Inland water

Dr Robert M Argent, Bureau of Meteorology

Acknowledgement of Country

The author acknowledges the traditional owners of Country throughout Australia, and their continuing connection to land, sea and community; and pays respect to them and their cultures, and to their Elders both past and present.
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This report may contain images, names of or references to deceased Aboriginal or Torres Strait Islander people.

Credits
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# Contents

- Executive summary ........................................ iv
  - Key findings .................................................. vi
- Approach ......................................................... 1
- Introduction ...................................................... 3
  - Australia’s water resources ................................. 3
  - Australia’s water use ......................................... 6
  - Inland water: 2011–16 in context .......................... 6
- Pressures affecting inland water environments .................. 9
  - Recent climate .................................................. 10
  - Water resource development ................................. 14
  - Changing land use and management ........................ 18
  - Pests and invasive species .................................... 19
- State and trends of inland water environments ................. 28
  - Water flows and levels ....................................... 29
  - Groundwater resources ....................................... 38
  - Water quality .................................................... 45
  - Ecological processes and species populations ............ 51
- Effectiveness of inland water management ....................... 59
  - Water management in Australia ............................. 59
  - Recent national assessments of management performance ........................................ 61
  - Reviews of state and regional management .................. 61
- Resilience of inland water environments ......................... 69
- Risks to inland water environments ............................. 72
  - Climate change .................................................. 72
  - Water abstraction and interception .......................... 75
  - Land and water use and management ........................ 75
- Outlook for inland water environments .......................... 79
- Acronyms and abbreviations .................................... 81
- Glossary ............................................................ 82
- Acknowledgements ................................................ 85
- References .......................................................... 86
- Index ................................................................. 94
Executive summary

Australia’s inland waters, both above and below the ground, are of considerable ecological significance. Their significance arises from both their intrinsic ecological values and the contribution they make in providing water to our communities and industries, and connecting our land, atmosphere, coastal and marine environments. This theme looks at both the ‘unregulated’ parts of the aquatic environment (upstream of major control structures), which are less affected by water management infrastructure, and the managed areas, where water policy and directed management actions are in play. Similar to the 2011 state of the environment assessment, this theme considers the pressures of climate, development, management and pests, and the resulting state and trends of surface waters, water quality, ecological processes and species populations. The state and trends of groundwater are also assessed for the first time. Water management is considered from a policy perspective and from the perspective of the observed outcomes of water management actions. The discussion of the resilience of aquatic ecosystems includes resilience benefits that have been reported in recent years, and a view to the future includes risks of resource development and the effective implementation of water-related policy.

The capricious nature of our nation’s water environment was evident during 2011–16. The period provided the first cooler than average year since 2001, along with record warm years. Urban water demand rose, with an increased focus on finding climate-resilient water supplies. Land-cover changes—because of, for example, fires and land clearing—continued to exert some pressure on aquatic ecosystems, along with invasive species such as cane toads and aquatic weeds. Aquatic environments responded to these pressures and post–millennium drought conditions, as well as to the benefits and detriments arising from the directed management of water resources. Online availability of flow data and water resources information has increased enormously since 2011, supporting ongoing assessment. The state of surface water and groundwater varied considerably during the past 5 years, largely in response to climate, with national surface-water storage levels dropping from above 80 per cent to below 50 per cent. Groundwater condition is mostly graded as poor, reflecting historical groundwater use, significant numbers of bores and low knowledge of the impacts on groundwater-dependent ecosystems. Water quality assessments varied; for example, results for the Lake Eyre Basin were generally consistent with previous reporting, the period sampled and the hydrological conditions, whereas some improving trends were noted for the Murray–Darling Basin. The state and trends of ecological processes and key species populations ranged from very poor, with deteriorating trends across the Murray–Darling Basin, to poor to good, with stable trends for the south-east and south-west, to good for much of the rest of the country.

