely considered in the environmental review process. However, limited research elsewhere indicates that significant stygofauna occur elsewhere in Western Australia, the Northern Territory, South Australia, Tasmania, Queensland, New South Wales and Christmas Island. Typically, each new area examined had unique fauna.

The overview provided by Tomlinson and Boulton (2008) of the biodiversity in subsurface groundwater-dependent ecosystems identified extensive gaps in knowledge of the distribution, composition and biodiversity value of Australian stygofauna. Despite this incomplete inventory, it is apparent that stygofauna are present across a variety of Australian subsurface environments and are generally characterised by high diversity and endemic species. They are also often of high scientific interest.

Eberhard et al. (2009) reported that the Pilbara region in north-western Australia contains the richest known groundwater fauna in Australia, with up to 54 species found at individual bores and a total of about 350 species recorded. Although the fauna is still being documented, it is apparent that the Pilbara contains globally significant numbers of groundwater species.

Cook et al. (2012) note that there are fewer studies of diversity and spatial genetic variation in the obligate subterranean aquatic fauna of alluvial aquifers or in eastern Australia compared with those available for western regions of Australia, particularly within calcrete and karst groundwater systems. However, there is an increasing body of published literature (Boulton et al. 2008; Cook et al. 2012) and company environmental impact statements (Jackson 2010; Stibbard 2011) on the stygofauna in eastern Australia. Stygofauna were recorded in groundwater at Carmichael Coal Mine (Galilee Basin, Queensland) in 2011/2012, from a bore that intersected the AB Coal Seam with an end-of-hole depth of 89 m (GHD 2012). A desktop review by 4T Consulting (4T Consultants 2012) found that the likelihood of stygofauna occurrence at a particular depth varies with the type of aquifer: stygofauna have been found to occur at depths up to 35 m in unconsolidated sediment aquifers, 65 m in fractured rock aquifers and less than 20 m in porous sedimentary rock aquifers. Further, stygofauna have been detected in 50% of the sampled unconsolidated sediment aquifers in the Bowen basin and in 55% of sampled alluvial aquifers across Queensland.

#### 2.3.5 The priority areas for bioregional assessment

#### 2.3.5.1 Lake Eyre Basin

The Lake Eyre Basin is one of the world's largest internally draining systems, covering about 1.2 million km<sup>2</sup>, equal to almost one-sixth of Australia, and is the fifth-largest terminal lake in the world. The Lake Eyre Basin is considered one of the world's last unregulated wild river systems. The vegetation of the basin reflects the patterns of arid and semi-arid regions that rely on variable water flows. As a consequence it is an area of high conservation significance, supporting wetlands such as the Ramsar-listed Coongie lakes, grasslands (Astrebla Downs National Park) and deserts (such as the Simpson Desert National Park) (LEBMF 2013).

The major rivers of the basin are the Georgina, Diamantina and Cooper. They are characterised by high variability and unpredictability in their flow, with high transmission losses downstream and very low gradients. All creeks and rivers of the basin are ephemeral, with short periods of flow following rain and long periods with no flow (LEBMF 2013).

The following description of the Lake Eyre Basin priority area is largely based on the characteristics of the Desert Channels NRM region (DCQ 2004). One reason for this is that the rivers in the Queensland section of the Lake Eyre Basin are the major contributors of inflow to Lake Eyre. It is estimated that of the water that enters South Australia some 40% is contributed by Cooper Creek and 60% by the Georgina and Diamantina catchments, respectively. The other reason is that the major coal resources in the Lake Eyre Basin, the Galilee and Cooper basins, underlie these catchments in the eastern half of the NRM region.

The north-east contains the Prairie/Torrens Creek Alluvials, the flattest part of the region, and the Alice Tableland, an area of sandstone ranges. The vast, rolling Mitchell Grass Downs bioregion dominates the north and central parts of the region. Dissected low (50 m to 100 m) residual hills are found throughout the Channel Country to the south. Away from these hills run braided streams that increase in width downstream to join the vast floodplains of the channel country. To the west, in the lower Georgina catchment, lies the Simpson Desert.

Soils are quite varied, ranging from the dune sands of the Simpson Desert, through grey and brown clays typical of the Mitchell Grass Downs and heavy grey clays on the flooded areas of the Channel Country, to the duplex soils and red earths and sands of the Mulga lands and the Desert Uplands. Generally, the most fertile soils are those of higher clay content with a tendency for cracking, as characterised by the channel country and the open downs. Poorer soils tend to have higher sand content and have been leached over a considerable time span, as characterised by the sand dunes in the west of the region and some of the deeper, sandier soils in the Desert Uplands. These areas are often recharge zones for groundwater.

Salinity is part of the landscape and probably a result of periods of inundation. Some ecosystems, particularly in the saline depressions, soaks, and lakes of the Channel Country, have high levels of salinity. The alluvial soils of the Georgina/Diamantina catchment have higher salt levels than those of the Cooper Creek system. There is limited information available on salinity in the region but generally it could be said that the present, largely natural vegetative cover has evolved to cope with salinity.

The Desert Channels Queensland region has a climate ranging from dry monsoonal in the north to temperate arid in the south. The region typically has a hot, dry climate with highly variable rainfall. Daily falls in excess of 150 mm have been recorded in most centres in the region. Temperatures in the region are amongst the highest recorded in Australia. Most centres in the catchment have recorded maxima in excess of 45°C. Evaporation is very high, with most of the catchment experiencing more than 2800 mm per annum.
The Lake Eyre Basin is notable for shallow gradients, variable stream flows and unique flow patterns. The streams reach their maximum mean flows around the middle of the catchment and not at the point where they discharge (usually the sea but in this case Lake Eyre). The upper parts of the catchments are not unlike the streams in the adjacent catchments of the Southern Gulf and the Burdekin. Streams are comparatively fast flowing and annual rainfall is in the range of 500 mm to 700 mm. It is further downstream in the vast eroded landscape of the Mitchell Grass Downs and the Channel Country that stream flows slow as the water splits into braided streams across the floodplains. The heavy soils of the floodplain act to reduce leakage into the streambed sediments, and numerous waterholes (some permanent) are found. They can be many kilometres long but the majority would not exceed 10 m in depth. In much of the Lake Eyre Basin, stream flows, although heading towards the lake, never arrive. The sands of the Simpson Desert are an obstacle to much of the water from Central Australia.

The GAB provides the most reliable water source in the region, underlying all but the northwest part. There are seven distinct aquifers in the basin, which can be tapped at quite shallow depths in the east; deeper bores (1000 m or more) are generally found to the southwest. Water quality varies considerably depending on formation and depth. Generally the water is cooler and better quality in the east and progressively gets hotter to the south-west. Bores around Birdsville have temperatures up to 100°C.

This highly variable climate is reflected in an environment where the flora and fauna are adapted to irregular rainfall and flooding events. The floodplains of the lower parts of the catchments are adapted to having much of the moisture provided by stream flows from further up the catchment rather than local rain. The intermittently flooded shallow swamps and lake systems throughout the region provide rich habitat for water birds including migratory shore birds. Mound springs occur in a band from Barcaldine up to Torrens Creek.

Other internal drainage basins of Lake Galilee and Lake Buchanan lie to the east of the NRM region on the Thomson River. Water in these lakes is fresh from stream flow, runoff and precipitation within the catchment but becomes brackish from leached terrestrial salts as it dries. Overall these lakes are shallow (thought to be less than 2 m) to seasonally dry (Miller and Worland 2004a, 2004b).

The northern headwaters of the Warrego River and Bulloo catchments in the South West NRM regions are in the Galilee data collection area. Mulga shrubland is the predominant vegetation type in the Warrego and Bulloo catchments. The Warrego River is the most northerly point of the Murray-Darling Basin. The Bulloo catchment is an internally draining system located between the Lake Eyre and Murray-Darling basins. In the lower reaches of the catchment the Bulloo River is dominated by a large lateral dune system that is vegetated by wetland communities. The area has extremely variable rainfall. Annual average rainfall in the Warrego catchment ranges from 250 mm in the lower reaches to more than 650 mm in the more elevated sections. Annual average rainfall is in the range of 150 mm in the southwest corner to more than 500 mm in the headwaters of the Bulloo River (South West NRM 2012).

#### 2.3.5.2 Sydney Basin

The Northern Sydney Basin and Southern Sydney Basin priority areas are divided by the Hawkesbury and Nepean Rivers but the majority of the combined area lies within the Sydney Basin bioregion. Therefore in this section of the report these priority areas are considered together. The Sydney Basin bioregion lies on the east coast and covers a large part of the catchments of the Hawkesbury-Nepean, Hunter and Shoalhaven Rivers.

The New South Wales National Parks and Wildlife Service (NSW NPWS 2003) describes the 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 basin 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 Sydney Basin bioregion is 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 of the bioregion. A small area in the west of the bioregion 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 2395 mm. Temperature varies across the bioregion, with areas of higher temperatures occurring along the coast and in the Hunter Valley and areas of lower temperature varies between 22.4°C and 31.9°C while the minimum average monthly temperature varies between -1.4°C and 8.1°C.

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

#### 2.3.5.3 Clarence-Moreton Basin

This priority area includes Queensland's Moreton Basin; New South Wales' Clarence Sandstone, Clarence Lowlands and Woodenbong; and the cross-jurisdictional Richmond-Tweed Scenic Rim subregions of the South East Queensland bioregion.

The Richmond-Tweed Scenic Rim subregion is characterised by volcanic caldera with the central plug of Mt Warning. The area has steep slopes and a relief of 1100 m. There are basement rocks exposed around the plug and an outer rim of volcanic flows with well-developed radial drainage pattern. Typical soils include red friable loams on basalts and texture-contrast and fabric-contrast soils on volcanic rocks on slopes with high fertility. Low-fertility texture-contrast soils occur on sandstones and shales with cracking clays in valleys. The vegetation includes subtropical and warm temperate rainforests and wet sclerophyll forests (NSW NPWS 2003).

The Woodenburg subregion is typified by hilly basalt ridges and plateau remnants with relief to 600 m. The geology of the area includes Jurassic lithic and quartz sandstones, and shales with areas of Tertiary basalts. Fertile red earths and red loams occur on basalt, while poor red, brown and yellow texture-contrast soils occur on sedimentary rocks. Sands and loams are common along streams. As for Richmond-Tweed, rainforests are common on basalt. Wet and dry sclerophyll, including New England blackbutt, red bloodwood and tallowwood occur on sedimentary rocks (NSW NPWS 2003).

The Clarence subregions have sandstones and claystones with extensive areas of alluvials and coastal barrier sands. The subregions contain low stepped hills and plains, with hillier areas in the west and south. Beach, dune and lagoon barrier systems and estuarine fills occur along the main streams. Mellow texture-contrast soils and areas of deep sand occur on Mesozoic rocks. Deep siliceous sands and podsols are common in dunes, organic sands and mud in estuaries. Dry sclerophyll forests and woodlands are found in the hills. Dune sequence includes paperbark, snappy gum, blackbutt, dwarf red bloodwood, bastard mahogany with banksia, Bangalow palm and areas of heath and paperbark swamp. Mangroves are found in estuaries (NSW NPWS 2003).

The general trend from east to west is from a subtropical climate on the coast with hot summers, through a sub-humid climate on the slopes, to a temperate climate in the uplands in the western part of the bioregion, characterised by warm summers and no dry season. Typically there is a sequence from coastal sand barrier, through low foothills and ranges, to the steep slopes and gorges of the escarpment itself, with rainfall increasing inland along this transect. Mean annual rainfall varies from 607 mm to 2912 mm; the maximum average monthly temperature varies between 20.3°C and 30.9°C; and the minimum average monthly temperature varies between –2.8°C to 9.8°C (NSW NPWS 2003).<sup>2</sup>

The national biodiversity hotspot Border Ranges North and South occurs in this priority area. The Gondwana Rainforests of Australia in the north of the Richmond River catchment includes the most extensive areas of subtropical rainforest in the world, large areas of warm temperate rainforest and nearly all of the Antarctic beech cool temperate rainforest. There is a concentration of primitive plant families that are direct links with the birth and spread of flowering plants over 100 million years ago, as well as some of the oldest elements of the world's ferns and conifers (DSEWPAC 2013c).

#### 2.3.5.4 Northern Inland Catchments

The Murray-Darling Basin covers 14% of Australia and contains around 440 000 km of rivers, of which 40 000 km are major, some 30 000 wetlands covering an area of around 25 000 km<sup>2</sup>, and about 60 000 km<sup>2</sup> of floodplain area, which represents approximately 6% of the basin area (BOM 2013f). 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 south-east and southern margins contributing most to total runoff (MDBA 2013a).

The southern part of the basin is mostly a regulated system. However, the northern part, including the Northern Inland Catchments priority area, consists mostly of unregulated systems, where many of the rivers and streams are ephemeral and fed by seasonal rainfall. Alluvial sedimentary aquifers are the most important for groundwater extraction, with nearly all of the extracted groundwater (more than 95%) coming from these aquifers (BOM 2013f). 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 them. Texture-contrast soils (Chromosols, Sodosols, and Kurosols) and shallow sandy soils (Tenosols) are common on

<sup>&</sup>lt;sup>2</sup> The reported climate data applies to the whole of the NSW North Coast bioregion as defined under IBRA version 5.1. The NSW subregions that occur within the Clarence-Moreton Basin priority area lie within the South East Queensland bioregion under the current IBRA version 7 but were in the NSW North Coast bioregion in IBRA version 5.1.

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 (Condamine Alliance 2013).

Stream flow within the Condamine catchment is highly variable, being predominantly sourced from unpredictable storm runoff rather than groundflow. 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 water levels in groundwater and a resulting outflow from river to groundwater. The majority of the Condamine River, its North Branch and the Oakey Creek tributary are under 'losing' conditions (to groundwater) equivalent to rates ranging from 0.4 ML per day/km to 1.8 ML per day/km. The river is losing at a rate of 0.20 ML per day/km up to Elbow Valley, upstream from the junction with Hodgson Creek. Immediately downstream of Chinchilla Weir, conditions change to the river 'gaining' at a rate from 0.05 ML per day/km to 0.11 ML per day/km (Condamine Alliance 2013).

The major rivers of the Queensland Border Rivers catchment 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 dryland cropping. The Macintyre River floodplains 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 (MDBA 2013b).

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 (Border Rivers-Gwydir CMA 2013).

The Border Rivers-Gwydir catchment has a temperate to subtropical climate, with a considerable gradient from east (cooler and wetter, 1200 mm annual rainfall) to west (hotter and drier, 600 mm annual rainfall). It contains distinct landform types of tablelands, slopes and plains, and four bioregions – New England Tablelands, Brigalow Belt South, Nandewar and Darling Riverine plains. The vegetation varies from high-altitude areas of the eastern catchment boundary, consisting of patches of extensively forested areas, to the graduation west with more open forest, shrublands and grassy plains. 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 (Border Rivers-Gwydir CMA 2013).

To the south, the Namoi River joins the Barwon River at Walgett. Major tributaries of the Namoi River include Coxs Creek and the Mooki, Peel, Cockburn, Manilla, and McDonald 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 GAB. Areas away from the river system access water from a fractured rock aquifer system (Namoi CMA 2013).

The Namoi Catchment Management Authority (CMA) (2013) has published information on the characteristics of the 22 land management units in a series of best management practice guides for the Namoi catchment. A summary of the predominant land management units in the catchment follows.

- Steep sedimentary hills with slopes above 15% occupy 9.4% of the catchment area. Soils include Rudosols, Chromosols, Vertosols and Kandasols and tend to be shallow with low water-holding capacity.
- Sedimentary hill slopes typified by land slope of between 8% and 15% occupy 10.5% of the land area; they have highly variable soil types that are shallow with high infiltration.
- Sedimentary foot slopes occupy 7.8% of the catchment area and encompass the gentler 2 to 8% slopes. Soil types include Red Kandosols (red earths), Red Chromosols (red brown earths), Red and Brown Sodosols (higher in sodium) and Yellow, Brown and Red Dermosols (stony red and chocolate soils). Soils can be relatively shallow, tend to have low to moderate water-holding capacity, can have reasonable infiltration rates but can set hard. Runoff can be high when soils are degraded, and shallow water tables (< 5 m) occur in some areas.
- Central black earth occupies 8.3% of the Namoi catchment and encompasses the highly productive agricultural lands associated with the floodplains in the central part of the catchment. Land slopes are generally less than 2% and soils are mainly Black, Grey or Brown Vertosols (cracking clays), with some Rudosols (alluvial soils). Soils are deep, tend to crack, and have high initial water infiltration followed by extremely slow infiltration when wet and high water-holding capacity. Flooding is common, as are shallow saline aquifers.
- Flat Pilliga outwash occupies 10.5% of the catchment. It is dominated by deep Sodosols (sodic soils) with sandy to loamy Tenosols (shallow sandy soils). The soils have poor structure and low water-holding capacity and can set hard. The area can be prone to erosion and scalding, and runoff can be high when soils are degraded.

The Namoi CMA (2013) holds additional data on land use, depth to water table, groundwater-dependent ecosystems, vegetation, riparian vegetation and salinity, as well as soil and land capability maps that indicate landform, erosion potential and soil acidity/sodicity potential.

The most southerly rivers within the Northern Inland Catchments priority area are the Castlereagh and Macquarie in the Central West NRM region and CMA. The upper reaches of the Castlereagh River are largely unregulated, while two dams regulate flows of the Macquarie. There are seven alluvium, four fractured rock and four porous rock groundwater management areas in the Central West catchment. The alluvial aquifers of the Upper and Lower Macquarie and the GAB are significant groundwater resources. In the upper catchments of all the groundwater management units, groundwater discharge contributes to stream baseflows and springs. There is limited information on the condition of groundwater-dependent ecosystems in the catchment, although a 2008 desktop assessment identified those of high priority. The relationship between surface water and groundwater is being investigated in the Macquarie Marshes, a Ramsar wetland in the catchment (NSW Government 2010).

In the Macquarie and Bogan valleys over 72% of the land is flat, with an additional 17% undulating to hilly. The remainder is steep to mountainous, rising progressively to elevations above 900 m. In the Castlereagh Valley the terrain is predominantly flat with about a fifth of the catchment area undulating to hilly and a small area of mountainous land. The maximum elevation is about 1210 m (ANRA 2009d).

The Central West CMA (2010) provides a description of the soils in the catchment. In the tablelands, high rainfall has led to lower nutrients and poorer soil types. Generally, coarse grained, acidic rocks that form fragile, erodible sandy textured soils dominate the geology of this area. The slopes are characterised by variable geology, with soils developed by movement down a slope and alluvial activity. Generally the soil types are less fragile and have higher nutrient levels. Many soils have naturally high salt stores, increasing the risk of poor soil health due to salinity. The plains are formed by alluvial and windblown soil development. These soil types are more fertile and have higher clay contents. These soils often crack open when dry and are susceptible to compaction. Soil acidity has not been an issue in the past due to lower total rainfall, but may become an increasing issue with intensive agriculture production systems.

The Castlereagh Valley experiences about half its annual rainfall during the summer months. while rain throughout the year is common in the Macquarie and Bogan valleys. Marked variations in rainfall occur over the headwaters of the Macquarie River due to the rugged nature of the terrain. Generally the peaks and tablelands in this area receive higher rainfall than the valleys, due to the shadowing effects of the surrounding ranges. Along the higher parts of the Great Dividing Range, which forms the eastern boundary of the drainage area, annual median rainfalls are from 750 mm to 900 mm. Where breaks in the Dividing Range allow the intrusion of moist easterly air streams inland, annual median rainfall of 750 mm or more is experienced further westward. The middle sections of the Castlereagh and Macquarie valleys and the headwaters of the Bogan River experience an annual median rainfall of about 300 mm to 400 mm. Rainfall variability increases from east to west, with summer rainfall generally more variable than winter rains. Rainfall also varies dramatically from year to year. Annual rainfall at a number of centres in the region has varied from more than 200% to less than 50% of the annual average figure. Potential average evaporation varies from less than 1 000 mm south-east of Bathurst up to more than 2 000 mm at Bourke. Evaporation exceeds annual precipitation over virtually the entire valley (ANRA 2009d).

Climate varies considerably throughout the Central West catchment area. At higher elevations in the east, temperatures range from a winter average minimum of 0°C to a summer average maximum of 25°C. Further west at Nyngan the average minimum winter temperature is around 3°C and the average maximum summer temperature is 37°C. A full range of temperatures from 16 to more than 50°C are recorded within the catchment. The variation in weather conditions throughout the catchment reflects the diversity of the ecosystem, which ranges from sub-alpine in the east to semi-arid rangeland ecosystems in the west (Central West CMA 2010).

#### 2.3.5.5 Gippsland Basin

The Gippsland Basin occurs on the south coast of Victoria to the west of Melbourne, predominantly within the West Gippsland NRM region. The following information is from the West Gippsland homepage at Victorian Resources Online (DPI 2012b), which provides a wide range of natural resources information and associated maps. Information can be accessed at both state-wide and regional levels across Victoria.

The Gippsland Plain includes flat, low-lying coastal and alluvial plains with a gently undulating terrain dominated by barrier dunes and floodplains and swampy flats. The soils associated with the upper terrain are both texture-contrast soils (Chromosols, Sodosols) and gradational texture soils (Dermosols), and typically support the lowland forest ecosystem.

The dunes are predominantly sandy soils (Podosols and Tenosols) supporting healthy woodland and damp sands with herb-rich woodland ecosystems. The fertile floodplains and swamps are earths and pale yellow and grey texture-contrast soils (Hydrosols) and support swamp scrub, plains grassy woodland, plains grassy forest, plains grassland and Gilgai wetland ecosystems. The predominant land use is dryland pasture, although extensive irrigated pasture occurs between Sale and Rosedale extending north towards Maffra.

The Strzelecki Ranges consists of moderate to steep slopes; deeply dissected blocks of alternating beds of sandstone, siltstone and shales; and swampy alluvial fans in the lowlands. The geology is of Mesozoic (252 million to 66 million years ago) non-marine deposits covered with a veneer of younger Cainozoic (66 million years ago to present, also known as Caenozoic, Cænozoic or Cenozoic) deposits, including newer basalts. The soils are mainly gradational textured acidic soils (Dermosols) together with friable red earths (Ferrosols). Land use in this area includes a combination of remnant vegetation, forest plantation and public land, with dryland pasture on the edges and some horticulture south of Trafalgar.

The West Gippsland region has a Mediterranean climate with maximum temperatures and minimum rainfall in summer. The climate varies with elevation, topography and distance from the coast. Lowlands tend to be warmer and drier, changing to cooler, wetter highlands. The Gippsland Plains are topographically uniform and show little variation in climatic conditions compared with mountain areas. Precipitation is lowest near the coast, increasing towards the highlands. There is also a trend for the rates of precipitation to decrease eastwards. Annual precipitation ranges from less than 700 mm at Sale to over 1300 mm at Erica. The Latrobe Valley has a maximum temperature of 26.4°C over summer and 13.6°C over winter. The average minimum temperature in July is 3.7°C.

The West Gippsland catchment management region largely encompasses the Latrobe, Thomson and South Gippsland basins. Many of the major river systems within the region flow into the Gippsland Lakes and wetland areas surrounding Lake Wellington. Much of the water resource lies below the ground—there are a number of major aquifers within the West Gippsland region, which provide an alternative water source to surface storage.

Throughout the Thomson River Basin, water quality is generally good, although elevated nutrient levels occur in some areas. Throughout the whole of the basin, salinity is low with slightly elevated levels in irrigation areas. The aquifer system is shallow within a large proportion of the basin and provides a relatively small proportion of water for irrigation compared to the volumes extracted from surface water. Groundwater quality is generally very good.

A series of streams flows south from the Great Divide and north from the Strzelecki Ranges to the Latrobe River. Water quality is generally poor in the major streams of the basin, particularly in the central zone of the Latrobe River, which is subject to discharge and pollution from urban, mining and industrial activities. Groundwater extraction such as that at Morwell to dewater the coal mining area has caused a major decrease in the Latrobe River Basin aquifer levels.

The South Gippsland Basin includes more than 10 major rivers and streams draining the coastal side of the South Gippsland uplands. Water quality within the South Gippsland Basin is significantly compromised due to elevated nutrient levels from intensive agricultural activity. The South Gippsland Basin comprises shallow and deep aquifers. In the deep Latrobe Group aquifer, the quality of groundwater is generally fresh to marginal with the exception of an area in the north-west of the basin and just north of Welshpool that yields marginal to brackish quality.

Both raw and summary data on water quality and quantity parameters are available through the *Victorian Water Resources Data Warehouse* (DSE 2013). Southern Rural Water (SRW 2013) has produced 3D-mapping of groundwater resources and is now producing atlases on the local groundwater cycle, local aquifer layers, how groundwater is used in each region and how it is managed.

# 2.3.6 Summary of ecological characteristics of the receiving environment

The extent of the receiving environment occurs over:

- a wide range of latitudes and longitudes with resultant subtropical, arid, semi-arid and temperate climates
- a variety of landforms including the ranges and escarpments of the eastern highlands, coastal plains and the extensive flats of the central lowlands
- clay-rich soils of eastern Australia and sandy dunes of the arid interior
- the fast flowing rivers of eastern Australia that drain into the Pacific Ocean, the moderately regulated rivers of the northern Murray-Darling Basin and the ephemeral wild rivers of the Lake Eyre Basin
- the GAB and numerous other aquifers.

Climate, topography, soils, hydrology, hydrogeology and ecology vary significantly across the defined extent of the receiving environment.

Nationally consolidated datasets exist for many of the ecological characteristics and may be used as inputs into exposure models during an environmental risk assessment. However, national datasets may have limitations. For example, data are frequently compiled from localised programs at state or catchment level and is unlikely to be uniform within or between jurisdictions on a nationwide basis. Data tend to be more frequently available for developed areas with concentrated population or of high agricultural value.

Many surface ecosystems across Australia are dependent on groundwater resources. The degree of reliance on groundwater varies and is not definitively known for all ecosystems. For these surface ecosystems the dependency suggests an exposure pathway to chemicals that may be present in groundwater resources because of coal seam gas extraction.

Subsurface groundwater-dependent ecosystems are now recognised to support diverse species. Efforts are being directed towards building knowledge of subsurface ecosystems. However, much remains unknown about the biodiversity present and its distribution, functional roles and interdependencies. While gaps exist in the understanding of these ecosystems, it is known that groundwater habitats have diverse microbial and invertebrate communities that are adapted to the conditions of this extreme habitat.

## 2.4 Ecological receptors

An ecological receptor is an entity that may be adversely affected by contact with or by exposure to a contaminant. This may be an organism, population, community, ecosystem or components of ecosystems. Ecological receptors may be any living organisms (other than humans), the habitat that supports such organisms, or natural resources that could be adversely affected by environmental contamination resulting from a release or migration of chemicals from a site. Many of the ecological characteristics described in the previous section are also ecological receptors. This includes habitat aspects such as soil, surface water and groundwater as well as the flora and fauna that occupy that habitat.

This section begins by describing environmental protection at a national level. In this context, potential ecological receptors with national conservation value that may occur within the six priority areas are identified.

#### 2.4.1 Environmental protection in Australia

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's central piece of environmental legislation. The objectives of the EPBC Act are to:

- provide for the protection of the environment, especially matters of national environmental significance
- conserve Australian biodiversity
- provide a streamlined national environmental assessment and approvals process
- enhance the protection and management of important natural and cultural places
- control the international movement of plants and animals (wildlife), wildlife specimens and products made or derived from wildlife
- promote ecologically sustainable development through the conservation and ecologically sustainable use of natural resources.

Chemicals associated with coal seam gas extraction may be of consequence to matters of national environmental significance, biodiversity or ecological sustainability as elaborated below.

The matters of national environmental significance protected under the EPBC Act include World Heritage properties and National Heritage places, wetlands listed under the Ramsar Convention, listed threatened species and ecological communities, migratory species protected under international agreements, Commonwealth marine areas and the Great Barrier Reef Marine Park. These matters are potential ecological receptors of chemicals in the receiving environment.

The EPBC Act specifies that components of biodiversity include species, habitats, ecological communities, genes, ecosystems and ecological processes. If chemicals enter the environment they may pose a risk to biological components of biodiversity, contaminate or change habitat conditions, and interrupt ecological processes. Chemicals may affect components of biodiversity, some of which are potential ecological receptors in the receiving environment.

Under the EPBC Act, one of the principles of ecologically sustainable development is for the health, diversity and productivity of the environment to be maintained or enhanced. Ecosystem health and productivity complement biodiversity as potential indicators of ecological sustainability. Knowledge of ecological receptors helps inform the selection of indicators as part of environmental risk assessment and management.

#### 2.4.2 Matters of national environmental significance

Matters of national environmental significance protected under the EPBC Act are potential receptors in the receiving environment. The matters that occur within the six priority areas were identified in a protected matters search (ERIN 2013).

The protected matters search included listed threatened, migratory, marine and/or cetacean species, threatened ecological communities, and internationally significant wetlands, heritage sites and water resources. The search used spatial information held by the Environmental

Resources Information Network (ERIN) of the Department of the Environment and Energy, such as that which underpins the Protected Matters Search Tool (DSEWPAC 2011a).

The search area included the six priority areas with underlying coal resources previously defined in this chapter. Protected matters in the marine environment immediately offshore of priority areas with coastline (within 1 km) were also identified in the search. Apart from this search in the marine environment, the protected matters search did not identify protected matters that may occur in catchments downstream of the priority areas.

In addition to identifying the protected matters that occur in each priority area, the occurrence of species and ecological community in each priority area was determined as a percentage of its current distribution. The findings are reported below.

#### 2.4.2.1 Listed species

The protected matters search (ERIN 2012) identified 490 listed species that may occur within the six priority areas. Each listed species may be a threatened, migratory, marine and/or cetacean species. The details of each listed species, including the applicable listing type(s) and the priority area(s) in which it occurs, is provided in Appendix D. The number of listed species that may occur in each priority area and the total number across all six priority areas are summarised in Table 2.1.

There are a total of 145 species listed, for which greater than 90% of their current distribution (known, likely and may occur) is within the six priority areas. Of these 145 species, 28 only occur in the Clarence-Moreton Basin, 25 only occur in the Northern Sydney Basin, 19 only occur in the Southern Sydney Basin, 10 only occur in the Northern Inland Catchments, five only occur in the Lake Eyre Basin and two only occur in the Gippsland Basin. The other 56 species occur across two or three of the priority areas. This suggests that 89 species are endemic to one of the six priority areas.

The principal findings for each type of listed species are outlined below. Additional summary information in each priority area is provided in Appendix E.

| EPBC listed species                | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake Eyre<br>Basin | Northern<br>Inland<br>Catchments | Northern<br>Sydney<br>Basin | Southern<br>Sydney<br>Basin | All <sup>a</sup> |
|------------------------------------|-------------------------------|--------------------|--------------------|----------------------------------|-----------------------------|-----------------------------|------------------|
| Threatened<br>(Vulnerable)         | 108                           | 37                 | 51                 | 85                               | 111                         | 85                          | 269              |
| Threatened<br>(Endangered)         | 61                            | 21                 | 17                 | 36                               | 55                          | 51                          | 145              |
| Threatened (Critically endangered) | 5                             | 2                  | 0                  | 4                                | 7                           | 6                           | 16               |
| Threatened (Total)                 | 174                           | 109                | 81                 | 145                              | 224                         | 142                         | 430              |
| Migratory                          | 59                            | 62                 | 14                 | 22                               | 64                          | 69                          | 77               |
| Marine                             | 48                            | 51                 | 13                 | 20                               | 54                          | 58                          | 62               |
| Cetacean                           | 7                             | 7                  | 0                  | 0                                | 6                           | 6                           | 9                |
| Total <sup>b</sup>                 | 220                           | 109                | 81                 | 145                              | 224                         | 197                         | 490              |

Table 2.1 Summary of the number of listed species protected under the EPBC Act that may occur within the six priority areas

a The distribution of listed species may occur across multiple priority areas. b A species may be concurrently listed as a threatened, migratory, marine or cetacean species.

#### 2.4.2.1.1 Threatened species

Listed threatened species (DSEWPAC 2012b) are native species facing:

- an extremely high risk of extinction in the wild in the immediate future (critically endangered)
- a very high risk of extinction in the wild in the near future (endangered)
- a high risk of extinction in the wild in the medium-term future (vulnerable).

The protected matters (ERIN 2012) search identified 430 listed threatened species that may occur across the six priority areas. Of these, 269 are classified as vulnerable, 145 as endangered and 16 as critically endangered. The Northern Sydney Basin has the highest number of threatened species that may occur, with 224 species. The Lake Eyre Basin has the lowest number of threatened species that may occur, with 81 species.

Threatened species included 311 plants, 32 birds, 28 mammals, 27 reptiles, nine fish, nine frogs, five sharks, three insects and three species of other classes.

#### 2.4.2.1.2 Migratory species

The list of migratory species established under the EPBC Act (DSEWPAC 2012c) comprises:

- migratory species that are native to Australia and are included in the appendices to the Bonn Convention (Convention on the Conservation of Migratory Species of Wild Animals Appendices I and II)
- migratory species included in annexes established under the Japan-Australia Migratory Bird Agreement (JAMBA) and the China-Australia Migratory Bird Agreement (CAMBA)

• native migratory species identified in a list established under, or an instrument made under, an international agreement approved by the Minister, such as the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA).

There are a total of 77 listed migratory species that may occur across the six priority areas. Of these, 58 are birds, 10 are mammals, six are reptiles and three are sharks. Only 17 of these listed migratory species are also listed threatened species.

#### 2.4.2.1.3 Marine species

Listed marine species are those that are declared under the EPBC Act and are protected in Commonwealth areas (DSEWPAC 2011b). There are a total of 62 listed marine species that may occur across the six priority areas or in the marine environment within 1 km of the shoreline (ERIN 2012). Of these, 55 are birds, six are reptiles and one is a mammal. Other than one bird species, all of these listed marine species are also listed migratory species. Eleven are listed threatened species.

#### 2.4.2.1.4 Cetacean species

Under the EPBC Act all cetaceans (whales, dolphins and porpoises) are protected in Australian waters (DEWHA 2010a). Nine cetacean species occur within, or in marine waters immediately offshore of, the priority areas (ERIN 2012). All of these species are listed migratory species but only three are listed threatened species.

#### 2.4.2.1.5 Listed threatened ecological communities

Listed threatened ecological communities (DSEWPAC 2012d) are those facing:

- an extremely high risk of extinction in the wild in the immediate future (critically endangered)
- a very high risk of extinction in the wild in the near future (endangered)
- a high risk of extinction in the wild in the medium-term future (vulnerable).

The protected matters search (ERIN 2012) identified 24 listed ecological communities that may occur within the six priority areas. The details of each listed ecological community, including the occurrence in each priority area, are provided in Appendix D – Listed species protected under the *Environment Protection and Biodiversity Conservation Act 1999* that may occur within the six priority areas. The number of listed threatened ecological communities that may occur in each priority area, and the total number across all six priority areas, is summarised in Appendix E and Appendix F. Of the 24 threatened ecological communities that may occur within the priority areas, 13 are endangered and 11 are critically endangered (Table 2.2).

Listed threatened ecological communities protected under the EPBC with greater than 90% of their current distribution (known, likely and may occur) within the six priority areas are also identified in Appendix F. These include six ecological communities that may occur across the combined Northern Sydney Basin and Southern Sydney Basin, and one that may occur within the Clarence-Moreton Basin.

| Table 2.2 St   | ummary of th  | ne number | of listed | species | protected | under th | e EPBC | Act that ma | y occur |
|----------------|---------------|-----------|-----------|---------|-----------|----------|--------|-------------|---------|
| within the six | priority area | as        |           | -       | -         |          |        |             | -       |

| Priority<br>Area         | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake<br>Eyre<br>Basin | Northern<br>Inland<br>Catchments | Northern<br>Sydney<br>Basin | Southern<br>Sydney<br>Basin | Alla |
|--------------------------|-------------------------------|--------------------|-----------------------|----------------------------------|-----------------------------|-----------------------------|------|
| Endangered               | 4                             | 1                  | 6                     | 8                                | 7                           | 5                           | 13   |
| Critically<br>endangered | 6                             | 3                  | 0                     | 3                                | 7                           | 5                           | 11   |
| Total                    | 10                            | 4                  | 6                     | 11                               | 14                          | 10                          | 24   |

a. The distribution of listed ecological communities may occur across multiple priority areas.

#### 2.4.2.2 Other matters of national environmental significance

The protected matters search (ERIN 2012) identified 12 Ramsar wetlands and six listed National Heritage places, two of which are also World Heritage properties, within the six priority areas. The details of each of the matters of national environmental significance are provided in Appendix G. A summary of other matters of environmental significance that occur within the six priority areas is presented in Table 2.3.

Table 2.3 Summary of the number of other matters of national environmental significance protected under the EPBC Act within the six priority areas

| Priority<br>Area                | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake<br>Eyre<br>Basin | Northern<br>Inland<br>Catchments | Northern<br>Sydney<br>Basin | Southern<br>Sydney<br>Basin | Alla |
|---------------------------------|-------------------------------|--------------------|-----------------------|----------------------------------|-----------------------------|-----------------------------|------|
| Ramsar<br>wetlands              | 1                             | 4                  | 2                     | 3                                | 1                           | 1                           | 12   |
| World<br>Heritage<br>properties | 1                             | 0                  | 0                     | 2                                | 1                           | 1                           | 2b   |
| National<br>Heritage<br>places  | 1                             | 0                  | 1                     | 3                                | 2                           | 3                           | 7    |

a. The extent of each matter of national environmental significance may occur across multiple priority areas. <sup>b</sup> These two World Heritage sites are also separately listed as National Heritage places and included in the count below.

#### 2.4.2.2.1 Ramsar wetlands

Ramsar wetlands are those that are included on the List of Wetlands of International Importance developed under the Ramsar convention. They are representative, rare or unique or are important for conserving biological diversity (DEWHA 2010b). Declared Ramsar wetlands are protected as a matter of national environmental significance under the EPBC Act.

Twelve Ramsar wetlands were identified within the priority areas. Ramsar areas are present in all of the priority areas, with the highest number in the Gippsland Basin (four) followed by the Northern Inland Catchments (three). The analysis did not identify Ramsar wetlands that may occur in catchments downstream of the priority areas.

#### 2.4.2.2.2 National Heritage places and World Heritage properties

A declared World Heritage property is an area that has been included in the World Heritage List or declared by the Minister to be a World Heritage property. The National Heritage List includes natural, historic and Indigenous places of outstanding heritage value. World Heritage properties and National Heritage places are recognised as a matter of national environmental significance under the EPBC Act (DSEWPAC 2011c).

Six National Heritage places with natural heritage values and assessed criteria relating to biodiversity (DEWHA 2010c) were identified across the six priority areas. Two of these, the Greater Blue Mountains Area and Gondwana Rainforests of Australia, are also World Heritage properties meeting *Criterion (X): Important habitats for conservation of biological diversity* (DEWHA 2008). The Gippsland Basin is the only priority area that does not contain a natural National Heritage place.

#### 2.4.3 Exposure potential

Ecosystem characteristics are described for some protected matters that reveal how they may become ecological receptors of chemicals associated with coal seam gas present in water resources.

The identified threatened plants include wetland-associated flora. For example, the three nationally threatened species — dwarf kerrawang, swamp everlasting and metallic sun-orchid — are found in the Gippsland Lakes Ramsar wetland (DSEWPAC 2011d). Several areas of the Temperate Highland Peat Swamps on Sandstone ecological community have been degraded through alterations to water flows and a change to the level of the water table (DSEWPAC 2012e). Interference with water flows is a known threatening process to this community and therefore to the habitat in which the Kangaloon sun-orchid occurs (DSEWPAC 2012e). It is inferred that species or communities that are sensitive to changes in water access may also be sensitive to changes in water quality. Wetland riparian and floodplain species have the potential to be exposed to chemicals present in surface water resources or runoff or present in groundwater of the underlying aquifers.

Either surface water or groundwater discharges to the marine environment may pose a threat to marine species. As reported for the Australian snubfin dolphin:

"...pollutants still enter coastal and estuarine waters and can be of many types (e.g. heavy metals, pesticides, herbicides, nutrients and sediments) and from many different sources (e.g. industrial and sewage discharges, catchment runoff and groundwater infiltration)...'

Source: DSEWPAC (2012f).

Marine species and the wider marine environment are potential receptors of chemicals in catchment runoff, surface water discharge or groundwater infiltration.

At least one of the threatened ecological communities identified to occur within the six priority areas is known to be a groundwater-dependent ecosystem. The community of native species dependent on natural discharge of groundwater from the GAB comprises assemblages of species associated with and dependent on the springs and wetland areas located at points where the GAB groundwater is discharged naturally (DSEWPAC 2011e). These spring communities and the taxa comprising them are potential receptors of chemicals that may be present in groundwater. Other groundwater dependencies may exist for the identified matters of national significance that may or may not rely on the surface expression of groundwater.

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.

#### 2.4.4 Summary of ecological receptors

The protected matters under the EPBC Act that occur within the six priority areas and are potential ecological receptors in the receiving environment include:

- 490 listed threatened, migratory, marine and/or cetacean species
- 24 threatened ecological communities
- 13 declared Ramsar wetlands
- six listed National Heritage places, two of which are also World Heritage properties.

Of these, 89 threatened species and seven ecological communities have the majority of their distribution restricted to within just one of the priority areas (or the combined Sydney Basin area), suggesting that these protected matters are endemic to those areas. Each priority area contains threatened species or ecological communities considered endemic to the area based on their current distribution.

One known surface groundwater-dependent ecosystem listed as a threatened ecological community occurs within the priority areas — the community of native species dependent on natural discharge of groundwater from the GAB. There are a small number of subsurface threatened species and ecological communities listed under the EPBC Act. None of these occur within the priority areas.

## 2.5 Site characterisation

This section describes the details of coal seam gas working sites that may be relevant to the potential exposure of surface water bodies to chemicals associated with hydraulic fracturing, emphasising company-specific information. This includes information on how sites are prepared and their size and configuration across regions, plus information on containment details and the volume of hydraulic fracturing chemicals stored and used on a site. The well pad size provides an indication of the potential containment capacity of a site. Information on the spacing between wells is needed to understand the potential for cumulative effects.

This section also outlines information on the surface infrastructure required for drilling and hydraulic fracturing, noting potential sources of exposure through leaks, spillages and uncontrolled releases. Discussion is also provided on the transport and storage of chemicals, along with methods of containment or mitigation of leaks, spillages and uncontrolled releases.

#### 2.5.1 Wider site characteristics

This section outlines the locations of working sites and site considerations for gas companies. In Queensland and New South Wales areas offering potential for coal seam gas production and areas used in agricultural production overlap (Hepburn 2012), as reflected in Arrow Energy's (undated) proposed land management specifications for various agricultural situations. Several planning constraints are considered, including the location of well sites, maintenance of drainage lines and inclusion of erosion control devices. The areas considered for well site location include the fringes of intensive land use, the corners of paddocks, areas unsuitable for farming, near access tracks, right of ways, easements and road reserves.

Santos (2010) lists various measures to limit environmental exposure to chemicals including:

- spill kits on transport trucks and in chemical storage areas
- restricted access to chemical storage areas
- training for personnel managing chemicals
- compliance with material safety data sheets (MSDS)
- external bunding around treatment facilities
- double-walled pipes and storage tanks
- shielding around pipes carrying dosing chemicals
- leak detection systems in outer pipes and bunds
- regular bund condition auditing and maintenance.