Looking to the future, our inland waters are at risk from Australia’s projected changes in climate, including the intensity of extreme rainfall events, time spent in drought and, in some areas, decreases in cool-season rainfall. Proposals for significant national infrastructure development and exploitation of coal-seam gas resources during the coming decades raise risks of surface-water regime change, surface-water pollution, increased groundwater extraction, seawater intrusion, and accelerated spread of pest plants and animals. However, we have a significant body of practice and knowledge to assist in avoiding the land and water management mistakes of the past. Australia’s water resources information is becoming increasingly available in many forms to support broader understanding and debate about the future of our water resources and aquatic environments. Also, inland waters continue to receive reasonable attention in national research and policy agendas, assuring a continuing supply of new ideas and knowledge. The outlook for the National Water Initiative, as Australia’s national blueprint for
water reform, is variable, with water markets and environmental water reforms operating well in some areas but having less traction in others. Finally, cultural water, and co-management of groundwater and surface water are areas where inland water environments will benefit from whole-of-government attention.

Moll Gorge, Kimberley, Western Australia
Photo by Helen McFadden
## Key findings

<table>
<thead>
<tr>
<th>Key finding</th>
<th>Explanatory text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>There has been a significant increase in the availability of consistent national-scale water data and information</strong></td>
<td>A modern, inclusive society requires ready access to environmental information. Recently, the Bureau of Meteorology, in its role as the national agency for water information, has produced a wide range of data, information and assessment products about the past, current and likely future state of inland waters. Other national agencies, such as Geoscience Australia and CSIRO, have also contributed to a significant increase in the information needed to support public understanding and debate on water resources and the environment.</td>
</tr>
<tr>
<td><strong>States and territories have increased access to water data online, but have also decreased value-added services such as assessments and reports</strong></td>
<td>State and territory agencies are key players in the implementation of the National Water Initiative, have major responsibilities with regard to water, and control much of Australia’s water monitoring infrastructure. Many of these agencies have moved to online publication of water data in recent years, increasing transparency about the current state of resources. However, during the same period, efforts to analyse, integrate, assess and report holistically on the state of inland waters have generally decreased, with a range of assessment methods and frameworks being either unused or infrequently applied.</td>
</tr>
<tr>
<td><strong>Responsibility for the National Water Initiative has been disaggregated, and reform impetus has decreased</strong></td>
<td>The National Water Initiative is Australia’s national blueprint for water reform. It is a national agreement that represents a shared appreciation of the need to implement a strategic framework to achieve an efficient and sustainable water industry. During the past 5 years, impetus for the reform process has decreased, and progress has slowed in areas such as development of comprehensive water plans, improvements in sustainable water use, standardisation and nationalisation of water markets, and broader adoption of water accounting. Urban water performance reporting has become more regularised and accessible, while national reporting on water markets is less so. Reform in the Murray–Darling Basin has continued to progress.</td>
</tr>
<tr>
<td><strong>Implementation of the Murray–Darling Basin Plan is delivering positive outcomes</strong></td>
<td>The Murray–Darling Basin Plan came into effect in late 2012. This plan sets long-term limits on the amount of water allocated to consumptive use, and specifies plans and frameworks covering water trading, water quality and environmental water provisions. Early indications are that environmental watering in the Basin, along with the effects of natural floods, contributes to ecological benefits for stream metabolism, macroinvertebrates, vegetation, frogs and fish.</td>
</tr>
<tr>
<td>Key finding</td>
<td>Explanatory text</td>
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<tr>
<td>---------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Consideration of groundwater resources and ecosystems has increased and is better informed</strong></td>
<td>Groundwater management gained significant attention and impetus during 2011–16, and focus on groundwater-dependent ecosystems has increased. A national suite of collated and standardised groundwater data is available, building on the long-term efforts of states and territories. The Bioregional Assessment Programme has increased baseline information and groundwater understanding for the 6 bioregions, with spin-off advantages likely to arise from general improvements in groundwater data quality and accessibility.</td>
</tr>
<tr>
<td><strong>Water use has increased, mitigated by variability in availability</strong></td>
<td>Water volumes extracted from the environment to support the Australian economy have grown recently, mitigated somewhat by variations in annual rainfall and the availability of water from storage. Moderate growth in urban water use was seen across most capital cities, reflecting the combined effects of population and per-person consumption. Agriculture continued to be the single largest water-consuming industry.</td>
</tr>
<tr>
<td><strong>Water quality has largely stabilised, with some signs of improvement, and risks exist from fragmented management efforts</strong></td>
<td>Water quality assessment for this report relied largely on water quality analysis and reporting by state, territory and other agencies, unlike the 2011 assessment. Local or regional report card assessments offered insight into water quality in some areas of the country. Water quality trends were found to be either stable or unclear across the country, with some areas improving. Water ecosystem condition was rated largely as poor. In managing water quality, risks have arisen as resources allocated to ongoing broadscale monitoring, analysis and reporting have diminished.</td>
</tr>
<tr>
<td><strong>Aquatic pest plants and animals remain an issue</strong></td>
<td>Understanding of the management context of pest plants and animals with regard to inland waters is very high across the country, with good awareness of threats and risks. Policy and planning operate well, and limited resources produce effective outcomes, with priority pest species being managed at local scales. Threats, however, continue to emerge and develop.</td>
</tr>
</tbody>
</table>
Approach