Other chemical exposure mitigation measures include:

- Drainage and stormwater management systems to manage the flood events and potential overflow situations which may transport chemicals from coal seam gas operations to surface water (Australia Pacific LNG 2010)
- positioning absorbent pads between sites and surface waters (API 2010, 2011)
- creating perimeter trenching systems and catchments that may be used to contain and collect any spilled fluids
- a management plan for fluids that remain in lines, tanks and other containment devices during unexpected delays or after the fracturing event (API 2010, 2011).

#### 2.5.2 Site characterisation summary

Surface infrastructure such as pipes and wellheads are potential source points for leakage of hydraulic fracturing chemicals. Publicly available information on volumes/amounts of chemicals transported to and stored on coal seam gas operation sites, and on the types and sizes of storage containers and the duration of storage is limited. Limited information was found on the requirements for site containment such as bunding and the extent of containment measures across the industry.

The uncertainty about the amounts of chemicals that may be released during transport, delivery and storage on-site, and through accidental releases, indicates that alternative data or assumptions will be required to inform the risk assessment and model development.

## 3 Modelling of environmental exposure from coal seam gas surface operations

## 3.1 Introduction

A risk assessment of chemicals used in coal seam gas operations should consider the potential for contamination of the surface environment, including water and soil. As previously discussed, sources of contamination include runoff from working sites, overflow at water storage sites, uncontrolled releases of produced water and disposal of treated and untreated water. The magnitude, frequency and concentration of associated chemicals in environmental compartments (e.g. water and soil) will need to be determined to assess the risk to these compartments. For the aquatic compartment, contamination from groundwater will be modelled by CSIRO (Mallants et al. 2017b, 2017c) and considered in conjunction with the surface component.

This section identifies exposure models that can potentially be applied to the coal seam gas context. Consideration will be given to common problems of model selection including paucity of input data, data treatment, and model uncertainty, communicating the findings from the model and the advantages and disadvantages of probabilistic modelling. The information has been drawn from published and unpublished reports as well as reviews by national and international agencies with expertise in risk assessment.

# 3.2 Quantitative modelling for risk assessments of coal seam gas chemicals

#### 3.2.1 Australia

In Australia, environmental risk assessments of hydraulic fracturing at coal seam gas operations in the Surat Basin and Bowen Basin have been conducted on behalf of Santos (Golder Associates 2010a) and Australia Pacific LNG (URS 2010). These risk assessments were submitted to the Coordinator-General (Queensland Department of State Development, Infrastructure and Planning). The Coordinator-General has wide-ranging powers to coordinate the planning, development and environmental impact of large-scale infrastructure projects.

To model organic chemicals of potential concern (COPCs) in groundwater, Santos (Golder 2010a) used a one-dimensional fate and transport model (Golder 2010b). This model will not be considered further as it is not applicable to surface exposure pathways.

The second proponent, Australia Pacific LNG (URS 2010), used a deterministic modelling approach established by the US EPA to consider toxicity and environmental exposure. The deterministic approach distinguishes high- and low-risk situations, through calculating a risk quotient (RQ) by dividing a point estimate of exposure by an estimate of toxicity.

Calculations of risk quotients by URS (2010) were based on ecological effects data, fate and transport data, and estimates of exposure to the COPCs. The exposure is the peak water concentration for the chemical in the injection water and the toxicity is the LC50 for the organism (fish). According to URS (2010), an RQ exceeding one indicates potentially unacceptable chemical intakes for the organism. However, if the RQ for fish, for example, is

less than one, then the chemical would be considered non-hazardous to fish. The proponent asserts that the screening assessment is "extremely conservative" (URS 2010) as it does not account for dilution and biodegradation of the COPCs in groundwater (or potential receiving surface water in the event of a spill).

The toxicity component was based on the LC50 rather than the commonly accepted method of comparing the exposure to the predicted no effect concentration (PNEC) (EPHC 2009a). PNECs may be derived from LC50s but include a safety factor (PNEC = LC50/safety factor. The safety factor (or assessment factor) accounts for the uncertainties of intra- and interspecies variations, the extrapolation of short-term toxicity to long-term exposure and the extrapolation of laboratory results to field conditions. When only one species in an aquatic system is tested, the safety factor is normally 1000.

The URS risk assessment (URS 2010) identified sodium hypochlorite, sodium hydroxide, acetic acid, monoethanolamine borate, guar gum, ferric chloride and potassium chloride as potential risks to fish.

#### 3.2.2 Overseas

The literature review revealed that quantitative (deterministic) modelling of surface exposure to coal seam gas chemicals had not been developed in the US (US EPA 2011a) and European Union (AEA 2012); nor in the United Kingdom (UK) (The Royal Society and The Royal Academy of Engineering 2012).

#### 3.2.3 Modelling conducted in regard to coal seam gas chemicals

In Australia, two independent assessments for hydraulic fracturing for coal seam gas extraction in the Surat Basin and Bowen Basin regions have been conducted in response to the Queensland Co-ordinator General's requirements. The assessments were qualitative, with almost no modelling of surface-to-surface exposure. Overseas assessments have used qualitative approaches.

### 3.3 Risk assessment

Australian environmental risk assessments (Golder 2010a; URS 2010) were provided to the Coordinator-General to address the following requirements:

- provide a complete inventory of biocides, corrosion inhibitors and other chemicals used in drilling, completions and stimulation operations
- provide toxicity data for each active ingredient and any mixture toxicity information
- detail where, when and how often fracturing is to be undertaken
- provide a risk assessment demonstrating that fracturing activities will not result in environmental harm
- develop and implement long-term monitoring of fracturing fluid chemical concentrations in coal seam gas water produced from wells that have been fractured.

The proponents proposed the following methodologies.

#### 3.3.1 Environmental risk assessment report 1 (Golder 2010a)

The response (Golder 2010a, p. 53) prepared for Santos included:

• A description of the existing environment, including an evaluation of the receiving environment.

- A description of the hydraulic fracturing process, including an assessment of physical risk to the coal seam associated with hydraulic fracturing.
- An inventory of chemicals used in hydraulic fracturing.
- An environmental risk assessment based on an evaluation of the aquatic toxicity of the hydraulic fracturing components and their environmental persistence and bioaccumulation potential. The risk assessment identified COPCs for further evaluation.
- Mass balance calculations of the hydraulic fracturing components and fate and transport modelling of COPC.
- A qualitative assessment of the environmental risk to the receiving aquatic environment associated with the injection of hydraulic fracturing fluids. This assessment focused on the subsurface injection of the hydraulic fracturing fluid rather than the storage and handling of the fluid and flowback and produced waters on the surface.
- An environmental risk assessment that ranked the hydraulic fracturing chemicals based on persistence (P), bioaccumulation (B) and toxic (T) potential (referred to as PBT). The assessment of persistence, bioaccumulation and toxicity was consistent with national and international guidance and the T assessment used aquatic toxicity information.

Chemical and physical properties were obtained (Golder 2010a, pp. 24–25) from the following sources in order of priority:

- the material safety datasheet provided to Golder Associates by Santos and BJ Services
- hazardous substances databank
- modelled data from US EPA (2009) EPISUITE<sup>™</sup> (Estimation Programs Interface Suite<sup>™</sup> for Microsoft<sup>®</sup> Windows) modelling software (only when data were not available from the material safety datasheet or the hazardous substances databank).

Acute and chronic aquatic ecotoxicological data were obtained (Golder 2010, p. 27) from the following sources in order of priority:

- US EPA (2009) ECOTOXicology Database Version 4.0
- Australasian Journal of Ecotoxicology.

Where ecotoxicological data were not available for the chemicals of interest or a suitable surrogate, data on toxicity to fish, aquatic invertebrates and algae in water were modelled using EPISUITE<sup>™</sup> ECOSAR<sup>™</sup> software. These toxic effect predictions were made using a set of quantitative structure-activity relationships (QSARs) models based on actual toxicity data of similar chemicals.

The Golder environmental risk assessment is a qualitative assessment based on the European Community's Technical Guidance Document on Risk Assessment. This approach is recommended in Australia (EPHC 2009a) when quantitative assessments cannot be performed.

The environmental risk assessment by Golder (2010a) scored highest those physical, chemical and toxicological values considered to pose high environmental risk. The parameter ranges and scores assigned to each physical, chemical and toxicological value were categorised into three risk scenarios, as follows:

- high risk assigned scores of 3
- moderate risk assigned scores of 2
- low risk assigned scores of 1.

#### 3.3.1.1 Evaluation of persistence and bioaccumulation

The framework devised by Golder Associates (2010a) was based predominantly on guidance published by Environment Canada (2003). This guidance is primarily focused on organic chemicals because it is difficult to predict the persistence and bioaccumulation potential of inorganic chemicals (Environment Canada 2003).

Where data were not available for a chemical, data for a suitable surrogate were used. Where a suitable surrogate chemical could not be identified, data were modelled using EPISUITE<sup>™</sup>. Where data could not be modelled, the parameter was excluded from the environmental risk assessment.

The approach for assessment of persistence by Golder (2010a) for inorganic and organic chemicals differs. Inorganic chemicals were assessed based on solubility and toxicity. Organic chemicals were assessed based on solubility, Henry's Law Constant, the soil water partition coefficient (*Koc*), and the aerobic degradation half-life in water.

An assumption was made that low water solubility of organic chemicals correlated with high bioaccumulation. For inorganic chemicals, the assumption was that aquatic toxicity is only exerted when the chemical is dissolved (Golder 2010a).

#### 3.3.1.2 Evaluation of toxicity

The following trophic levels were considered in the aquatic risk assessment:

- plants
- invertebrates
- fish

The following endpoints were selected by Golder (2010a): mortality (acute), growth (chronic) and reproduction (chronic) for plants, invertebrates and fish.

Golder (2010a) did not consider:

- studies shorter than 24 hours
- chronic mortality exposures
- L(E)Cx endpoints other than L(E)C50 (namely EC0, EC100, EC10, EC20, etc.).

Additional chronic endpoints including lowest observed effect concentration, maximum acceptable toxicant concentration and EC50 were considered in the risk assessment to reduce the uncertainty associated with no observed effect concentration data. If measured lowest observed effect concentration/maximum acceptable toxicant concentration or EC50 endpoint data were not available then EPISUITE<sup>™</sup> and ECOSAR<sup>™</sup> were used to model this data. Chronic aquatic ecotoxicity ranges were assigned by Golder (2010a) after consideration of information provided in European Commission (2003) and UNECE (2009 and 2011).

The assessment used the highest score for either acute or chronic data. This was considered to be a more conservative approach than using average values.

According to Golder (2010a) the environmental risk is not a comprehensive evaluation of all of the environmental risks associated with the chemicals considered.

The environmental risk assessment did not consider:

- breakdown or reactive products of the chemicals that may pose more or less of an environmental risk than the parent compound
- the quality, adequacy or accuracy of the available information noting that only sources considered to be reputable were used
- endocrine disruption effects that are not assessed by standard ecotoxicological tests
- combination effects of chemicals when present in mixture (Golder 2010a).

Golder (2010a) acknowledged the limitations of such assessments and that different assessment approaches are likely to produce different rankings and may produce different risk assessment results.

#### 3.3.2 Environmental risk assessment report 2 (URS 2010)

Another report (URS 2010) prepared for Australia Pacific LNG proposed a different methodology for risk assessment of chemicals used in hydraulic fracturing. The modelling (see above) indicated that several chemicals exceeded the risk quotient threshold criterion of one.

According to URS (2010), consideration could be given to other matters relating to chemicals to determine whether they should be regarded as of potential concern. Accordingly, the following was determined:

- Acetic acid is classified as 'food grade', which is generally recognised as safe for use in foods by the US Food and Drug Administration (FDA). Acetates are common constituents of plant and animal tissues. They are normal metabolic intermediates produced in relatively large quantities during the digestion and metabolism of foods. As acetic acid typically biodegrades within three days in groundwater, it is not considered hazardous to the environment and was discounted as a COPC (URS 2010).
- Similarly guar gum is widely used as an emulsifier and firming agent in foodstuffs such as cheese, milk products, baked goods and baking mixes. Guar gum is classified as food grade by the US Food and Drug Administration and hence is recognised as safe for use in foods. Guar gum is the natural substance obtained from the maceration of the seed of the guar plant. Guar gum has relatively little effect when added to the diets of animals in amounts considerably greater than those present in the human diet. Guar gum is considered safe for human consumption and was not considered a COPC (URS 2010).
- Sodium hypochlorite is typically used in household products as a disinfectant and bleaching agent. The water treatment plants also use sodium hypochlorite in water purification. Sodium hypochlorite reacts in saline waters under aerobic conditions to create chlorinated compounds. To counteract this process, Australia Pacific LNG has used sodium thiosulfate to neutralise hypochlorite in the hydraulic fracturing water. As a result of this process the hypochlorite is removed and hence can be discounted as a COPC (URS 2010).
- Sodium hydroxide (caustic soda) is used in the industry as a key component to neutralise acidic materials. In water, sodium hydroxide rapidly dissolves and

dissociates. Effective neutralisation with acid is expected to result in this chemical no longer being considered hazardous to the environment, and it can be discounted as a COPC (URS 2010).

- There is limited toxicity data available for monoethanolamine borate. Therefore, boric acid was used as a surrogate. According to URS (2010), boric acid is often used as an antiseptic, insecticide and flame retardant. Boric acid is also found in nature as a constituent of many minerals, such as borax. Boric acid is very soluble in water but adsorbs poorly to soil. Neutralisation of boric acid occurs when it is mixed with a base, such as sodium carbonate or sodium hydroxide. If boric acid is neutralised in the hydraulic fracturing water, it was no longer considered a COPC (URS 2010).
- Ferric chloride is routinely used in the Australian drinking water treatment process, and was endorsed by the National Health and Medical Research Council as a drinking water treatment chemical in 1983. It is used as a primary coagulant to remove turbidity during the treatment of drinking water. Conventional water treatment processes remove most of the ferric ions produced when ferric chloride is used for coagulation. Residual chloride at low levels does not adversely affect drinking water quality. If ferric chloride is to be used in the Australia Pacific LNG hydraulic fracturing process to only treat the source water, it will no longer be considered as a COPC (URS 2010).
- Potassium chloride is used in foods, fertilisers, nutrient and dietary supplements, flame retardants and water treatments. Potassium chloride is ubiquitous in the environment, occurring in minerals, soil and sediments and natural waters. Potassium and chloride are essential nutrients and two of the most abundant ions in human and animal species. Potassium chloride is recognised by the US Food and Drug Administration as 'food grade' and is considered safe to be used as a nutrient and/or dietary supplement in animal drugs, feeds and related products, and hence was no longer considered a COPC (URS 2010).

In summary, URS (2010) assessed that these chemicals generally have low toxicity. Those with significant toxicity (based on ecotoxicity data and the specified assumptions) are unlikely to be persistent in the groundwater environment, and pose low risks to groundwater receptors.

#### 3.3.3 Overseas

#### 3.3.3.1 United Kingdom

In the UK, a qualitative risk assessment for shale gas extraction (but not coal seam gas), included a review of hydraulic fracturing (The Royal Society and The Royal Academy of Engineering 2012). The assessment of risk assumed that the impact of any spills of fracturing fluid (or wastewater) on-site could be mitigated using established best practices.

According to The Royal Society and The Royal Academy of Engineering (2012), installing impermeable site lining (bunding) is typically a condition of local planning permission in the UK. The impact of fracturing fluid spills can be further mitigated by using non-hazardous chemicals where possible.

#### 3.3.3.2 European Union

The potential risks for the environment and human health arising from operations involving hydraulic fracturing were investigated in Europe (AEA 2012). The investigation covered coalbed methane (equivalent to coal seam gas), tight gas and shale gas.

A risk prioritisation approach was adopted (AEA 2012) to enable the most serious potential impacts to be prioritised for further investigation. This follows established principles of screening and prioritisation for environmental risk and impact assessment and management (e.g. UK Department for Environment, Transport and the Regions 2000).

The risk prioritisation according to the European Commission (AEA 2012) was carried out by classifying environmental and human hazards on the following basis (based on King 2012):

- Slight: Slight environmental effect e.g. a planned or unplanned discharge which does not exceed an environmental quality standard.
- Minor: Minor environmental effect e.g. a planned or unplanned discharge which could exceed an environmental quality standard in the immediate vicinity of the release point, but which would not be expected to have significant environmental or health effects.
- Moderate: Localised environmental effect e.g. a discharge or incident resulting in
  potential effects on natural ecosystems in the vicinity of the release point or incident;
  ongoing effects on people in the vicinity of a site due to impacts such as noise, odour
  or traffic.
- Major: Major environmental effect e.g. an ongoing discharge resulting in persistent concentrations that exceed European environmental quality standards; permanent degradation of a protected habitat.
- Catastrophic: Massive environmental effect e.g. a pollution incident resulting in harm to the health of members of the public over a wide area due to contamination of drinking water supplies; accident resulting in death or serious injury to workers and/or members of the public.
- No data: Insufficient data to allow a preliminary judgement to be reached.

The frequencies or probabilities of hazards occurring were classified on the following basis:

- Rare: Encountered rarely or never in the history of the industry; not forecast to be encountered under foreseeable future circumstances in view of current knowledge and existing controls on oil and gas extraction.
- Occasional: Encountered several times in this industry; could potentially occur under foreseeable future circumstances if management or regulatory controls fall below best practice standards.
- Periodic: Occurs several times a year in this industry; a short-term impact would be expected to occur with the use of hydraulic fracturing for hydrocarbon operations.
- Frequent/definite: Occurs several times a year at a specific site; a long-term impact would be expected to occur with the use of hydraulic fracturing for hydrocarbon operations.
- No data: Insufficient data to allow a preliminary judgement to be reached.

Considering the hazard significance and associated probability enables risks to be prioritised and screened using a risk matrix (adapted from King 2012). This is illustrated in Table 3.1.

| Probability classification   | Hazard classification |          |           |           |              |          |  |  |
|------------------------------|-----------------------|----------|-----------|-----------|--------------|----------|--|--|
|                              | Slight                | Minor    | Moderate  | Major     | Catastrophic | No data  |  |  |
| Rare                         | Low                   | Low      | Moderate  | Moderate  | High         | 7        |  |  |
| Occasional                   | Low                   | Moderate | Moderate  | High      | Very high    | lot c    |  |  |
| Periodic short-term definite | Low                   | Moderate | High      | Very high | Very high    | lassifia |  |  |
| Frequent long-term definite  | Moderate              | High     | Very high | Very high | Very high    | ıble     |  |  |
| No data                      | Not classifiable      |          |           |           |              |          |  |  |

Table 3.1 Risk matrix

Source: WorkCover Corporation of South Australia (2002)

Where more than one scenario was envisaged, the combination giving rise to highest risk was presented.

According to the European Commission (AEA 2012) this approach is useful for evaluating the risks that could result if mitigation measures are not carried out. A selection of risk evaluations relevant to surface water contamination is presented below (Table 3.2).

Literature review: Environmental risks posed by chemicals used in coal seam gas operations

| Stage   | Risk<br>characterisation                     | Hazard<br>classification | Probability classification | Risk ranking |
|---|--|--------------------------|----------------------------|--------------|
| Stage 1: Well<br>pad site<br>identification<br>and<br>preparation | Individual installation                      | Minor                    | Rare                       | Low          |
|   | Cumulative effects of multiple installations | Moderate                 | Rare                       | Moderate     |
| Stage 2: Well<br>design,<br>drilling,<br>casing and<br>cementing  | Individual installation                      | Moderate                 | Rare                       | Moderate     |
|   | Cumulative effects of multiple installations | Moderate                 | Rare                       | Moderate     |
| Stage 3:<br>Technical<br>hydraulic<br>fracturing                  | Individual installation                      | Moderate                 | Occasional                 | High         |
|   | Cumulative effects of multiple installations | Major                    | Rare                       | Moderate     |
| Stage 4: Well completion  | Individual installation                      | Moderate                 | Occasional                 | High         |
|   | Cumulative effects of multiple installations | Moderate                 | Occasional                 | High         |
| Stage 5: Well production  | Individual installation                      | Minor                    | Rare                       | Low          |
|   | Cumulative effects of multiple installations | Minor                    | Occasional                 | Moderate     |

 Table 3.2 Overall evaluations of risks arising from various stages of shale gas extraction

# 3.4 Characterisation of risk assessment and modelling in regard to coal seam gas

#### 3.4.1 Approaches to risk assessment and modelling

According to the Environmental Health Committee (enHealth 2012), the level of risk can be described either qualitatively (using categories such as 'high', 'medium' or 'low') or quantitatively (with a numerical estimate). Semi-quantitative risk assessments are also possible. Such risk assessments combine elements of both the qualitative and the quantitative risk approaches and often involve categorising risks with a score (FAO/WHO 2009).

The World Health Organisation FAO/WHO (2009) considered data and modelling requirements for the various types of risk assessments described above, highlighting that, regardless of the type of risk assessment, as much numerical data as possible should be provided.

# 3.4.2 Analysis of modelling and risk assessment conducted in regard to coal seam gas in Australia

Both of the risk assessments conducted in relation to coal seam gas extraction in Australia are qualitative (Golder 2010a and URS 2010). Similarly, both of the overseas risk assessments conducted for unconventional gas extraction are qualitative (The Royal Society and Royal Academy of Engineering 2012 and AEA 2012).

The risk assessment performed by URS (2010) includes a deterministic assessment of direct exposure to hydraulic fracturing fluid. Most of the chemicals showed a potentially unacceptable risk for direct exposure (RQ > 1).

The FAO/WHO (2009) considers that qualitative analysis is useful as the first stage of risk assessment and risk management. The FAO suggests that if a qualitative assessment indicates significant risks then it may be useful, or necessary, to complement the qualitative assessment with quantitative analysis.

According to FAO/WHO (2009) qualitative risk assessment is prone to subjective judgements when quantitative data is converted into categories such as high, intermediate and low. It may be difficult to unambiguously define these terms, so repeatability is less certain. This was acknowledged by Golder (2010a) in their risk assessment. Further, while a fully qualitative risk assessment can identify pathways or scenarios that lead to extremes of risk, the relative risk from other scenarios cannot be differentiated (enHealth 2012).

Accordingly FAO/WHO (2009) conclude that when all else is equal, quantitative risk assessment is preferred over a qualitative or semi-quantitative risk assessments. Additionally, quantitative risk assessments tend to be better suited to situations where mathematical models and the requisite data are available. Similarly in Australia, it is recommended that, whenever possible, the evaluation of environmental exposure should be done quantitatively using appropriate mathematical models (EPHC 2009a).

Therefore, based on the evidence of the literature, investigation into quantitative risk assessment methodologies and associated modelling is warranted.

# 3.5 Guidance on modelling and quantitative risk assessment methodologies

Although quantitative risk assessment is considered preferable, if exposure or toxicity data are lacking, then qualitative risk assessment is appropriate (US EPA 1998). In this regard FAO/WHO (2009) lists the following key properties of quantitative risk assessments:

- well-specified scenarios
- appropriately selected models, supported as far as possible by data
- detail appropriate to the level of the assessment (e.g. screening versus refined)
- evaluation of uncertainty in scenarios
- evaluation of uncertainty in models
- explanation of all assumptions and choice of data used in the analysis
- quantification and evaluation of uncertainty in model predictions
- identification of key opportunities for risk mitigation
- identification of key opportunities for reducing uncertainty.

#### 3.5.1 *Model appropriateness and data inputs*

Field data and studies may provide representations of reality but can be limited by a lack of replication, bias in obtaining representative samples, or failure to measure critical components of the system or random variations. Further, a lack of observed effects in a field survey may occur because the measurements lack the sensitivity to detect ecological effects (US EPA 1998).

Australian monitoring data are seldom available or are limited. Even if monitoring data within Australia are available for a substance, the quality of these data should be assessed prior to being used (EPHC 2009b).

Therefore, especially where field monitoring data are inadequate, reactive transport (fate) models are useful for estimating chemical concentrations (enHealth 2012).

Accordingly, modelling is often used in exposure assessment as a means of estimating human or other exposures in the absence of monitoring data (enHealth 2012). In this regard, modelling provides a mathematical expression representing a simplification of the essential elements of exposure processes (enHealth 2012).

Types of fate models include:

- simple dilution models, where a measured concentration in an effluent is divided by a dilution factor, or the chemical release rate is divided by a dilution factor, or the chemical release rate is divided by the bulk flow rate of the medium
- equilibrium models, which predict the distribution of a chemical in the environment based on partitioning ratios or fugacity (the tendency of a chemical to move from one environmental phase to another)
- dispersion models, which predict reductions in concentrations from point sources based on assumed mathematical functions or dispersion properties of the chemical or environmental processes like wind or river flow
- transport models, which predict concentration changes over distance and can represent dispersion, biochemical degradation and absorption.

Exposure models may be informed by site models or flow diagrams describing specific exposure scenarios. It is important that users of these models are aware of their components and assumptions and understand the nature and sensitivity of data inputs that can influence the outcomes (enHealth 2012).

Misleading results may arise from inappropriate models that are overstandardised or oversimplified, or exclude important factors (EPHC 2009b; enHealth 2012). Additionally the model complexity could lead to mistakes, or provide a false or misleading sense of precision.

According to Fryer et al. (2006), mechanistic modelling is generally preferred to other types. Mechanistic modelling may include sophisticated mathematical approximations of the underlying processes involved. But, if these are not properly validated then errors in these approximations could give results that have no basis in reality.

FAO/WHO (2006) considered the role of worst-case scenarios as a filtering technique to determine whether significant risks are likely.

However, methods using worst-case values may produce unrealistic exposures due to compounding bias in sequential conservative estimates (Fryer et al. 2006; enHealth 2012).

One method of dealing with these problems is to use probabilistic approaches to exposure modelling (Fryer et al. 2006; enHealth 2012). However, the development of probabilistic approaches is still in its infancy. Current limitations in the quality and quantity of available data and mathematical models required for probabilistic exposure assessments are a major barrier (Fryer et al. 2006; enHealth 2012; EPHC 2009b).

Fryer et al. (2006) recommend that the design of mathematical models should take into account the quantity of data and its level of sophistication, regardless of whether the model is probabilistic or deterministic.

US EPA (1997) considers that Monte Carlo analysis may add value to a risk assessment. However, Monte Carlo analysis generally requires large data sets and is not well suited to assessments where there is limited or incomplete data (enHealth 2012).

Additionally, the complexity of Monte Carlo methods can create difficulties in risk communication and community consultation (enHealth 2012; EPHC (2009b).

#### 3.5.2 Model uncertainty

Models represent simplifications of real systems. Scenario uncertainty can arise from failure to identify key receptor populations and pathways of exposure or selecting inappropriate spatial and temporal scales for exposure (Fryer et al. 2006). EnHealth (2012) notes that even complex models provide only a static picture of a dynamic world. Similarly the US EPA (2011b) regards all model parameters as uncertain.

FAO/WHO (2009) and enHealth (2012) indicate that probabilistic techniques, including Monte Carlo analysis, are usually more complicated than mechanistic models. Additionally, if uncertainty in models is inappropriately or incompletely quantified it could give a false sense of precision (EPHC 2009b).

Further, all risk assessment methods involve subjective judgements. Judgements are necessary when defining the scope of the problem, selecting (and rejecting) data, defining exposure pathways, applying weightings to data, selecting model parameters and characterising environmental effects (FAO/WHO 2009).

#### 3.5.3 Data choice

Data choice critically affects the validity of the output (the results) of environmental models (US EPA 2011a).

There are often several sources of data for a given input parameter. These must be weighted or combined, or both, in appropriate ways reflecting their importance in estimating the parameter in question (FAO/WHO 2009).

Any default data and assumptions should be identified and justified (enHealth 2012)

#### 3.5.4 Quantification of randomness, variability and uncertainty

Parameter variability may be defined as true heterogeneity in an input parameter, while uncertainty reflects a lack of knowledge of the true value (Fryer et al. 2006 citing Hertwich et al. 2000). Randomness is a kind of unpredictable fluctuation for which there are mathematical theories (e.g. Gaussian distribution).

Variability is an inherent characteristic (of a population) that will not be reduced with additional data but will be better characterised (enHealth 2012).

It is important to distinguish variability (measurable factors) from uncertainties that arise from lack of knowledge (EPHC 2009b). This distinction facilitates the interpretation and communication of results.

FAO/WHO (2009) recommends treating uncertainty or variability by incorporating them mathematically as distributions. Where there are several sources of data for a given input parameter, they must be weighted or combined, or both, in appropriate mathematical ways reflecting their importance in estimating the parameter in question.

Parameters that are distributions rather than single values (e.g. 95<sup>th</sup> percentile) allow the inherent variability in model parameters to be incorporated into the exposure assessment, along with any associated uncertainty (Fryer et al. 2006). However, the data must be assessed to determine whether it is sufficient to adequately characterise the variability and the extremes of the distribution (enHealth 2012).

According to EPHC (EPHC 2009b), probabilistic methods can quantify variability. They allow assessors to take account of the high level of natural variability that exists in both exposure and effects. This provides a more thorough description of the range of risks and avoids the problems of using worst-case assumptions such as a lack of consensus in defining the worst case, and the generation of unrealistically extreme assessments.

Further information pertaining to modelling environmental exposure to coal seam gas chemicals and completed as part of the set of technical reports that make up the National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia includes the following reports:

- Department of the Environment and Energy (2017a) "Environmental exposure conceptualisation for surface to surface water pathways"
- Department of the Environment and Energy (2017b) "Environmental risks associated with surface handling of chemicals used in coal seam gas extraction".

## 3.6 Conclusions

Contemporary guidance from international regulatory agencies indicates that quantitative models should be appropriately selected, have all assumptions and choice of data explained, and the uncertainty should be quantified.

For any model it is important that there is sufficient quality input data. The choice of data critically affects the validity of the results. Therefore datasets must be chosen carefully, as their quality may vary considerably. If there are several sources of data they must be weighted and/or combined in appropriate mathematical ways. Generally, probabilistic models require more data (which may not be available) than deterministic models.

The guidance recommends that deterministic assessments should have a tiered structure. The first tier can be used as a screening step. It is usually based on a worst-case scenario and uses simple models, limited data and conservative assumptions. In a second tier, more complex modelling, site-specific data and fewer assumptions are used. In a third tier, with extensive data and complex modelling, probabilistic approaches should be used, with variability and uncertainty delineated as far as possible.EPA 2004).

Figure 3.1 illustrates a tiered approach to risk assessment. Tier 1 is a simple model with conservative input data. If Tier 2 is required, then the model should be more detailed, requiring additional site-specific inputs. Tier 3 requires advanced modelling (US EPA 2004).





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

Source: US EPA (2004)

# 4 Key Findings

This literature review has identified the environmental entities that may be affected by chemicals used and investigated the approaches to assessment of the environmental risks posed.

## 4.1 Receiving environments

Australia has substantial coal resources. Black coal basins with economically viable gas seams are located:

- in the far northeast near Cooktown in Queensland
- in the northwest stretching inland from Broome in Western Australia
- along the southern half of the continental west coast
- within the Lake Eyre catchment
- on both sides of the Great Diving Range in the eastern states extending from south of Wollongong in New South Wales to north of Mackay in Queensland
- Eastern Tasmania.

Brown coal occurs all along the southern coastline from Esperance in Western Australia across to Gippsland in Victoria and extends north under the lower reaches of the Murray River.

The Australian Government is completing bioregional assessments to better understand the potential impacts of coal seam gas and large coal mining developments on water resources and water-dependent assets. The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) provides oversight of the Australian Government's Bioregional Assessment Program. This program is focusing on those regions subject to significant existing or anticipated mining pressure. Bioregional assessments are underway in the following regions:

- the Galilee, Cooper, Pedirika and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions within the Northern Sydney Basin bioregion
- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

The movement of a chemical in the receiving environment, and its ultimate fate, are determined by the physical, biological and chemical properties of that environment.

The receiving environment for chemicals associated with coal seam gas extraction includes terrestrial, surface and subsurface aquatic ecosystems. The available information indicates that the extent of the receiving environment occurs over:

- a wide range of latitudes and longitudes with resultant tropical, subtropical, arid, semiarid and temperate climates
- a variety of landforms including the ranges and escarpment of the eastern highlands, coastal plains of Victoria and the extensive flats of the central low lands
- clay-rich soils of eastern Australia and sandy dunes of the arid interior
- the fast-flowing rivers of eastern Australia draining into the Pacific Ocean, the highly modified rivers of the Murray-Darling Basin and the slow, meandering rivers of the Lake Eyre Basin
- the Great Artesian Basin and numerous other aquifers.

The climate, topography, soils, hydrology, hydrogeology and ecology vary greatly across these regions.

National data sources exist to characterise some of these features of each region – for example, those relating to climate. Other data sources may be available at a state, natural resource management or catchment level, but they vary between each jurisdiction.

The ecology of surface ecosystems has been extensively studied. There is a general consensus that the following components of ecosystems are potential receptors of chemicals: organisms, species, communities, habitat (soil, water) and ecological assets (wetlands).

Some surface ecosystems across Australia are dependent on groundwater and are potential receptors of chemical contaminants of groundwater.

The understanding of subsurface ecosystems is incomplete and much remains unknown about the species diversity, distribution, functional roles and interdependencies in subsurface ecosystems. Evidence suggests that receptors of chemicals in these ecosystems are similar to those of surface ecosystems, albeit that the species are adapted to subsurface conditions.

Matters of national environmental significance that are protected under the EPBC Act are also potential receptors of chemicals in the receiving environment. The protected matters that occur within the six priority areas include:

- 490 listed threatened, migratory, marine and/or cetacean species
- 24 threatened ecological communities
- 13 declared Ramsar wetlands
- 6 listed natural national heritage places, two of these are also world heritage areas.
- 1 surface groundwater dependent ecosystem

There is early evidence suggesting that each priority area contains threatened species or ecological communities that are endemic to that area.

### 4.2 Modelling

Previous Australian risk assessments of chemicals used in coal seam gas extraction were mostly qualitative, with only limited quantitative exposure modelling.

In general, guidance on risk assessment methodologies suggests that quantitative models should be specifically designed for the particular exposure pathway, use numerical inputs for all parameters and be evaluated for uncertainty. All assumptions and choices of data should be clearly explained. Mechanistic models of essential exposure pathways are recommended.

The literature suggests that a simple, well selected screening tool should be used prior to complex modelling. This will ensure that time and expense is not wasted on modelling where it is unwarranted.

For any model, it is important that there is reliable data available. Probabilistic models require more data than deterministic models and this extra data is seldom available for coal seam gas chemicals. Therefore, deterministic models are expected to be better suited to routine assessment of these chemicals, at least until a larger body of information based on contemporary Australian industry practices is compiled.

The choice of data critically affects the validity of the results produced by a model. Therefore, input data must be chosen carefully. If there are several sources of data they must be weighted and / or combined in ways that are both mathematically sound and scientifically reasonable. Caution is also required when using extreme values in distributions (such as the 99<sup>th</sup> percentile) for model inputs as this may result in overly conservative findings.

A simple, but conservative exposure scenario may be considered at Tier 1 for an initial screening assessment. The Tier 1 screening assessment should require only basic input data and the models used should be based on conservative assumptions that are nevertheless informed by the known industrial practices for the coal seam gas industry in Australia. In a second tier, more complex models involving site-specific data and fewer assumptions may be used. In a third and final tier, complex modelling with extensive specific data and fewer assumptions should be used.

As a general principle, variability and uncertainty in both model inputs and outputs should be considered when drawing conclusions at any tier of assessment.

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## Appendix A - The main natural resource management regions in each of the six priority areas

| Priority area                              | State | NRM region   | NRM management body and website  |
|--|-------|--|--|
| Lake Eyre Basin <sup>a</sup>               | Qld   | Desert<br>Channels                                 | Desert Channels Queensland<br>http://www.dcq.org.au/   |
|  | SA    | South Australia<br>Arid Lands                      | South Australian Arid Lands Natural<br>Resources Management Board<br>http://www.saalnrm.sa.gov.au/ |
|  | NT    | Northern<br>Territory (Arid<br>Lands<br>subregion) | Territory Natural Resource Management<br>http://www.territorynrm.org.au/                           |
| Northern Inland<br>Catchments <sup>b</sup> | NSW   | Border Rivers-<br>Gwydir                           | Border Rivers-Gwydir Catchment<br>Management Authority<br>http://www.brg.cma.nsw.gov.au/           |
|  |       | Namoi  | Namoi Catchment Management Authority<br>http://www.namoi.cma.nsw.gov.au/                           |
|  |       | Central West                                       | Central West Catchment Management<br>Authority<br>http://cw.cma.nsw.gov.au/                        |
|  | Qld   | Border Rivers<br>and Maranoa-<br>Balonne           | Queensland Murray Darling Committee<br>http://www.qmdc.org.au/                                     |
|  |       | Condamine  | Condamine Alliance<br>http://www.condaminealliance.com.au/   |
| Northern Sydney<br>Basin                   | NSW   | Hunter-Central<br>Rivers                           | Hunter-Central Rivers Catchment<br>Management Authority  |
|  |       | Hawkesbury-<br>Nepean                              | Hawkesbury Nepean Catchment Management<br>Authority  |
| Southern Sydney                            | NSW   | Sydney Metro                                       | Sydney Metropolitan Catchment Management   |
| Basin <sup>c</sup>                         |       |  | Authority<br>http://www.sydney.cma.nsw.gov.au/   |
|  |       | Southern<br>Rivers                                 | Southern Rivers Catchment Management<br>Authority  |
|  |       |  | http://www.nrm.gov.au/about/nrm/regions/nsw-<br>sriv.html  |

| Priority area             | State | NRM region                   | NRM management body and website   |
|---------------------------|-------|------------------------------|---|
| Clarence-Moreton<br>Basin | NSW   | Northern<br>Rivers           | Northern Rivers Catchment Management<br>Authority<br>http://www.northern.cma.nsw.gov.au/        |
|                           | Qld   | South East<br>Queensland     | SEQ Catchments<br>http://www.seqcatchments.com.au/  |
| Gippsland Basin           | Vic   | West<br>Gippsland            | West Gippsland Catchment Management<br>Authority<br>http://www.wgcma.vic.gov.au/                |
|                           |       | Port Phillip and Westernport | Port Phillip and Westernport Catchment<br>Management Authority<br>http://www.ppwcma.vic.gov.au/ |

a. The Galilee data collection area also includes areas of the Southern Gulf, Burkedin and South West Queensland NRMs in Queensland. The Arckaringa Basin also extends into the Alinytjara Wilurana NRM in South Australia; <sup>b</sup> The Surat basin also underlies small sections of the South West Queensland and Western (New South Wales) NRM regions; <sup>c</sup> The Southern Sydney Basin priority area also incorporates a section of the Hawkesbury-Nepean NRM region.

## Appendix B – Drainage divisions and river basins of the six priority areas

| Priority area                    | Drainage Division                        | Coal Basin                 | River basins  |
|----------------------------------|--|----------------------------|---|
| Lake Eyre<br>Basin               | Lake Eyre                                | Galilee/Eromanga<br>Cooper | Georgina, Diamantina, Barcoo Cooper   |
|                                  |  | Pedirka                    | Finke, Todd, Hay  |
|                                  |  | Arckaringa                 | Lake Frome, Gairdner, Warburton   |
| Galilee data collection area     | Bulloo-Bancannia                         | Galilee/Eromanga           | Bulloo  |
|                                  | Murray-Darling                           | Galilee                    | Warrego   |
|                                  | North East Coast                         | Galilee                    | Burdekin (Belyando)   |
|                                  | Gulf of Carpentaria                      | Galilee                    | Flinders  |
| Northern<br>Inland<br>Catchments | Murray-Darling                           | Surat/Bowen                | Condamine-Culgoa (including<br>Balonne, Maranoa), Moonie, Border<br>Rivers (Dumaresq, Macintyre) Gwydir |
|                                  |  | Surat/Gunnedah             | Namoi, Castlereagh, Macquarie-<br>Bogan,  |
| Northern<br>Sydney Basin         | South East Coast<br>(New South<br>Wales) | Sydney                     | Hawkesbury, Macquarie-Tuggerah,<br>Hunter   |
|                                  |  | Gloucester                 | Manning, Karuah   |
| Southern<br>Sydney Basin         | South East Coast<br>(New South<br>Wales) | Sydney                     | Hawkesbury-Nepean, Sydney Coast-<br>Georges, Wollongong Coast,<br>Shoalhaven                            |
| Clarence<br>Moreton Basin        | South East Coast<br>(New South<br>Wales) | Sydney                     | Clarence, Richmond, Brunswick,<br>Tweed   |
|                                  | North East Coast                         | Sydney                     | Logan-Albert  |
| Gippsland<br>Basin               | South East Coast<br>(Victoria)           | Gippsland                  | Tambo, Mitchell, Avon, Thomson-<br>Macalister, Latrobe, South Gippsland                                 |

## Appendix C – The main bioregions in each of the six priority areas based on IBRA version 7

| Priority area                 | Coal Basin                | Code | Bioregion  |
|-------------------------------|---------------------------|------|--|
| Lake Eyre Basin               | Galilee/Eromanga          | MGD  | Mitchell Grass Downs (eastern half)                            |
|                               |                           | DEU  | Desert Uplands (eastern areas)                                 |
|                               |                           | MUL  | Mulga Lands (northern areas)                                   |
|                               | Cooper                    | СНС  | Channel Country  |
|                               | Pedirka and<br>Arckaringa | SSD  | Simpson Strzelecki Dunefields                                  |
|                               |                           | FIN  | Finke  |
|                               |                           | STP  | Stony Plains   |
| Northern Inland<br>Catchments | Surat/Bowen               | BBS  | Brigalow Belt South (subregions north of Moree)                |
|                               |                           | MUL  | Mulga Lands (eastern areas)                                    |
|                               | Surat/Gunnedah            | DRP  | Darling Riverine Plains (subregions to the east of Bourke)     |
|                               |                           | BBS  | Brigalow Belt South (subregions south of Moree)                |
| Combined Sydney<br>Basin      | Sydney                    | SYD  | Sydney Basin   |
|                               | Gloucester                | SYD  | Sydney Basin   |
|                               |                           | NNC  | New South Wales North Coast                                    |
| Clarence-Moreton<br>Basin     | Clarence-Moreton          | SEQ  | South Eastern Queensland (subregions from Moreton Basin south) |
| Gippsland Basin               | Gippsland                 | SCP  | South East Coastal Plain (Gippsland Plain only)                |
|                               |                           | SEH  | South Eastern Highlands (Strezlecki Ranges only )              |