The approach used for this theme follows that outlined in the Approach report, with some changes required by the nature of inland waters, and the availability of associated data and information. Various challenges were found in applying the general approach, around both the timeframe of the assessment and the individual assessment components. For some components, it is clearly possible to assess changes in the past 5 years, whereas, for other components, changes to data, information and understanding in the past 5 years mean that we may have a different understanding of that component now. Overall, however, the approach used here compares well with that used in the 2011 State of the Environment (SoE) report.

The 4 high-level pressures from 2011 (climate, development, land use and management, and pests and invasive species) are all considered here. In all of these, there have been changes in both the pressure and the information available in the past 5 years.

A new section on groundwater has been added to state and trends reporting, reflecting the dramatic change in national availability of consistent groundwater data and information since 2011, as well as increased national focus on groundwater in aquatic ecological systems. Assessment of the state and trends of water levels and flows also benefits greatly from increased access to national, collated information sources. Water quality, conversely, suffers from a lack of a large and comprehensive national analysis, such as that undertaken as a one-off for 2011. The state and condition of aquatic ecology use a somewhat comparable approach to 2011, albeit, again, without being able to draw on a one-off SoE-focused analysis.

The assessment for effectiveness of management focuses more on water resource development than in 2011, where effects of inland water management were assessed as part of both flows and levels, and with regard to management effectiveness. This more clearly separates the ‘state’ of water, as directly influenced by the ‘pressures’, from the state of water affected by management activities.

The approaches used for resilience and risks are largely comparable with those used in 2011. Consideration of resilience has been somewhat extended to consider the evidence that may exist on, and the characteristics that may be evident in, the resilient behaviour of aquatic ecosystems, because these ecosystems have responded to the highs and lows of recent years and decades.
Inland water

Joffre Falls, Karijini, Western Australia

Photo by Helen McFadden
Introduction

The capricious nature of our nation’s water resources was evident during 2011–16, with:

- record rainfall and record dryness at local, regional and state scales
- extended and extensive flooding
- national water storage levels varying from above 80 per cent to below 50 per cent
- groundwater systems exhibiting a range of significant trends.

The aquatic environment has responded to the wetter conditions experienced after the sustained impacts of the millennium drought (which occurred from 2000 to 2010—although in some areas it began as early as 1997 and ended as late as 2012). The environment has also responded to variable pressures, as well as to the benefits and detriments arising from the directed management of water resources.

Intense interest in, and debate about, the water-related impacts of coal-seam gas and large coalmining developments have contributed to a large investment in the Bioregional Assessment Programme. This program focuses on the geography, geology, hydrogeology, hydrology and ecology of 6 potentially affected bioregions. These assessments add to the state of knowledge about these systems and describe baseline conditions against which future changes may be measured. The bioregional assessment methodology provides a useful tool for future regional assessments of aquatic environments.

Past variations in the nature, scale and timing of the water component of state and territory SoE reports continue to confound attempts to synthesise these detailed explorations of hydrology and ecology into consistent national reporting. However, other national-scale reporting, such as through the Australian Bureau of Statistics and the Bureau of Meteorology, provides a counterpoint, moving us along the path towards ready access to environmental information where and when it is needed.