## Appendix D – Listed species protected under the *Environment Protection and Biodiversity Conservation Act 1999* that may occur within the six priority areas

| Name                           | Common name                            | Species | EPBC A                              | ct listi  | ing typ | е        | Clarence | Gippsland<br>Basin | Lake          |
|--------------------------------|--|---------|-------------------------------------|-----------|---------|----------|----------|--------------------|---------------|
|                                |  | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin    |                    | Eyre<br>Basin |
| Acanthiza iredalei<br>iredalei | Slender-billed<br>Thornbill (western)  | Birds   | V                                   |           |         |          |          |                    | Yes           |
| Actitis hypoleucos             | Common<br>Sandpiper                    | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Amytornis<br>barbatus barbatus | Grey Grasswren<br>(Bulloo)             | Birds   | V                                   |           |         |          |          |                    | Yes           |
| Amytornis textilis<br>modestus | Thick-billed<br>Grasswren<br>(eastern) | Birds   | V                                   |           |         |          |          |                    | Yes           |
| Anthochaera<br>phrygia         | Regent Honeyeater                      | Birds   | E                                   |           |         |          | Yes      | Yes                |               |
| Apus pacificus                 | Fork-tailed Swift                      | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                | Yes           |
| Ardea alba                     | Great Egret, White<br>Egret            | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                | Yes           |
| Ardea ibis                     | Cattle Egret                           | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                | Yes           |
| Arenaria interpres             | Ruddy Turnstone                        | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Botaurus<br>poiciloptilus      | Australasian Bittern                   | Birds   | E                                   |           |         |          | Yes      | Yes                | Yes           |
| Calidris<br>acuminata          | Sharp–tailed<br>Sandpiper              | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Calidris alba                  | Sanderling                             | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Calidris canutus               | Red Knot, Knot                         | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Calidris ferruginea            | Curlew Sandpiper                       | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Calidris ruficollis            | Red-necked Stint                       | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |
| Calidris<br>tenuirostris       | Great Knot                             | Birds   |                                     | Yes       | Yes     |          | Yes      | Yes                |               |

| Name                                      | Common name   | Species | EPBC A                              | ct listi  | ing typ | e        | Clarence Gippsland |       | Lake  |
|---|---|---------|-------------------------------------|-----------|---------|----------|--------------------|-------|-------|
|   |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin              | Dasin | Basin |
| Calonectris<br>leucomelas                 | Streaked<br>Shearwater  | Birds   |                                     | Yes       | Yes     |          |                    |       |       |
| Charadrius<br>bicinctus                   | Double-banded<br>Plover   | Birds   |                                     | Yes       | Yes     |          | Yes                | Yes   |       |
| Charadrius<br>leschenaultii               | Greater Sand<br>Plover, Large Sand<br>Plover  | Birds   |                                     | Yes       | Yes     |          | Yes                | Yes   |       |
| Charadrius<br>mongolus                    | Lesser Sand<br>Plover, Mongolian<br>Plover  | Birds   |                                     | Yes       | Yes     |          | Yes                | Yes   |       |
| Charadrius<br>veredus                     | Oriental Plover,<br>Oriental Dotterel   | Birds   |                                     | Yes       | Yes     |          | Yes                | Yes   | Yes   |
| Cyclopsitta<br>diophthalma<br>coxeni      | Coxen's Fig-Parrot  | Birds   | E                                   | Yes       |         |          | Yes                |       |       |
| Dasyornis<br>brachypterus                 | Eastern Bristlebird   | Birds   | E                                   |           |         |          | Yes                |       |       |
| Diomedea<br>antipodensis                  | Antipodean<br>Albatross   | Birds   |                                     | Yes       | Yes     |          |                    | Yes   |       |
| Diomedea<br>epomophora<br>epomophora      | Southern Royal<br>Albatross   | Birds   | V                                   |           |         |          |                    | Yes   |       |
| Diomedea<br>epomophora<br>sanfordi        | Northern Royal<br>Albatross   | Birds   | E                                   |           |         |          |                    | Yes   |       |
| Diomedea<br>epomophora<br>(sensu stricto) | Southern Royal<br>Albatross   | Birds   |                                     | Yes       | Yes     |          |                    | Yes   |       |
| Diomedea<br>exulans gibsoni               | Gibson's Albatross  | Birds   | V                                   |           |         |          |                    | Yes   |       |
| Diomedea gibsoni                          | Gibson's Albatross  | Birds   |                                     | Yes       | Yes     |          |                    | Yes   |       |
| Diomedea<br>sanfordi                      | Northern Royal<br>Albatross   | Birds   |                                     | Yes       | Yes     |          |                    | Yes   |       |
| Erythrotriorchis<br>radiatus              | Red Goshawk   | Birds   | V                                   |           |         |          | Yes                |       | Yes   |
| Fregetta grallaria<br>grallaria           | White-bellied<br>Storm-Petrel<br>(Tasman Sea),<br>White-bellied<br>Storm-Petrel<br>(Australasian) | Birds   | V                                   |           |         |          | Yes                | Yes   |       |

| Name                               | Common name                                       | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence Gippslan |       | Lake  |
|------------------------------------|---|---------|-------------------------------------|-----------|--------|----------|-------------------|-------|-------|
|                                    |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin             | Dasin | Basin |
| Gallinago<br>hardwickii            | Latham's Snipe,<br>Japanese Snipe                 | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   | Yes   |
| Geophaps scripta<br>scripta        | Squatter Pigeon<br>(southern)                     | Birds   | V                                   |           |        |          | Yes               |       | Yes   |
| Glareola<br>maldivarum             | Oriental Pratincole                               | Birds   |                                     | Yes       | Yes    |          |                   |       | Yes   |
| Haliaeetus<br>leucogaster          | White-bellied Sea-<br>Eagle                       | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   | Yes   |
| Heteroscelus<br>brevipes           | Grey-tailed Tattler                               | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   |       |
| Hirundapus<br>caudacutus           | White-throated<br>Needletail                      | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   | Yes   |
| Lathamus discolor                  | Swift Parrot                                      | Birds   | E                                   |           | Yes    |          | Yes               | Yes   |       |
| Leipoa ocellata                    | Malleefowl  | Birds   | V                                   | Yes       |        |          |                   | Yes   | Yes   |
| Limicola<br>falcinellus            | Broad-billed<br>Sandpiper                         | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   |       |
| Limosa lapponica                   | Bar-tailed Godwit                                 | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   |       |
| Limosa limosa                      | Black-tailed Godwit                               | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   |       |
| Macronectes<br>giganteus           | Southern Giant-<br>Petrel                         | Birds   | E                                   | Yes       | Yes    |          | Yes               | Yes   |       |
| Macronectes halli                  | Northern Giant-<br>Petrel                         | Birds   | V                                   | Yes       | Yes    |          | Yes               | Yes   |       |
| Merops ornatus                     | Rainbow Bee-eater                                 | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   | Yes   |
| Monarcha<br>melanopsis             | Black-faced<br>Monarch                            | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   | Yes   |
| Monarcha<br>trivirgatus            | Spectacled<br>Monarch                             | Birds   |                                     | Yes       | Yes    |          | Yes               |       |       |
| Myiagra<br>cyanoleuca              | Satin Flycatcher                                  | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   | Yes   |
| Neochmia<br>ruficauda<br>ruficauda | Star Finch<br>(eastern), Star<br>Finch (southern) | Birds   | E                                   |           |        |          | Yes               |       | Yes   |
| Neophema<br>chrysogaster           | Orange-bellied<br>Parrot                          | Birds   | CE                                  | Yes       | Yes    |          |                   | Yes   |       |
| Numenius<br>madagascariensis       | Eastern Curlew                                    | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   |       |
| Numenius                           | Little Curlew, Little                             | Birds   |                                     | Yes       | Yes    |          | Yes               | Yes   |       |

| Name                                       | Common name                                  | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence Gippsland |       | Lake  |
|--|--|---------|-------------------------------------|-----------|--------|----------|--------------------|-------|-------|
|  |  | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin              | Basin | Basin |
| minutus                                    | Whimbrel                                     |         |                                     |           |        |          |                    |       |       |
| Numenius<br>phaeopus                       | Whimbrel                                     | Birds   |                                     | Yes       | Yes    |          | Yes                | Yes   |       |
| Pedionomus<br>torquatus                    | Plains-wanderer                              | Birds   | V                                   |           |        |          |                    |       | Yes   |
| Pluvialis fulva                            | Pacific Golden<br>Plover                     | Birds   |                                     | Yes       | Yes    |          | Yes                | Yes   |       |
| Pluvialis<br>squatarola                    | Grey Plover                                  | Birds   |                                     | Yes       | Yes    |          | Yes                | Yes   |       |
| Poephila cincta<br>cincta                  | Black-throated<br>Finch (southern)           | Birds   | E                                   |           |        |          | Yes                |       | Yes   |
| Polytelis<br>swainsonii                    | Superb Parrot                                | Birds   | V                                   |           |        |          |                    |       |       |
| Pterodroma<br>neglecta neglecta            | Kermadec Petrel<br>(western)                 | Birds   | V                                   |           |        |          | Yes                |       |       |
| Puffinus griseus                           | Sooty Shearwater                             | Birds   |                                     | Yes       | Yes    |          |                    |       |       |
| Puffinus<br>leucomelas                     | Streaked<br>Shearwater                       | Birds   |                                     | Yes       |        |          |                    |       |       |
| Puffinus pacificus                         | Wedge-tailed<br>Shearwater                   | Birds   |                                     | Yes       | Yes    |          |                    |       |       |
| Puffinus<br>tenuirostris                   | Short-tailed<br>Shearwater                   | Birds   |                                     | Yes       | Yes    |          |                    |       |       |
| Rhipidura<br>rufifrons                     | Rufous Fantail                               | Birds   |                                     | Yes       | Yes    |          | Yes                | Yes   | Yes   |
| Rostratula<br>australis                    | Australian Painted<br>Snipe                  | Birds   | V                                   |           |        |          | Yes                | Yes   | Yes   |
| Rostratula<br>benghalensis<br>(sensu lato) | Painted Snipe                                | Birds   |                                     | Yes       | Yes    |          | Yes                | Yes   | Yes   |
| Sterna albifrons                           | Little Tern                                  | Birds   |                                     | Yes       | Yes    |          | Yes                | Yes   |       |
| Sternula nereis<br>nereis                  | Fairy Tern<br>(Australian)                   | Birds   | V                                   |           |        |          |                    | Yes   |       |
| Thalassarche<br>bulleri                    | Buller's Albatross                           | Birds   | V                                   | Yes       | Yes    |          |                    | Yes   |       |
| Thalassarche<br>cauta cauta                | Shy Albatross,<br>Tasmanian Shy<br>Albatross | Birds   | V                                   |           |        |          |                    | Yes   |       |
| Thalassarche                               | Salvin's Albatross                           | Birds   | V                                   |           |        |          |                    | Yes   |       |

| Name                                     | Common name                                     | Species | s EPBC Act listing type Clarence Gippsla |           | Gippsland | Lake     |       |     |       |
|--|---|---------|--|-----------|-----------|----------|-------|-----|-------|
|  |   | class   | Threatened<br>Category <sup>a</sup>      | Migratory | Marine    | Cetacean | Basin |     | Basin |
| cauta salvini                            |   |         |  |           |           |          |       |     |       |
| Thalassarche<br>cauta steadi             | White-capped<br>Albatross                       | Birds   | V  |           |           |          |       |     |       |
| Thalassarche<br>cauta (sensu<br>stricto) | Shy Albatross,<br>Tasmanian Shy<br>Albatross    | Birds   |  | Yes       | Yes       |          |       | Yes |       |
| Thalassarche<br>impavida                 | Campbell Albatross                              | Birds   |  | Yes       | Yes       |          | Yes   | Yes |       |
| Thalassarche<br>melanophris<br>impavida  | Campbell Albatross                              | Birds   | V  |           |           |          | Yes   | Yes |       |
| Thalassarche<br>salvini                  | Salvin's Albatross                              | Birds   |  | Yes       | Yes       |          |       | Yes |       |
| Thalassarche<br>steadi*                  | White-capped<br>Albatross                       | Birds   |  | Yes       | Yes       |          |       |     |       |
| Tringa glareola                          | Wood Sandpiper                                  | Birds   |  | Yes       | Yes       |          | Yes   | Yes |       |
| Tringa stagnatilis                       | Marsh Sandpiper,<br>Little Greenshank           | Birds   |  | Yes       | Yes       |          | Yes   | Yes |       |
| Turnix<br>melanogaster                   | Black-breasted<br>Button-quail                  | Birds   | V  |           |           |          | Yes   |     |       |
| Xanthomyza<br>phrygia                    | Regent Honeyeater                               | Birds   |  | Yes       |           |          | Yes   | Yes |       |
| Xenus cinereus                           | Terek Sandpiper                                 | Birds   |  | Yes       | Yes       |          | Yes   | Yes |       |
| Chlamydogobius<br>squamigenus            | Edgbaston Goby                                  | Fish    | V  |           |           |          |       |     | Yes   |
| Epinephelus<br>daemelii                  | Black Rockcod,<br>Black Cod, Saddled<br>Rockcod | Fish    | V  |           |           |          | Yes   |     |       |
| Galaxiella pusilla                       | Eastern Dwarf<br>Galaxias, Dwarf<br>Galaxias    | Fish    | V  |           |           |          |       | Yes |       |
| Maccullochella<br>macquariensis          | Trout Cod                                       | Fish    | E  |           |           |          |       |     |       |
| Maccullochella<br>peelii                 | Murray Cod                                      | Fish    | V  |           |           |          | Yes   |     | Yes   |
| Macquaria<br>australasica                | Macquarie Perch                                 | Fish    | E  |           |           |          |       |     |       |
| Nannoperca<br>oxleyana                   | Oxleyan Pygmy<br>Perch                          | Fish    | E  |           |           |          | Yes   |     |       |

| Name   | Common name   | Species | EPBC A                              | ct listi  | ing typ | е        | Clarence Gippsland |       | Lake  |
|--|---|---------|-------------------------------------|-----------|---------|----------|--------------------|-------|-------|
|  |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin              | Basin | Basin |
| Neoceratodus<br>forsteri                                 | Australian Lungfish,<br>Queensland<br>Lungfish  | Fish    | V                                   |           |         |          | Yes                |       |       |
| Prototroctes<br>maraena                                  | Australian Grayling   | Fish    | V                                   |           |         |          |                    | Yes   |       |
| Heleioporus<br>australiacus                              | Giant Burrowing<br>Frog   | Frogs   | V                                   |           |         |          |                    | Yes   |       |
| Litoria aurea  | Green and Golden<br>Bell Frog   | Frogs   | V                                   |           |         |          | Yes                | Yes   |       |
| Litoria<br>booroolongensis                               | Booroolong Frog   | Frogs   | E                                   |           |         |          | Yes                |       |       |
| Litoria littlejohni                                      | Littlejohn's Tree<br>Frog, Heath Frog   | Frogs   | V                                   |           |         |          |                    |       |       |
| Litoria<br>olongburensis                                 | Wallum Sedge Frog   | Frogs   | V                                   |           |         |          | Yes                |       |       |
| Litoria raniformis                                       | Growling Grass<br>Frog, Southern Bell<br>Frog, Green and<br>Golden Frog, Warty<br>Swamp Frog  | Frogs   | V                                   |           |         |          |                    | Yes   |       |
| Mixophyes balbus   | Stuttering Frog,<br>Southern Barred<br>Frog (in Victoria)   | Frogs   | V                                   |           |         |          | Yes                |       |       |
| Mixophyes fleayi   | Fleay's Frog  | Frogs   | E                                   |           |         |          | Yes                |       |       |
| Mixophyes<br>iteratus                                    | Giant Barred Frog,<br>Southern Barred<br>Frog   | Frogs   | E                                   |           |         |          | Yes                |       |       |
| Paralucia<br>spinifera                                   | Bathurst Copper<br>Butterfly, Purple<br>Copper Butterfly,<br>Bathurst Copper,<br>Bathurst Copper<br>Wing, Bathurst-<br>Lithgow Copper,<br>Purple Copper | Insects | V                                   |           |         |          |                    |       |       |
| Phyllodes<br>imperialis<br>(southern subsp<br>ANIC 3333) | Pink Underwing<br>Moth  | Insects | E                                   |           |         |          | Yes                |       |       |
| Synemon plana  | Golden Sun Moth   | Insects | CE                                  |           |         |          |                    | Yes   |       |
| Balaenoptera   | Bryde's Whale   | Mammals |                                     | Yes       |         | Yes      | Yes                | Yes   |       |

| Name  | Common name  | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence Gippslan |     | Lake  |
|---|--|---------|-------------------------------------|-----------|--------|----------|-------------------|-----|-------|
|   |  | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin             |     | Basin |
| edeni   |  |         |                                     |           |        |          |                   |     |       |
| Balaenoptera<br>musculus  | Blue Whale   | Mammals | E                                   | Yes       |        | Yes      |                   | Yes |       |
| Caperea<br>marginata  | Pygmy Right Whale  | Mammals |                                     | Yes       |        | Yes      |                   | Yes |       |
| Chalinolobus<br>dwyeri  | Large-eared Pied<br>Bat, Large Pied Bat  | Mammals | V                                   |           |        |          | Yes               |     |       |
| Dasycercus<br>cristicauda   | Mulgara  | Mammals | V                                   |           |        |          |                   |     | Yes   |
| Dasycercus hillieri   | Ampurta  | Mammals | E                                   |           |        |          |                   |     | Yes   |
| Dasyuroides<br>byrnei   | Kowari   | Mammals | V                                   |           |        |          |                   |     | Yes   |
| Dasyurus<br>hallucatus  | Northern Quoll   | Mammals | E                                   |           |        |          | Yes               |     | Yes   |
| Dasyurus<br>maculatus<br>maculatus (SE<br>mainland<br>population) | Spot-tailed Quoll,<br>Spotted-tail Quoll,<br>Tiger Quoll<br>(southeastern<br>mainland<br>population) | Mammals | E                                   |           |        |          | Yes               | Yes |       |
| Dugong dugon  | Dugong   | Mammals |                                     | Yes       | Yes    |          | Yes               |     |       |
| Eubalaena<br>australis  | Southern Right<br>Whale  | Mammals | E                                   | Yes       |        | Yes      | Yes               | Yes |       |
| lsoodon obesulus<br>obesulus                                      | Southern Brown<br>Bandicoot (Eastern)  | Mammals | E                                   |           |        |          |                   | Yes |       |
| Lagenorhynchus<br>obscurus  | Dusky Dolphin  | Mammals |                                     | Yes       |        | Yes      | Yes               | Yes |       |
| Macrotis lagotis  | Greater Bilby  | Mammals | V                                   |           |        |          |                   |     | Yes   |
| Megaptera<br>novaeangliae   | Humpback Whale   | Mammals | V                                   | Yes       |        | Yes      | Yes               | Yes |       |
| Notomys fuscus  | Dusky Hopping-<br>mouse, Wilkiniti   | Mammals | V                                   |           |        |          |                   |     | Yes   |
| Notoryctes<br>typhlops  | Southern Marsupial<br>Mole, Yitjarritjarri,<br>Itjaritjari   | Mammals | E                                   |           |        |          |                   |     | Yes   |
| Nyctophilus<br>corbeni  | South-eastern<br>Long-eared Bat  | Mammals | V                                   |           |        |          | Yes               |     | Yes   |
| Onychogalea<br>fraenata*  | Bridled Nail-tail<br>Wallaby   | Mammals | E                                   |           |        |          |                   |     | Yes   |

| Name   | Common name  | Species | EPBC A                              | ct listi  | ng typ | e        | Clarence Gippsland |       | Lake  |
|--|--|---------|-------------------------------------|-----------|--------|----------|--------------------|-------|-------|
|  |  | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin              | Basin | Basin |
| Orcaella<br>brevirostris   | Irrawaddy Dolphin  | Mammals |                                     | Yes       |        | Yes      | Yes                |       |       |
| Orcinus orca   | Killer Whale, Orca   | Mammals |                                     | Yes       |        | Yes      | Yes                | Yes   |       |
| Petrogale<br>penicillata   | Brush-tailed Rock-<br>wallaby  | Mammals | V                                   |           |        |          | Yes                | Yes   | Yes   |
| Phascolarctos<br>cinereus<br>(combined<br>populations of<br>Qld, NSW and the<br>ACT) | Koala (combined<br>populations of<br>Queensland New<br>South Wales and<br>the Australian<br>Capital Territory) | Mammals | V                                   |           |        |          | Yes                |       | Yes   |
| Potorous<br>tridactylus<br>tridactylus   | Long-nosed<br>Potoroo (SE<br>mainland)   | Mammals | V                                   |           |        |          | Yes                | Yes   |       |
| Pseudomys<br>australis   | Plains Rat   | Mammals | V                                   |           |        |          |                    |       | Yes   |
| Pseudomys<br>fumeus*   | Konoom, Smoky<br>Mouse   | Mammals | E                                   |           |        |          |                    | Yes   |       |
| Pseudomys<br>novaehollandiae   | New Holland<br>Mouse   | Mammals | V                                   |           |        |          | Yes                | Yes   |       |
| Pseudomys oralis   | Hastings River<br>Mouse  | Mammals | E                                   |           |        |          | Yes                |       |       |
| Pseudomys<br>pilligaensis  | Pilliga Mouse  | Mammals | V                                   |           |        |          |                    |       |       |
| Pteropus<br>poliocephalus  | Grey-headed<br>Flying-fox  | Mammals | V                                   |           |        |          | Yes                | Yes   |       |
| Sminthopsis<br>douglasi  | Julia Creek Dunnart  | Mammals | E                                   |           |        |          |                    |       | Yes   |
| Sminthopsis<br>psammophila*  | Sandhill Dunnart   | Mammals | E                                   |           |        |          |                    |       | Yes   |
| Sousa chinensis  | Indo-Pacific<br>Humpback Dolphin   | Mammals |                                     | Yes       |        | Yes      | Yes                |       |       |
| Xeromys myoides  | Water Mouse,<br>False Water Rat  | Mammals | V                                   |           |        |          | Yes                |       |       |
| Zyzomys<br>pedunculatus*   | Central Rock-rat   | Mammals | E                                   |           |        |          |                    |       | Yes   |
| Cycas ophiolitica  |  | Other   | E                                   |           |        |          | Yes                |       |       |
| Lychnothamnus<br>barbatus*   | a green alga   | Other   | E                                   |           |        |          | Yes                |       |       |

| Name   | Common name                                       | Species | EPBC A                              | ct listi  | ing typ | е        | Clarence | Gippsland<br>Basin | Lake<br>Eyre<br>Basin |
|--|---|---------|-------------------------------------|-----------|---------|----------|----------|--------------------|-----------------------|
|  |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin    |                    |                       |
| Macrozamia<br>conferta*                      |   | Other   | V                                   |           |         |          |          |                    |                       |
| Macrozamia<br>machinii                       |   | Other   | V                                   |           |         |          |          |                    |                       |
| Megascolides<br>australis*                   | Giant Gippsland<br>Earthworm                      | Other   | V                                   |           |         |          |          | Yes                |                       |
| Thersites<br>mitchellae                      | Mitchell's<br>Rainforest Snail                    | Other   | CE                                  |           |         |          | Yes      |                    |                       |
| Acacia<br>ammophila                          |   | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia bynoeana                              | Bynoe's Wattle,<br>Tiny Wattle                    | Plants  | V                                   |           |         |          |          |                    |                       |
| Acacia crombiei                              | Pink Gidgee                                       | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia curranii*                             | Curly-bark Wattle                                 | Plants  | V                                   |           |         |          |          |                    |                       |
| Acacia<br>deuteroneura*                      |   | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia<br>flocktoniae*                       | Flockton Wattle                                   | Plants  | V                                   |           |         |          |          |                    |                       |
| Acacia gordonii                              |   | Plants  | E                                   |           |         |          |          |                    |                       |
| Acacia handonis*                             | Hando's Wattle,<br>Percy Grant Wattle             | Plants  | V                                   |           |         |          |          |                    |                       |
| Acacia latzii                                | Latz's Wattle                                     | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia lauta*                                |   | Plants  | V                                   |           |         |          |          |                    |                       |
| Acacia peuce*                                | Waddy, Waddi,<br>Waddy-wood,<br>Birdsville Wattle | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia pickardii                             | Birds Nest Wattle                                 | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia<br>pubescens*                         | Downy Wattle,<br>Hairy Stemmed<br>Wattle          | Plants  | V                                   |           |         |          |          |                    |                       |
| Acacia ramiflora                             |   | Plants  | V                                   |           |         |          |          |                    | Yes                   |
| Acacia ruppii*                               | Rupp's Wattle                                     | Plants  | E                                   |           |         |          | Yes      |                    |                       |
| Acacia terminalis<br>subsp. terminalis<br>MS | Sunshine Wattle                                   | Plants  | E                                   |           |         |          |          |                    |                       |
| Acacia wardellii*                            |   | Plants  | V                                   |           |         |          |          |                    |                       |

|   | Name                         | Common name  | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence | Gippsland | Lake  |
|---|------------------------------|--|---------|-------------------------------------|-----------|--------|----------|----------|-----------|-------|
|   |                              |  | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Basin     | Basin |
|   | Acronychia<br>littoralis*    | Scented<br>Acronychia  | Plants  | E                                   |           |        |          | Yes      |           |       |
|   | Acrophyllum<br>australe      |  | Plants  | V                                   |           |        |          |          |           |       |
|   | Allocasuarina<br>defungens   | Dwarf Heath<br>Casuarina   | Plants  | E                                   |           |        |          | Yes      |           |       |
|   | Allocasuarina<br>glareicola* |  | Plants  | E                                   |           |        |          |          |           |       |
|   | Allocasuarina<br>portuensis  | Nielsen Park She-<br>oak   | Plants  | E                                   |           |        |          |          |           |       |
|   | Amphibromus<br>fluitans      | River Swamp<br>Wallaby-grass,<br>Floating Swamp<br>Wallaby-grass | Plants  | V                                   |           |        |          |          | Yes       |       |
|   | Amyema<br>scandens*          |  | Plants  | E                                   |           |        |          | Yes      |           |       |
|   | Angophora<br>inopina         | Charmhaven Apple   | Plants  | V                                   |           |        |          |          |           |       |
|   | Angophora robur              | Sandstone Rough-<br>barked Apple                                 | Plants  | V                                   |           |        |          | Yes      |           |       |
|   | Arthraxon<br>hispidus        | Hairy-joint Grass  | Plants  | V                                   |           |        |          | Yes      |           | Yes   |
|   | Asterolasia<br>elegans       |  | Plants  | E                                   |           |        |          |          |           |       |
|   | Astrotricha<br>crassifolia   | Thick-leaf Star-hair   | Plants  | V                                   |           |        |          |          |           |       |
|   | Astrotricha roddii           |  | Plants  | E                                   |           |        |          |          |           |       |
|   | Austrobryonia<br>argillicola |  | Plants  | E                                   |           |        |          |          |           | Yes   |
|   | Baeckea kandos               | a shrub  | Plants  | Е                                   |           |        |          |          |           |       |
|   | Baloghia<br>marmorata        | Marbled Balogia,<br>Jointed Baloghia                             | Plants  | V                                   |           |        |          | Yes      |           |       |
|   | Baloskion<br>longipes        | Dense Cord-rush  | Plants  | V                                   |           |        |          |          |           |       |
|   | Bertya<br>ernestiana*        | a shrub  | Plants  | V                                   |           |        |          | Yes      |           |       |
| ļ | Bertya opponens              |  | Plants  | V                                   |           |        |          | Yes      |           |       |
|   | Bertya pinifolia             | a shrub  | Plants  | V                                   |           |        |          | Yes      |           |       |

| Name   | Common name                                       | Species | EPBC A                              | ct listi  | ing typ | e        | Clarence          | e Gippsland<br>Basin | Lake<br>Eyre<br>Basin |
|--|---|---------|-------------------------------------|-----------|---------|----------|-------------------|----------------------|-----------------------|
|  |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | -Moreton<br>Basin |                      |                       |
| Boronia deanei                                   | Deane's Boronia                                   | Plants  | V                                   |           |         |          |                   |                      |                       |
| Boronia umbellata                                | Orara Boronia                                     | Plants  | V                                   |           |         |          | Yes               |                      |                       |
| Bosistoa selwynii                                | Heart-leaved<br>Bosistoa                          | Plants  | V                                   |           |         |          | Yes               |                      |                       |
| Bosistoa selwynii                                | Heart-leaved<br>Bosistoa                          | Plants  | V                                   |           |         |          | Yes               |                      |                       |
| Bosistoa<br>transversa                           | Three-leaved<br>Bosistoa                          | Plants  | V                                   |           |         |          | Yes               |                      |                       |
| Bosistoa<br>transversa*                          | Three-leaved<br>Bosistoa                          | Plants  | V                                   |           |         |          | Yes               |                      |                       |
| Bossiaea<br>oligosperma                          |   | Plants  | V                                   |           |         |          |                   |                      |                       |
| Bothriochloa<br>biloba                           | Lobed Blue-grass                                  | Plants  | V                                   |           |         |          |                   |                      |                       |
| Bothriochloa<br>bunyensis*                       | Satin-top Grass                                   | Plants  | V                                   |           |         |          | Yes               |                      |                       |
| Budawangia<br>gnidioides                         | Budawangs Cliff-<br>heath                         | Plants  | V                                   |           |         |          |                   |                      |                       |
| Bulbophyllum<br>globuliforme*                    | Miniature Moss-<br>orchid, Hoop Pine<br>Orchid    | Plants  | V                                   |           |         |          | Yes               |                      | Yes                   |
| Cadellia<br>pentastylis                          | Ooline  | Plants  | V                                   |           |         |          | Yes               |                      | Yes                   |
| Cajanus<br>mareebensis                           |   | Plants  | E                                   |           |         |          |                   |                      | Yes                   |
| Caladenia<br>fragrantissima<br>subsp. orientalis | Cream Spider-<br>orchid, Eastern<br>Spider Orchid | Plants  | E                                   |           |         |          |                   | Yes                  |                       |
| Caladenia<br>robinsonii*                         | Frankston Spider-<br>orchid                       | Plants  | E                                   |           |         |          |                   | Yes                  |                       |
| Caladenia<br>tessellata*                         | Thick-lipped<br>Spider-orchid,<br>Daddy Long-legs | Plants  | V                                   |           |         |          |                   | Yes                  |                       |
| Caladenia<br>thysanochila                        | Fringed Spider-<br>orchid                         | Plants  | E                                   |           |         |          |                   | Yes                  |                       |
| Callistemon<br>pungens                           |   | Plants  | V                                   |           |         |          |                   |                      |                       |
| Calytrix<br>gurulmundensis                       |   | Plants  | V                                   |           |         |          |                   |                      |                       |

| Name  | Common name   | Species | s EPBC Act listing type             |           |        | Clarence | Gippsland | Lake |       |
|---|---|---------|-------------------------------------|-----------|--------|----------|-----------|------|-------|
|   |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin     |      | Basin |
| Clematis<br>fawcettii*                        | Stream Clematis   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Commersonia<br>argentea                       | a shrub   | Plants  | V                                   |           |        |          |           |      | Yes   |
| Commersonia<br>rosea                          | Sandy Hollow<br>Commersonia   | Plants  | E                                   |           |        |          |           |      |       |
| Coopernookia<br>scabridiuscula*               |   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Corchorus<br>cunninghamii*                    | Native Jute   | Plants  | E                                   |           |        |          | Yes       |      |       |
| Corokia whiteana                              |   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Corybas<br>montanus                           | Small Helmet-<br>orchid   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Corynocarpus<br>rupestris subsp.<br>Rupestris | Glenugie Karaka   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Cryptocarya<br>foetida                        | Stinking<br>Cryptocarya,<br>Stinking Laurel   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Cryptostylis<br>hunteriana*                   | Leafless Tongue-<br>orchid  | Plants  | V                                   |           |        |          | Yes       | Yes  |       |
| Cupaniopsis<br>shirleyana                     | Wedge-leaf<br>Tuckeroo  | Plants  | V                                   |           |        |          | Yes       |      |       |
| Cupaniopsis<br>tomentella                     | Boonah Tuckeroo   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Cynanchum<br>elegans                          | White-flowered<br>Wax Plant   | Plants  | E                                   |           |        |          | Yes       |      |       |
| Cyperus<br>semifertilis                       |   | Plants  | V                                   |           |        |          | Yes       |      |       |
| Daphnandra<br>johnsonii                       | Illawarra<br>Socketwood   | Plants  | E                                   |           |        |          |           |      |       |
| Darwinia biflora                              |   | Plants  | V                                   |           |        |          |           |      |       |
| Davidsonia<br>jerseyana                       | Davidson's Plum   | Plants  | E                                   |           |        |          | Yes       |      |       |
| Davidsonia<br>johnsonii                       | Smooth<br>Davidsonia,<br>Smooth Davidson's<br>Plum, Small-leaved<br>Davidson's Plum | Plants  | E                                   |           |        |          | Yes       |      |       |

| Name                          | Common name                                     | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence | Gippsland | Lake          |
|-------------------------------|---|---------|-------------------------------------|-----------|--------|----------|----------|-----------|---------------|
|                               | Small-leaved                                    | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Basin     | Eyre<br>Basin |
| Denhamia<br>parvifolia*       | Small-leaved<br>Denhamia                        | Plants  | V                                   |           |        |          | Yes      |           |               |
| Desmodium<br>acanthocladum*   | Thorny Pea                                      | Plants  | V                                   |           |        |          | Yes      |           |               |
| Deyeuxia<br>appressa          |   | Plants  | E                                   |           |        |          |          |           |               |
| Dianella amoena               | Matted Flax-lily                                | Plants  | E                                   |           |        |          |          | Yes       |               |
| Dichanthium<br>queenslandicum | King Blue-grass                                 | Plants  | V                                   |           |        |          | Yes      |           | Yes           |
| Dichanthium<br>setosum        | bluegrass                                       | Plants  | V                                   |           |        |          |          |           |               |
| Digitaria porrecta            | Finger Panic Grass                              | Plants  | E                                   |           |        |          | Yes      |           | Yes           |
| Diospyros<br>mabacea*         | Red-fruited Ebony,<br>Silky Persimmon,<br>Ebony | Plants  | E                                   |           |        |          | Yes      |           |               |
| Diploglottis<br>campbellii    | Small-leaved<br>Tamarind                        | Plants  | E                                   |           |        |          | Yes      |           |               |
| Diuris aequalis               | Buttercup<br>Doubletail                         | Plants  | V                                   |           |        |          |          |           |               |
| Diuris praecox*               | Newcastle<br>Doubletail                         | Plants  | V                                   |           |        |          |          |           |               |
| Eidothea<br>hardeniana        | Nightcap Oak                                    | Plants  | CE                                  |           |        |          | Yes      |           |               |
| Elaeocarpus<br>sedentarius*   | Minyon Quandong                                 | Plants  | E                                   |           |        |          | Yes      |           |               |
| Elaeocarpus<br>williamsianus* | Hairy Quandong                                  | Plants  | E                                   |           |        |          | Yes      |           |               |
| Eleocharis<br>papillosa*      | Dwarf Desert<br>Spike-rush                      | Plants  | V                                   |           |        |          |          |           | Yes           |
| Endiandra floydii*            | Floyd's Walnut                                  | Plants  | E                                   |           |        |          | Yes      |           |               |
| Endiandra<br>hayesii*         | Rusty Rose Walnut,<br>Velvet Laurel             | Plants  | V                                   |           |        |          | Yes      |           |               |
| Epacris hamiltonii            |   | Plants  | E                                   |           |        |          |          |           |               |
| Epacris sparsa                |   | Plants  | V                                   |           |        |          |          |           |               |
| Eremophila<br>tetraptera*     |   | Plants  | V                                   |           |        |          |          |           | Yes           |
| Eriocaulon                    | Salt Pipewort,                                  | Plants  | E                                   |           |        |          |          |           | Yes           |

| Name  | Common name   | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence | e Gippsland<br>n Basin | Lake  |
|---|---|---------|-------------------------------------|-----------|--------|----------|----------|------------------------|-------|
|   | Button Grass  | Class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    |                        | Basin |
| carsonii  | Button Grass  |         |                                     |           |        |          |          |                        |       |
| Eryngium<br>fontanum*                           | Blue Devil  | Plants  | E                                   |           |        |          |          |                        | Yes   |
| Eucalyptus<br>alligatrix subsp.<br>miscella     | a stringybark   | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>aquatica                          | Mountain Swamp<br>Gum, Broad-leaved<br>Sallee, Broad-<br>leaved Sally                             | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>argophloia*                       | Queensland White<br>Gum, Queensland<br>Western White<br>Gum, Lapunyah,<br>Scrub Gum, White<br>Gum | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>benthamii*                        | Camden White<br>Gum, Nepean River<br>Gum  | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>camfieldii                        | Camfield's<br>Stringybark   | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>copulans*                         |   | Plants  | E                                   |           |        |          |          |                        |       |
| Eucalyptus<br>glaucina                          | Slaty Red Gum   | Plants  | V                                   |           |        |          | Yes      |                        |       |
| Eucalyptus infera                               |   | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>langleyi*                         | Albatross Mallee  | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>macrorhyncha<br>subsp. cannonii*  | Cannon's<br>Stringybark   | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>pachycalyx<br>subsp. banyabba     | Banyabba Shiny-<br>barked Gum   | Plants  | E                                   |           |        |          | Yes      |                        |       |
| Eucalyptus<br>parramattensis<br>subsp. decadens | Earp's Gum, Earp's<br>Dirty Gum   | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus<br>pulverulenta                      | Silver-leaved<br>Mountain Gum,<br>Silver-leaved Gum   | Plants  | V                                   |           |        |          |          |                        |       |
| Eucalyptus pumila                               | Pokolbin Mallee   | Plants  | V                                   |           |        |          |          |                        |       |

| Name   | Common name                                     | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence | Gippsland<br>Basin | Lake  |
|--|---|---------|-------------------------------------|-----------|--------|----------|----------|--------------------|-------|
|  |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    |                    | Basin |
| <i>Eucalyptus sp.</i><br>Howes Swamp<br>Creek (M.Doherty<br>26)* |   | Plants  | E                                   |           |        |          |          |                    |       |
| Eucalyptus<br>strzeleckii  | Strzelecki Gum                                  | Plants  | V                                   |           |        |          |          | Yes                |       |
| Eucalyptus<br>tetrapleura*                                       | Square-fruited<br>Ironbark                      | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Eucalyptus virens  |   | Plants  | V                                   |           |        |          |          |                    | Yes   |
| Euphrasia arguta   |   | Plants  | CE                                  |           |        |          |          |                    |       |
| Euphrasia bella  | Lamington<br>Eyebright, Mt.<br>Merino Eyebright | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Euphrasia<br>bowdeniae*  |   | Plants  | V                                   |           |        |          |          |                    |       |
| Euphrasia collina<br>subsp. muelleri                             | Purple Eyebright,<br>Mueller's Eyebright        | Plants  | E                                   |           |        |          |          | Yes                |       |
| Floydia praealta*  | Ball Nut, Possum<br>Nut, Big Nut,<br>Beefwood   | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Fontainea<br>australis*  | Southern Fontainea                              | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Fontainea<br>venosa*   |   | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Genoplesium<br>plumosum*   | Plumed Midge-<br>orchid                         | Plants  | E                                   |           |        |          |          |                    |       |
| Genoplesium<br>vernale*  | East Lynne Midge-<br>orchid                     | Plants  | V                                   |           |        |          |          |                    |       |
| Gentiana<br>wingecarribiensis*                                   | Wingecarribee<br>Gentian                        | Plants  | E                                   |           |        |          |          |                    |       |
| Glycine<br>latrobeana*   | Clover Glycine,<br>Purple Clover                | Plants  | V                                   |           |        |          |          | Yes                |       |
| Gossia<br>fragrantissima*  | Sweet Myrtle,<br>Small-leaved Myrtle            | Plants  | E                                   |           |        |          | Yes      |                    |       |
| Gossia<br>gonoclada*   | Angle-stemmed<br>Myrtle                         | Plants  | E                                   |           |        |          | Yes      |                    |       |
| Grevillea<br>banyabba  |   | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Grevillea  | Beadle's Grevillea                              | Plants  | E                                   |           |        |          | Yes      |                    |       |

| Name   | Name Common name                      |        |                                     | ct listi  | ng typ | е        | Clarence | Gippsland<br>Basin | Lake  |
|--|---------------------------------------|--------|-------------------------------------|-----------|--------|----------|----------|--------------------|-------|
|  |                                       | Class  | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    |                    | Basin |
| beadleana  |                                       |        |                                     |           |        |          |          |                    |       |
| Grevillea caleyi   | Caley's Grevillea                     | Plants | E                                   |           |        |          |          |                    |       |
| Grevillea<br>evansiana   |                                       | Plants | V                                   |           |        |          |          |                    |       |
| Grevillea masonii  |                                       | Plants | E                                   |           |        |          | Yes      |                    |       |
| Grevillea<br>molyneuxii*   |                                       | Plants | E                                   |           |        |          |          |                    |       |
| Grevillea<br>obtusiflora   | Grey Grevillea                        | Plants | E                                   |           |        |          |          |                    |       |
| Grevillea<br>parviflora subsp.<br>parviflora*  | Small-flower<br>Grevillea             | Plants | V                                   |           |        |          |          |                    |       |
| Grevillea<br>quadricauda   |                                       | Plants | V                                   |           |        |          | Yes      |                    |       |
| Grevillea rivularis  | Carrington Falls<br>Grevillea         | Plants | E                                   |           |        |          |          |                    |       |
| Grevillea shiressii  |                                       | Plants | V                                   |           |        |          |          |                    |       |
| Hakea dohertyi*  | a shrub                               | Plants | E                                   |           |        |          |          |                    |       |
| Hakea<br>maconochieana   |                                       | Plants | V                                   |           |        |          |          |                    | Yes   |
| Hakea pulvinifera  |                                       | Plants | E                                   |           |        |          |          |                    |       |
| <i>Haloragis exalata</i><br>subsp <i>. exalata*</i>                                    | Wingless Raspwort,<br>Square Raspwort | Plants | V                                   |           |        |          |          |                    |       |
| Haloragis exalata<br>subsp. velutina*  | Tall Velvet Sea-<br>berry             | Plants | V                                   |           |        |          | Yes      |                    |       |
| Haloragodendron<br>lucasii   | Hal                                   | Plants | E                                   |           |        |          |          |                    |       |
| Hibbertia crispula*  | Ooldea Guinea-<br>flower              | Plants | V                                   |           |        |          |          |                    | Yes   |
| Hibbertia<br>marginata*  |                                       | Plants | V                                   |           |        |          | Yes      |                    |       |
| <i>Hibbertia sp.<br/>Bankstown</i><br>(R.T.Miller and C.<br>P.Gibson s.n.<br>18/10/06) |                                       | Plants | CE                                  |           |        |          |          |                    |       |
| Hicksbeachia<br>pinnatifolia*  | Monkey Nut,<br>Bopple Nut, Red        | Plants | V                                   |           |        |          | Yes      |                    |       |

| Name                            | Common name  | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence | Gippsland<br>Basin | Lake  |
|---------------------------------|--|---------|-------------------------------------|-----------|--------|----------|----------|--------------------|-------|
|                                 |  | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    |                    | Basin |
|                                 | Bopple, Red<br>Bopple Nut, Red<br>Nut, Beef Nut, Red<br>Apple Nut, Red<br>Boppel Nut, Ivory<br>Silky Oak |         |                                     |           |        |          |          |                    |       |
| Homopholis<br>belsonii*         | Belson's Panic   | Plants  | V                                   |           |        |          |          |                    |       |
| Homoranthus<br>darwinioides*    |  | Plants  | V                                   |           |        |          |          |                    |       |
| Homoranthus<br>decumbens*       |  | Plants  | V                                   |           |        |          |          |                    |       |
| Hydrocharis<br>dubia*           | Frogbit  | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Indigofera efoliata             |  | Plants  | E                                   |           |        |          |          |                    |       |
| Irenepharsus<br>trypherus*      | Delicate Cress,<br>Illawarra Irene   | Plants  | E                                   |           |        |          |          |                    |       |
| lsoglossa<br>eranthemoides      | Isoglossa  | Plants  | E                                   |           |        |          | Yes      |                    |       |
| lsopogon fletcheri              | Fletcher's<br>Drumsticks   | Plants  | V                                   |           |        |          |          |                    |       |
| Kennedia retrorsa               |  | Plants  | V                                   |           |        |          |          |                    |       |
| Kunzea<br>cambagei*             |  | Plants  | V                                   |           |        |          |          |                    |       |
| Kunzea rupestris                |  | Plants  | V                                   |           |        |          |          |                    |       |
| Lasiopetalum<br>joyceae         |  | Plants  | V                                   |           |        |          |          |                    |       |
| Lasiopetalum<br>longistamineum* |  | Plants  | V                                   |           |        |          |          |                    |       |
| Lawrencia<br>buchananensis*     |  | Plants  | V                                   |           |        |          |          |                    | Yes   |
| Leionema<br>Iachnaeoides        |  | Plants  | E                                   |           |        |          |          |                    |       |
| Leionema<br>obtusifolium        |  | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Leionema<br>sympetalum          | Rylstone Bell  | Plants  | V                                   |           |        |          |          |                    |       |
| Lepidium<br>aschersonii         | Spiny Pepper-cress   | Plants  | V                                   |           |        |          |          |                    |       |

| Name Common name  |   | Species | EPBC A                              | ct listi  | ing typ | e        | Clarence | Gippsland | Lake  |
|---|---|---------|-------------------------------------|-----------|---------|----------|----------|-----------|-------|
|   |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin    | Dasin     | Basin |
| Lepidium<br>hyssopifolium                                       | Basalt Pepper-<br>cress   | Plants  | E                                   |           |         |          |          |           |       |
| Lepidium<br>peregrinum*   | Wandering Pepper-<br>cress  | Plants  | E                                   |           |         |          | Yes      |           |       |
| Leptospermum<br>deanei*   | Deane's Tea-tree  | Plants  | V                                   |           |         |          |          |           |       |
| Leptospermum<br>thompsonii*                                     | Monga Tea-tree  | Plants  | V                                   |           |         |          |          |           |       |
| Leucochrysum<br>albicans var.<br>tricolor*                      | Hoary Sunray,<br>Grassland Paper-<br>daisy  | Plants  | E                                   |           |         |          |          |           |       |
| Leucopogon<br>exolasius*  | Woronora Beard-<br>heath  | Plants  | V                                   |           |         |          |          |           |       |
| <i>Leucopogon sp.</i><br>Coolmunda<br>(D.Halford Q<br>1635)*    |   | Plants  | E                                   |           |         |          |          |           |       |
| Macadamia<br>integrifolia*                                      | Macadamia Nut,<br>Queensland Nut,<br>Smooth-shelled<br>Macadamia, Bush<br>Nut, Nut Oak                        | Plants  | V                                   |           |         |          | Yes      |           |       |
| Macadamia<br>tetraphylla  | Rough-shelled<br>Bush Nut,<br>Macadamia Nut,<br>Rough-shelled<br>Macadamia,<br>Rough-leaved<br>Queensland Nut | Plants  | V                                   |           |         |          | Yes      |           |       |
| Marsdenia<br>coronata*  | Slender Milkvine  | Plants  | V                                   |           |         |          | Yes      |           |       |
| Marsdenia<br>longiloba*   | Clear Milkvine  | Plants  | V                                   |           |         |          | Yes      |           |       |
| Melaleuca<br>biconvexa*   | Biconvex<br>Paperbark   | Plants  | V                                   |           |         |          |          |           |       |
| Melaleuca deanei  | Deane's Melaleuca   | Plants  | V                                   |           |         |          |          |           |       |
| Melaleuca<br>kunzeoides*  |   | Plants  | V                                   |           |         |          |          |           | Yes   |
| Melichrus sp.<br>Gibberagee<br>(A.S.Benwell and<br>J.B.Williams | Narrow-leaf<br>Melichrus  | Plants  | E                                   |           |         |          | Yes      |           |       |

| Name  | Common name   | Species<br>class | EPBC A                              | ct listi  | ng typ | е        | Clarence | e Gippsland<br>Basin | Lake<br>Eyre |
|---|---|------------------|-------------------------------------|-----------|--------|----------|----------|----------------------|--------------|
|   |   |                  | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    |                      | Basin        |
| 97239)  |   |                  |                                     |           |        |          |          |                      |              |
| <i>Melichrus sp.</i><br>Newfoundland<br>State Forest<br>(P.Gilmour 7852)* | Hairy Melichrus                                     | Plants           | E                                   |           |        |          | Yes      |                      |              |
| Microcarpaea<br>agonis*   |   | Plants           | E                                   |           |        |          |          |                      |              |
| Micromyrtus<br>blakelyi   |   | Plants           | V                                   |           |        |          |          |                      |              |
| Micromyrtus<br>minutiflora  |   | Plants           | V                                   |           |        |          |          |                      |              |
| Microtis angusii  | Angus's Onion<br>Orchid                             | Plants           | E                                   |           |        |          |          |                      |              |
| Myrsine<br>richmondensis  | Purple-leaf<br>Muttonwood,<br>Lismore<br>Muttonwood | Plants           | E                                   |           |        |          | Yes      |                      |              |
| Notelaea<br>ipsviciensis*   | Cooneana Olive                                      | Plants           | CE                                  |           |        |          | Yes      |                      |              |
| Notelaea lloydii*   | Lloyd's Olive                                       | Plants           | V                                   |           |        |          | Yes      |                      |              |
| Ochrosia moorei*  | Southern Ochrosia                                   | Plants           | E                                   |           |        |          | Yes      |                      |              |
| Olearia cordata*  |   | Plants           | V                                   |           |        |          |          |                      |              |
| Olearia<br>flocktoniae*   | Dorrigo Daisy-bush                                  | Plants           | E                                   |           |        |          | Yes      |                      |              |
| Owenia cepiodora  | Onionwood, Bog<br>Onion, Onion<br>Cedar             | Plants           | V                                   |           |        |          | Yes      |                      |              |
| Ozothamnus<br>tesselatus*   |   | Plants           | V                                   |           |        |          |          |                      |              |
| Ozothamnus<br>vagans*   |   | Plants           | V                                   |           |        |          | Yes      |                      |              |
| Parsonsia<br>dorrigoensis*  | Milky Silkpod                                       | Plants           | E                                   |           |        |          | Yes      |                      |              |
| Paspalidium<br>grandispiculatum   | a grass   | Plants           | V                                   |           |        |          | Yes      |                      |              |
| Pelargonium sp.<br>Striatellum<br>(G.W.Carr 10345)                        | Omeo Stork's-bill                                   | Plants           | E                                   |           |        |          |          |                      |              |
| Persicaria elatior*   | Knotweed  | Plants           | V                                   |           |        |          | Yes      |                      |              |

| Name  | Common name                                       | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence | Gippsland<br>Basin | Lake  |
|---|---|---------|-------------------------------------|-----------|--------|----------|----------|--------------------|-------|
|   |   | Class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    |                    | Basin |
| Persoonia<br>acerosa                        | Needle Geebung                                    | Plants  | V                                   |           |        |          |          |                    |       |
| Persoonia<br>bargoensis*                    | Bargo Geebung                                     | Plants  | V                                   |           |        |          |          |                    |       |
| Persoonia<br>glaucescens*                   | Mittagong Geebung                                 | Plants  | V                                   |           |        |          |          |                    |       |
| Persoonia hirsuta                           |   | Plants  | Е                                   |           |        |          |          |                    |       |
| Persoonia<br>marginata*<br>Persoonia mollis |   | Plants  | V                                   |           |        |          |          |                    |       |
| Persoonia mollis<br>subsp. maxima*          |   | Plants  | Е                                   |           |        |          |          |                    |       |
| Persoonia nutans                            | Nodding Geebung                                   | Plants  | Е                                   |           |        |          |          |                    |       |
| Persoonia<br>pauciflora                     | North Rothbury<br>Persoonia                       | Plants  | CE                                  |           |        |          |          |                    |       |
| Phaius australis                            | Lesser Swamp-<br>orchid                           | Plants  | Е                                   |           |        |          | Yes      |                    |       |
| Phebalium<br>distans*                       | Mt Berryman<br>Phebalium                          | Plants  | CE                                  |           |        |          | Yes      |                    |       |
| Pherosphaera<br>fitzgeraldii                | Dwarf Mountain<br>Pine                            | Plants  | E                                   |           |        |          |          |                    |       |
| Philotheca<br>ericifolia*                   |   | Plants  | V                                   |           |        |          |          |                    |       |
| Philotheca<br>sporadica                     | Kogan Waxflower                                   | Plants  | V                                   |           |        |          |          |                    |       |
| Phyllota<br>humifusa*                       | Dwarf Phyllota                                    | Plants  | V                                   |           |        |          |          |                    |       |
| Picris evae                                 | Hawkweed  | Plants  | V                                   |           |        |          | Yes      |                    |       |
| Pimelea curviflora<br>var. curviflora       |   | Plants  | V                                   |           |        |          |          |                    |       |
| Pimelea spicata*                            | Spiked Rice-flower                                | Plants  | Е                                   |           |        |          |          |                    |       |
| Planchonella<br>eerwah*                     | Shiny-leaved<br>Condoo, Black<br>Plum, Wild Apple | Plants  | E                                   |           |        |          | Yes      |                    |       |
| Plectranthus<br>habrophyllus                |   | Plants  | E                                   |           |        |          | Yes      |                    |       |
| Plectranthus<br>nitidus*                    | Nightcap<br>Plectranthus                          | Plants  | E                                   |           |        |          | Yes      |                    |       |

| Name   | Common name   | Species<br>class | EPBC Act listing type               |           |        |          | Clarence | Gippsland | Lake  |
|--|---|------------------|-------------------------------------|-----------|--------|----------|----------|-----------|-------|
|  |   |                  | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Dasin     | Basin |
| Pomaderris<br>brunnea  | Rufous Pomaderris   | Plants           | V                                   |           |        |          |          |           |       |
| Pomaderris<br>cotoneaster*                                   | Cotoneaster<br>Pomaderris   | Plants           | E                                   |           |        |          |          |           |       |
| Pomaderris<br>reperta*                                       | Denman<br>Pomaderris  | Plants           | CE                                  |           |        |          |          |           |       |
| Pomaderris<br>sericea*                                       | Bent Pomaderris   | Plants           | V                                   |           |        |          |          |           |       |
| Prasophyllum<br>affine*                                      | Jervis Bay Leek<br>Orchid, Culburra<br>Leek-orchid,<br>Kinghorn Point<br>Leek-orchid                                | Plants           | E                                   |           |        |          |          |           |       |
| Prasophyllum<br>correctum*                                   | Gaping Leek-orchid  | Plants           | E                                   |           |        |          |          | Yes       |       |
| Prasophyllum<br>frenchii                                     | Maroon Leek-<br>orchid, Slaty Leek-<br>orchid, Stout Leek-<br>orchid, French's<br>Leek-orchid,<br>Swamp Leek-orchid | Plants           | E                                   |           |        |          |          | Yes       |       |
| Prasophyllum<br>fuscum*                                      | Tawny Leek-orchid,<br>Slaty Leek-orchid   | Plants           | V                                   |           |        |          |          |           |       |
| Prasophyllum<br>fuscum*                                      | Tawny Leek-orchid,<br>Slaty Leek-orchid   | Plants           | V                                   |           |        |          |          |           |       |
| Prasophyllum<br>petilum*                                     | Tarengo Leek<br>Orchid  | Plants           | E                                   |           |        |          |          |           |       |
| <i>Prasophyllum sp.</i><br>Wybong<br>(C.Phelps ORG<br>5269)* | a leek-orchid   | Plants           | CE                                  |           |        |          |          |           |       |
| Prasophyllum<br>spicatum*                                    | Dense Leek-orchid   | Plants           | V                                   |           |        |          |          | Yes       |       |
| Prasophyllum<br>uroglossum*                                  | Wingecarribee<br>Leek-orchid, Dark<br>Leek-orchid   | Plants           | E                                   |           |        |          |          |           |       |
| Prasophyllum<br>uroglossum*                                  | Wingecarribee<br>Leek-orchid, Dark<br>Leek-orchid   | Plants           | E                                   |           |        |          |          |           |       |
| Prostanthera<br>askania                                      | Tranquility<br>Mintbush   | Plants           | E                                   |           |        |          |          |           |       |

| Name   | Common name                                | Species<br>class | EPBC Act listing type               |           |        |          | Clarence | Gippsland | Lake  |
|--|--|------------------|-------------------------------------|-----------|--------|----------|----------|-----------|-------|
|  |  |                  | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Basin     | Basin |
| Prostanthera<br>cineolifera*                                   |  | Plants           | V                                   |           |        |          |          |           |       |
| Prostanthera<br>cryptandroides*                                | Wollemi Mintbush                           | Plants           | V                                   |           |        |          |          |           |       |
| Prostanthera<br>densa  | Villous Mintbush                           | Plants           | V                                   |           |        |          |          |           |       |
| Prostanthera<br>discolor                                       |  | Plants           | V                                   |           |        |          |          |           |       |
| Prostanthera<br>galbraithiae                                   | Wellington<br>Mintbush                     | Plants           | V                                   |           |        |          |          | Yes       |       |
| Prostanthera<br>junonis*                                       | Somersby Mintbush                          | Plants           | E                                   |           |        |          |          |           |       |
| Prostanthera<br>marifolia*                                     | Seaforth Mintbush                          | Plants           | CE                                  |           |        |          |          |           |       |
| Prostanthera sp.<br>Bundjalong Nat.<br>Pk. (B.J.Conn<br>3471)* |  | Plants           | V                                   |           |        |          | Yes      |           |       |
| Prostanthera sp.<br>Dunmore<br>(D.M.Gordon 8A)*                |  | Plants           | V                                   |           |        |          |          |           |       |
| Prostanthera sp.<br>Mt Tinbeerwah<br>(C.Sandercoe<br>C1256)*   |  | Plants           | V                                   |           |        |          | Yes      |           |       |
| Prostanthera<br>staurophylla*                                  | a mint-bush                                | Plants           | V                                   |           |        |          | Yes      |           |       |
| Prostanthera<br>stricta  | Mount Vincent<br>Mintbush                  | Plants           | V                                   |           |        |          |          |           |       |
| Pterostylis<br>bicornis*                                       |  | Plants           | V                                   |           |        |          | Yes      |           |       |
| Pterostylis<br>chlorogramma*                                   | Green-striped<br>Greenhood                 | Plants           | V                                   |           |        |          |          | Yes       |       |
| Pterostylis<br>cobarensis*                                     | Cobar Greenhood<br>Orchid                  | Plants           | V                                   |           |        |          | Yes      |           |       |
| Pterostylis<br>cucullata*                                      | Leafy Greenhood                            | Plants           | V                                   |           |        |          |          | Yes       |       |
| Pterostylis<br>gibbosa   | Illawarra<br>Greenhood, Rufa<br>Greenhood, | Plants           | E                                   |           |        |          |          |           |       |
| Name   | Common name   | Species | EPBC Act listing type               |           |        |          | Clarence | Gippsland<br>Basin | Lake<br>Evre |
|--|---|---------|-------------------------------------|-----------|--------|----------|----------|--------------------|--------------|
|  |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Basin              | Basin        |
|  | Pouched<br>Greenhood  |         |                                     |           |        |          |          |                    |              |
| Pterostylis<br>pulchella   | Pretty Greenhood  | Plants  | V                                   |           |        |          |          |                    |              |
| Pterostylis<br>saxicola  | Sydney Plains<br>Greenhood  | Plants  | Е                                   |           |        |          |          |                    |              |
| <i>Pterostylis sp.</i><br>Botany Bay<br>(A.Bishop J221/1-<br>13)*                        | Botany Bay<br>Bearded<br>Greenhood, Botany<br>Bay Bearded<br>Orchid | Plants  | E                                   |           |        |          |          |                    |              |
| <i>Pterostylis sp.</i><br>Flat Rock Creek<br>(D.L.Jones<br>15873 and<br>K.J.Fitzgerald)* | Spring Tiny<br>Greenhood  | Plants  | CE                                  |           |        |          |          |                    |              |
| Pultenaea aristata   |   | Plants  | V                                   |           |        |          |          |                    |              |
| Pultenaea<br>baeuerlenii   | Budawangs Bush-<br>pea  | Plants  | V                                   |           |        |          |          |                    |              |
| Pultenaea elusa  | Elusive Bush-pea  | Plants  | E                                   |           |        |          |          |                    |              |
| Pultenaea glabra   | Smooth Bush-pea,<br>Swamp Bush-pea                                  | Plants  | V                                   |           |        |          |          |                    |              |
| Pultenaea<br>parviflora*   |   | Plants  | V                                   |           |        |          |          |                    |              |
| Pultenaea sp.<br>Genowlan Point<br>(NSW 417813)<br>NSW Herbarium                         | Genowlan Point<br>Pultenaea,<br>Genowlan<br>Pultenaea               | Plants  | CE                                  |           |        |          |          |                    |              |
| Randia moorei  | Spiny Gardenia  | Plants  | E                                   |           |        |          | Yes      |                    |              |
| Rhaphidospora<br>bonneyana   |   | Plants  | V                                   |           |        |          |          |                    | Yes          |
| Rhaponticum<br>australe  | Austral Cornflower,<br>Native Thistle                               | Plants  | V                                   |           |        |          | Yes      |                    |              |
| Rhizanthella<br>slateri  | Eastern<br>Underground<br>Orchid                                    | Plants  | E                                   |           |        |          |          |                    |              |
| Rulingia<br>procumbens   |   | Plants  | V                                   |           |        |          |          |                    |              |
| Rulingia prostrata   | Dwarf Kerrawang   | Plants  | E                                   |           |        |          |          | Yes                |              |
| Rutidosis  | Heath Wrinklewort   | Plants  | V                                   |           |        |          | Yes      |                    |              |

| Name  | Common name   | Species | EPBC A                              | ct listi  | ing typ | е        | Clarence Gippsland |       | Lake          |
|---|---|---------|-------------------------------------|-----------|---------|----------|--------------------|-------|---------------|
|   |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin              | Basin | Eyre<br>Basin |
| heterogama  |   |         |                                     |           |         |          |                    |       |               |
| <i>Samadera sp.</i><br>Moonee Creek<br>(J.King s.n. 1949) |   | Plants  | E                                   |           |         |          | Yes                |       |               |
| Sarcochilus<br>fitzgeraldii                               | Ravine Orchid   | Plants  | V                                   |           |         |          | Yes                |       |               |
| Sarcochilus<br>hartmannii                                 | Waxy Sarcochilus,<br>Blue Knob Orchid   | Plants  | V                                   |           |         |          | Yes                |       |               |
| Sarcochilus<br>weinthalii                                 | Blotched<br>Sarcochilus,<br>Weinthals Sarcanth  | Plants  | V                                   |           |         |          | Yes                |       |               |
| Sclerolaena<br>walkeri*                                   |   | Plants  | V                                   |           |         |          |                    |       | Yes           |
| Sophora fraseri   |   | Plants  | V                                   |           |         |          | Yes                |       |               |
| Streblus<br>pendulinus                                    | Siah's Backbone,<br>Sia's Backbone,<br>Isaac Wood   | Plants  | E                                   |           |         |          | Yes                |       |               |
| Swainsona<br>murrayana                                    | Slender Darling-<br>pea, Slender<br>Swainson, Murray<br>Swainson-pea                      | Plants  | V                                   |           |         |          |                    |       |               |
| Swainsona<br>plagiotropis*                                | Red Darling-pea,<br>Red Swainson-pea  | Plants  | V                                   |           |         |          |                    |       |               |
| Swainsona recta   | Small Purple-pea,<br>Mountain<br>Swainson-pea   | Plants  | E                                   |           |         |          |                    |       |               |
| Symplocos<br>baeuerlenii                                  | Small-leaved<br>Hazelwood,<br>Shrubby<br>Hazelwood  | Plants  | V                                   |           |         |          | Yes                |       |               |
| Syzygium<br>hodgkinsoniae                                 | Smooth-bark Rose<br>Apple, Red Lilly<br>Pilly   | Plants  | V                                   |           |         |          | Yes                |       |               |
| Syzygium moorei*  | Rose Apple,<br>Coolamon, Robby,<br>Durobby,<br>Watermelon Tree,<br>Coolamon Rose<br>Apple | Plants  | V                                   |           |         |          | Yes                |       |               |
| Syzygium<br>paniculatum                                   | Magenta Lilly Pilly,<br>Magenta Cherry,<br>Pocket-less Brush                              | Plants  | V                                   |           |         |          |                    |       |               |

| Name  | Common name   | Species | EPBC A                              | ct listi  | ng typ | e        | Clarence | Gippsland<br>Basin | Lake<br>Evre |
|---|---|---------|-------------------------------------|-----------|--------|----------|----------|--------------------|--------------|
|   |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Basin              | Basin        |
|   | Cherry, Scrub<br>Cherry, Creek Lilly<br>Pilly, Brush Cherry |         |                                     |           |        |          |          |                    |              |
| Taeniophyllum<br>muelleri                                   | Minute Orchid,<br>Ribbon-root Orchid                        | Plants  | V                                   |           |        |          | Yes      |                    |              |
| Tetratheca<br>glandulosa*                                   | Glandular Pink-bell   | Plants  | V                                   |           |        |          |          |                    |              |
| Tetratheca<br>juncea*                                       | Black-eyed Susan  | Plants  | V                                   |           |        |          |          |                    |              |
| Thelymitra<br>epipactoides                                  | Metallic Sun-orchid   | Plants  | E                                   |           |        |          |          | Yes                |              |
| Thelymitra<br>matthewsii*                                   | Spiral Sun-orchid   | Plants  | V                                   |           |        |          |          | Yes                |              |
| <i>Thelymitra sp.</i><br>Kangaloon<br>(D.L.Jones<br>18108)* | Kangaloon Sun-<br>orchid                                    | Plants  | CE                                  |           |        |          |          |                    |              |
| Thesium australe  | Austral Toadflax,<br>Toadflax                               | Plants  | V                                   |           |        |          | Yes      |                    |              |
| Tinospora<br>tinosporoides                                  | Arrow-head Vine   | Plants  | V                                   |           |        |          | Yes      |                    |              |
| Triplarina<br>imbricata                                     |   | Plants  | E                                   |           |        |          | Yes      |                    |              |
| Triplarina<br>nowraensis*                                   | Nowra Heath-<br>myrtle                                      | Plants  | E                                   |           |        |          |          |                    |              |
| Tylophora linearis  |   | Plants  | E                                   |           |        |          | Yes      |                    | Yes          |
| Tylophora<br>woollsii*                                      |   | Plants  | E                                   |           |        |          | Yes      |                    |              |
| Uromyrtus<br>australis*                                     | Peach Myrtle  | Plants  | E                                   |           |        |          | Yes      |                    |              |
| Velleia perfoliata  |   | Plants  | V                                   |           |        |          |          |                    |              |
| Westringia<br>parvifolia                                    |   | Plants  | V                                   |           |        |          |          |                    |              |
| Westringia<br>rupicola*                                     |   | Plants  | V                                   |           |        |          | Yes      |                    |              |
| Wollemia nobilis  | Wollemi Pine  | Plants  | E                                   |           |        |          |          |                    |              |
| Xerochrysum<br>palustre                                     | Swamp Everlasting   | Plants  | V                                   |           |        |          |          | Yes                |              |

| Name                          | Common name  | Species  | EPBC A                              | ct listi  | ing typ | е        | Clarence Gippsland |       | Lake  |
|-------------------------------|--|----------|-------------------------------------|-----------|---------|----------|--------------------|-------|-------|
|                               |  | class    | Threatened<br>Category <sup>a</sup> | Migratory | Marine  | Cetacean | Basin              | Basin | Basin |
| Xerothamnella<br>herbacea     |  | Plants   | E                                   |           |         |          |                    |       |       |
| Xerothamnella<br>parvifolia   |  | Plants   | V                                   |           |         |          |                    |       | Yes   |
| Zieria baeuerlenii            | Bomaderry Zieria,<br>Bomaderry Creek<br>Zieria             | Plants   | E                                   |           |         |          |                    |       |       |
| Zieria collina                |  | Plants   | V                                   |           |         |          | Yes                |       |       |
| Zieria covenyi                |  | Plants   | Е                                   |           |         |          |                    |       |       |
| Zieria granulata              | Hill Zieria, Hilly<br>Zieria, Illawarra<br>Zieria          | Plants   | E                                   |           |         |          |                    |       |       |
| Zieria ingramii               | Ingram's Zieria  | Plants   | Е                                   |           |         |          |                    |       |       |
| Zieria involucrata            |  | Plants   | V                                   |           |         |          |                    |       |       |
| Zieria murphyi                |  | Plants   | V                                   |           |         |          |                    |       |       |
| Zieria obcordata              |  | Plants   | Е                                   |           |         |          | Yes                |       |       |
| Zieria verrucosa              |  | Plants   | V                                   |           |         |          |                    |       |       |
| Acanthophis<br>hawkei         | Plains Death Adder   | Reptiles | V                                   |           |         |          |                    |       | Yes   |
| Anomalopus<br>mackayi         | Five-clawed Worm-<br>skink, Long-legged<br>Worm-skink      | Reptiles | V                                   |           |         |          | Yes                |       |       |
| Aprasia<br>parapulchella      | Pink-tailed Worm-<br>lizard, Pink-tailed<br>Legless Lizard | Reptiles | V                                   |           |         |          |                    |       |       |
| Caretta caretta*              | Loggerhead Turtle  | Reptiles | Е                                   | Yes       | Yes     |          | Yes                | Yes   |       |
| Chelonia mydas                | Green Turtle   | Reptiles | V                                   | Yes       | Yes     |          | Yes                | Yes   |       |
| Coeranoscincus<br>reticulatus | Three-toed Snake-<br>tooth Skink                           | Reptiles | V                                   |           |         |          | Yes                |       |       |
| Delma impar                   | Striped Legless<br>Lizard                                  | Reptiles | V                                   |           |         |          |                    |       |       |
| Delma torquata                | Collared Delma   | Reptiles | V                                   |           |         |          | Yes                |       | Yes   |
| Denisonia<br>maculata         | Ornamental Snake   | Reptiles | V                                   |           |         |          |                    |       | Yes   |
| Dermochelys<br>coriacea       | Leatherback Turtle,<br>Leathery Turtle,<br>Luth            | Reptiles | E                                   | Yes       | Yes     |          | Yes                | Yes   |       |

| Name  | Common name  | Species  | EPBC A                              | ct listi  | ng typ | е        | Clarence | Gippsland | Lake  |
|---|--|----------|-------------------------------------|-----------|--------|----------|----------|-----------|-------|
|   |  | class    | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | Basin    | Basin     | Basin |
| Egernia rugosa  | Yakka Skink  | Reptiles | V                                   |           |        |          | Yes      |           | Yes   |
| Elseya belli  | Bell's Turtle, Namoi<br>River Turtle, Bell's<br>Saw-shelled Turtle                         | Reptiles | V                                   |           |        |          | Yes      |           |       |
| <i>Emydura<br/>macquarii signata</i><br>(Bellinger River,<br>NSW) | Bellinger River<br>Emydura   | Reptiles | V                                   |           |        |          | Yes      |           |       |
| Eretmochelys<br>imbricata   | Hawksbill Turtle   | Reptiles | V                                   | Yes       | Yes    |          | Yes      |           |       |
| Eulamprus<br>Ieuraensis   | Blue Mountains<br>Water Skink  | Reptiles | E                                   |           |        |          |          |           |       |
| Furina dunmalli   | Dunmall's Snake  | Reptiles | V                                   |           |        |          | Yes      |           | Yes   |
| Hoplocephalus<br>bungaroides                                      | Broad-headed<br>Snake  | Reptiles | V                                   |           |        |          |          |           |       |
| Lepidochelys<br>olivacea  | Olive Ridley Turtle,<br>Pacific Ridley Turtle  | Reptiles | E                                   | Yes       | Yes    |          | Yes      |           |       |
| Lerista vittata   | Mount Cooper<br>Striped Lerista  | Reptiles | V                                   |           |        |          |          |           | Yes   |
| Liopholis kintorei  | Great Desert Skink,<br>Tjakura, Warrarna,<br>Mulyamiji                                     | Reptiles | V                                   |           |        |          |          |           | Yes   |
| Liopholis slateri<br>slateri                                      | Slater's Skink,<br>Floodplain Skink  | Reptiles | Е                                   |           |        |          |          |           | Yes   |
| Natator<br>depressus  | Flatback Turtle  | Reptiles | V                                   | Yes       | Yes    |          | Yes      |           |       |
| Ophidiocephalus<br>taeniatus                                      | Bronzeback Snake-<br>lizard  | Reptiles | V                                   |           |        |          |          |           | Yes   |
| Paradelma<br>orientalis   | Brigalow Scaly-foot  | Reptiles | V                                   |           |        |          | Yes      |           | Yes   |
| Rheodytes<br>leukops  | Fitzroy River Turtle,<br>Fitzroy Tortoise,<br>Fitzroy Turtle,<br>White-eyed River<br>Diver | Reptiles | V                                   |           |        |          |          |           | Yes   |
| Tympanocryptis<br>pinguicolla                                     | Grassland Earless<br>Dragon  | Reptiles | E                                   |           |        |          |          |           |       |
| Uvidicolus<br>sphyrurus   | Border Thick-tailed<br>Gecko, Granite Belt<br>Thick-tailed Gecko                           | Reptiles | V                                   |           |        |          | Yes      |           |       |

| Name   | Common name   | Species | EPBC A                              | ct listi  | ng typ | е        | Clarence          | Gippsland | Lake          |
|--|---|---------|-------------------------------------|-----------|--------|----------|-------------------|-----------|---------------|
|  |   | class   | Threatened<br>Category <sup>a</sup> | Migratory | Marine | Cetacean | -Moreton<br>Basin | Basin     | Eyre<br>Basin |
| <i>Carcharias taurus</i><br>(east coast<br>population) | Grey Nurse Shark<br>(east coast<br>population)          | Sharks  | CE                                  |           |        |          | Yes               |           |               |
| Carcharodon<br>carcharias                              | Great White Shark                                       | Sharks  | V                                   | Yes       |        |          | Yes               | Yes       |               |
| Lamna nasus  | Porbeagle,<br>Mackerel Shark                            | Sharks  |                                     | Yes       |        |          | Yes               | Yes       |               |
| Pristis microdon                                       | Freshwater Sawfish                                      | Sharks  | V                                   |           |        |          |                   |           | Yes           |
| Pristis zijsron  | Green Sawfish,<br>Dindagubba,<br>Narrowsnout<br>Sawfish | Sharks  | V                                   |           |        |          | Yes               |           |               |
| Rhincodon typus  | Green Sawfish,<br>Dindagubba,<br>Narrowsnout<br>Sawfish | Sharks  | V                                   | Yes       |        |          | Yes               |           |               |

\* More than 90% of the current distribution (known, likely and may occur) for this species is within the six priority area. a V vulnerable, E endangered, CE critically endangered.

## Appendix E – Summary of the number of listed species protected under the *Environment Protection and Biodiversity Conservation Act 1999* by class of species in the six priority areas

| Туре    | Category                                   | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake<br>Eyre<br>Basin | Northe<br>Inland<br>Catchr |
|---------|--|-------------------------------|--------------------|-----------------------|----------------------------|
| Birds   | Threatened species (Vulnerable)            | 8                             | 12                 | 8                     |                            |
|         | Threatened species (Endangered)            | 8                             | 5                  | 3                     |                            |
|         | Threatened species (Critically endangered) |                               | 1                  |                       |                            |
|         | Migratory                                  | 42                            | 49                 | 14                    |                            |
|         | Marine                                     | 41                            | 48                 | 13                    |                            |
|         | Total‡                                     | 55                            | 62                 | 24                    |                            |
| Fish    | Threatened species (Vulnerable)            | 3                             | 2                  | 2                     |                            |
|         | Threatened species (Endangered)            | 1                             |                    |                       |                            |
|         | Total‡                                     | 4                             | 2                  | 2                     |                            |
| Frogs   | Threatened species (Vulnerable)            | 3                             | 3                  |                       |                            |
|         | Threatened species (Endangered)            | 3                             |                    |                       |                            |
|         | Total‡                                     | 6                             | 3                  |                       |                            |
| Insects | Threatened species (Vulnerable)            |                               |                    |                       |                            |
|         | Threatened species (Endangered)            | 1                             |                    |                       |                            |
|         | Threatened species (Critically endangered) |                               | 1                  |                       |                            |
|         | Total‡                                     | 1                             | 1                  |                       |                            |
| Mammals | Threatened species (Vulnerable)            | 9                             | 5                  | 8                     |                            |
|         | Threatened species (Endangered)            | 4                             | 5                  | 7                     |                            |
|         | Threatened species (Critically endangered) |                               |                    |                       |                            |
|         | Migratory                                  | 8                             | 7                  |                       |                            |
|         | Marine                                     | 1                             |                    |                       |                            |
|         | Cetacean                                   | 7                             | 7                  |                       |                            |

| Туре     | Category                                   | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake<br>Eyre<br>Basin | Northe<br>Inland<br>Catchr |
|----------|--|-------------------------------|--------------------|-----------------------|----------------------------|
|          | Total‡                                     | 19                            | 14                 | 15                    |                            |
| Reptiles | Threatened species (Vulnerable)            | 12                            | 1                  | 10                    |                            |
|          | Threatened species (Endangered)            | 3                             | 2                  | 1                     |                            |
|          | Threatened species (Critically endangered) |                               |                    |                       |                            |
|          | Migratory                                  | 6                             | 3                  |                       |                            |
|          | Marine                                     | 6                             | 3                  |                       |                            |
|          | Total‡                                     | 15                            | 3                  | 11                    |                            |
| Sharks   | Threatened species (Vulnerable)            | 3                             |                    |                       |                            |
|          | Threatened species (Endangered)            |                               |                    |                       |                            |
|          | Threatened species (Critically endangered) | 1                             |                    |                       |                            |
|          | Migratory                                  | 3                             | 3                  |                       |                            |
|          | Total‡                                     | 5                             | 3                  | 1                     |                            |
| Plants   | Threatened species (Vulnerable)            | 70                            | 11                 | 22                    |                            |
|          | Threatened species (Endangered)            | 39                            | 9                  | 6                     |                            |
|          | Threatened species (Critically endangered) | 3                             | 2                  |                       |                            |
|          | Total‡                                     | 112                           | 2                  | 28                    |                            |
| Other    | Threatened species (Vulnerable)            |                               | 1                  |                       |                            |
|          | Threatened species (Endangered)            | 2                             |                    |                       |                            |
|          | Threatened species (Critically endangered) | 1                             |                    |                       |                            |
|          | Total‡                                     | 3                             | 1                  |                       |                            |

*†* The distribution of listed species may occur across multiple priority areas. Therefore, the total occurring across all priority areas is not additive. *‡* Species may be concurrently listed as a threatened, migratory, marine or cetacean species. Therefore, the total number of listed species is not additive.

## Appendix F – Listed threatened ecological communities protected under the *Environment Protection and Biodiversity Conservation Act* 1999 that may occur within the six priority areas

| Name   | Category                 | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake<br>Eyre<br>Basin | Northern<br>Inland<br>Catchments | Ne<br>Sy<br>Ba |
|--|--------------------------|-------------------------------|--------------------|-----------------------|----------------------------------|----------------|
| Blue Gum High Forest of the Sydney Basin<br>Bioregion  | Critically<br>endangered |                               |                    |                       |                                  |                |
| Brigalow ( <i>Acacia harpophylla</i> dominant and co-dominant)   | Endangered               | Yes                           |                    | Yes†                  | Yes <sup>†</sup>                 |                |
| Coolibah - Black Box Woodlands of the<br>Darling Riverine Plains and the Brigalow Belt<br>South Bioregions                       | Endangered               | Yes                           |                    | Yes                   | Yes <sup>†</sup>                 | Ye             |
| Cumberland Plain Shale Woodlands and Shale-Gravel Transition Forest  | Critically<br>endangered |                               |                    |                       |                                  | Ye             |
| Eastern Suburbs Banksia Scrub of the Sydney Region   | Endangered               |                               |                    |                       |                                  |                |
| Giant Kelp Marine Forests of South East<br>Australia   | Endangered               |                               | Yes                |                       |                                  |                |
| Gippsland Red Gum ( <i>Eucalyptus tereticornis</i><br>subsp. <i>mediana</i> ) Grassy Woodland and<br>Associated Native Grassland | Critically<br>endangered |                               | Yes                |                       |                                  |                |
| Grey Box ( <i>Eucalyptus microcarpa</i> ) Grassy<br>Woodlands and Derived Native Grasslands<br>of South-eastern Australia        | Endangered               |                               |                    |                       | Yes <sup>†</sup>                 | Ye             |
| Littoral Rainforest and Coastal Vine Thickets of Eastern Australia   | Critically<br>endangered | Yes                           |                    |                       |                                  | Ye             |
| Lowland Rainforest of Subtropical Australia  | Critically<br>endangered | Yes <sup>†</sup>              |                    |                       |                                  | Ye             |
| Natural Grasslands of the Queensland<br>Central Highlands and the northern Fitzroy<br>Basin                                      | Endangered               |                               |                    | Yes†                  | Yes                              |                |
| Natural Temperate Grassland of the<br>Southern Tablelands of New South Wales<br>and the Australian Capital Territory             | Endangered               |                               |                    |                       |                                  | Ye             |

| Name  | Category                 | Clarence-<br>Moreton<br>Basin | Gippsland<br>Basin | Lake<br>Eyre<br>Basin | Northern<br>Inland<br>Catchments | N<br>Sy<br>B |
|---|--------------------------|-------------------------------|--------------------|-----------------------|----------------------------------|--------------|
| Natural grasslands on basalt and fine-<br>textured alluvial plains of northern New<br>South Wales and southern Queensland | Critically<br>endangered | Yes                           |                    |                       | Yes <sup>†</sup>                 | Y            |
| New England Peppermint ( <i>Eucalyptus nova-<br/>anglica</i> ) Grassy Woodlands   | Critically<br>endangered | Yes                           |                    |                       | Yes <sup>†</sup>                 | Y            |
| Seasonal Herbaceous Wetlands<br>(Freshwater) of the Temperate Lowland<br>Plains   | Critically<br>endangered |                               | Yes                |                       |                                  |              |
| Semi-evergreen vine thickets of the Brigalow<br>Belt (North and South) and Nandewar<br>Bioregions                         | Endangered               | Yes                           |                    | Yes†                  | Yes <sup>†</sup>                 |              |
| Shale/Sandstone Transition Forest   | Endangered               |                               |                    |                       |                                  | Y            |
| Swamp Tea-tree ( <i>Melaleuca irbyana</i> ) Forest of South-east Queensland   | Critically<br>endangered | Yes                           |                    |                       |                                  |              |
| Temperate Highland Peat Swamps on Sandstone   | Endangered               |                               |                    |                       |                                  | Y            |
| The community of native species dependent<br>on natural discharge of groundwater from the<br>Great Artesian Basin         | Endangered               |                               |                    | Yes <sup>†</sup>      | Yes                              |              |
| Turpentine-Ironbark Forest in the Sydney Basin Bioregion  | Critically<br>endangered |                               |                    |                       |                                  | Y            |
| Upland Basalt Eucalypt Forests of the<br>Sydney Basin Bioregion   | Endangered               |                               |                    |                       | Yes                              | Y            |
| Weeping Myall Woodlands   | Endangered               | Yes                           |                    | Yes                   | Yes <sup>†</sup>                 | Y            |
| White Box-Yellow Box-Blakely's Red Gum<br>Grassy Woodland and Derived Native<br>Grassland                                 | Critically<br>endangered | Yes                           | Yes                |                       | Yes <sup>†</sup>                 | Y            |

† Indicates the predominant priority areas of occurrence for the case where more than one priority area contains the community; ‡ The area methodology is not appropriate to consider the extent of occurrence within the priority regions. For the marine environment only a 1 km edge was considered along the coast and does not consider the full extent of the community seaward. For springs in the Great Artesian Basin, the number of springs (or number of super groups) is a more relevant measure of occurrence.

## Appendix G – Other Matters of National Environmental Significance (MNES) that occur within the six priority areas

| Name   | Clarence<br>-<br>Moreton<br>Basin | Gippsla<br>nd Basin | Lake<br>Eyre<br>Basin | Northern<br>Inland<br>Catchme<br>nts | Northern<br>Sydney<br>Basin | Souther<br>n<br>Sydney<br>Basin |
|--|-----------------------------------|---------------------|-----------------------|--------------------------------------|-----------------------------|---------------------------------|
| Internationally important<br>wetlands (declared Ramsar<br>wetlands)                    |                                   |                     |                       |                                      |                             |                                 |
| Moreton Bay  | Yes                               |                     |                       |                                      |                             |                                 |
| Corner Inlet   |                                   | Yes                 |                       |                                      |                             |                                 |
| Western Port   |                                   | Yes                 |                       |                                      |                             |                                 |
| Gippsland Lakes  |                                   | Yes                 |                       |                                      |                             |                                 |
| Edithvale-Seaford Wetlands   |                                   | Yes                 |                       |                                      |                             |                                 |
| Coongie Lakes  |                                   |                     | Yes                   |                                      |                             |                                 |
| Lake Pinaroo (Fort Grey Basin)   |                                   |                     | Yes                   |                                      |                             |                                 |
| The Macquarie Marshes  |                                   |                     |                       | Yes                                  |                             |                                 |
| Gwydir Wetlands: Gingham and<br>Lower Gwydir (Big Leather)<br>Watercourses             |                                   |                     |                       | Yes                                  |                             |                                 |
| Narran Lake Nature Reserve   |                                   |                     |                       | Yes                                  |                             |                                 |
| Hunter Estuary Reserve   |                                   |                     |                       |                                      | Yes                         |                                 |
| Towra Point Nature Reserve   |                                   |                     |                       |                                      |                             | Yes                             |
| National heritage place<br>(natural values with criterion<br>relating to biodiversity) |                                   |                     |                       |                                      |                             |                                 |
| The Greater Blue Mountains<br>Area†  |                                   |                     |                       | Yes                                  | Yes                         | Yes                             |
| Gondwana Rainforests of<br>Australia†  | Yes                               |                     |                       | Yes                                  |                             |                                 |
| Great Artesian Basin Springs:<br>Witjira-Dalhousie                                     |                                   |                     | Yes                   |                                      |                             |                                 |
| Warrumbungle National Park   |                                   |                     |                       | Yes                                  |                             |                                 |
| Ku-ring-gai Chase National<br>Park, Lion, Long and Spectacle<br>Island Nature Reserves |                                   |                     |                       |                                      | Yes                         | Yes                             |

| Name  | Clarence<br>-<br>Moreton<br>Basin | Gippsla<br>nd Basin | Lake<br>Eyre<br>Basin | Northern<br>Inland<br>Catchme<br>nts | Northern<br>Sydney<br>Basin | Souther<br>n<br>Sydney<br>Basin |
|---|-----------------------------------|---------------------|-----------------------|--------------------------------------|-----------------------------|---------------------------------|
| Royal National Park and<br>Garawarra State Conservation<br>Area |                                   |                     |                       |                                      |                             | Yes                             |

*†* Also a world heritage property meeting Criterion (X) Important habitats for conservation of biological diversity