Overall, we are well placed to assess the state of Australia’s inland water environments. This report presents:

- the natural and anthropogenic pressures on our inland waters
- the state and trends of key components of aquatic environment systems
- the management undertaken to deliver on our water needs—economic, ecological and social
- emerging issues and opportunities.

Australia’s water resources

Drainage divisions are the fundamental spatial unit for assessing the state of the inland water environment. As discussed in SoE 2011, these provide a scale of resolution that supports assessment of the health of entire systems, while recognising the variations and variability that lie within.

Four changes have occurred to the interim Australian drainage divisions used in 2011:

- The South East Coast division was divided into 2 divisions: South East Coast (New South Wales), covering catchments north from Towamba River, and South East Coast (Victoria), covering catchments west from the East Gippsland river region.
- The Gulf of Carpentaria division was renamed the Carpentaria Coast division.
- The Indian Ocean division was renamed the Pilbara–Gascoyne division.
- The Timor Sea division was renamed the Tanami–Timor Sea Coast division.

These updated divisions, shown in Figure WAT1, are used in this report.
Figure WAT1    Australian drainage divisions

Source: Topographic drainage divisions and river regions; © Commonwealth of Australia (Bureau of Meteorology) 2016
Australia is the world’s second driest continent, after Antarctica, with a long-term average rainfall of 430 millimetres (mm) and variations ranging across Australia from below 100 mm to above 3000 mm per year (Figure WAT2). Most of this is lost through evapotranspiration (loss of water from Earth through evaporation and transpiration from plants), and the annual average run-off coefficient (a measure comparing the amount of run-off with the amount of precipitation) is about 12 per cent. Thus, on average, some 383,000 gigalitres (GL) remain after evapotranspiration to enter Australian water environments, of which around 70,000–95,000 GL is used each year to meet Australia’s consumptive water needs.

Source: Average annual, seasonal and monthly rainfall; © Commonwealth of Australia (Bureau of Meteorology) 2016

Figure WAT2 Average annual rainfall
Australia’s water use

Rainfall and run-off amounts vary widely from year to year and place to place, and we have a water management infrastructure with an accessible capacity of more than 80,000 GL to assist in redistributing water across time and space. States and territories have a strong and direct role in managing water resources for both consumptive and environmental purposes.

Water volumes extracted from the environment to support the Australian economy have grown in recent years, from 75,000 GL in 2011–12 to 92,300 GL in 2013–14 (ABS 2014a, 2015a). During this time, annual water use by households and industry was between 16,000 and 19,700 GL, and households’ expenditure on distributed water grew from $4.3 billion to $5.3 billion. Agriculture was the single largest water-consuming industry, accounting for some 9400–12,800 GL per year. Between 63,700 and 78,200 GL was returned to the environment in regulated discharges. Agriculture, forestry and fishing spends some $0.6–0.7 billion on water each year, paying an average price of around 7 cents per kilolitre (kL).

We have a mature water policy regime that operates to direct water to meet both high-priority needs and highest market value use. Water markets have grown and developed over the past 3 decades, with the annual value of water traded now around $1.5–2.5 billion per year. Under the 2004 National Water Initiative, successive Australian, and state and territory governments have worked through a considerable water reform agenda that includes:

- planning
- entitlements
- pricing
- governance and institutional arrangements
- accounting, engagement and consultation
- resolution of overallocation and overuse.

Environmental water holdings reflect the government acquisition of water entitlements, for purposes that include protecting and restoring environmental assets. The Victorian Environmental Water Holder (VEWH), for example, holds 25 entitlements, including some held in trust for the Living Murray. In exercising its authority, the VEWH delivered more than 640 GL of environmental water to priority rivers, wetlands (including Ramsar wetlands’1) and floodplain systems from July 2015 to April 2016. The Commonwealth Environmental Water Holder, who holds environmental water in the Murray–Darling Basin, increased holdings from 993 GL to 2410 GL from 2010–11 to 2015–16, and has used these to deliver more than 5400 GL of environmental water.

Some of the reported benefits of environmental watering include increases in native fish abundance and diversity, successful breeding in platypus (*Ornithorhynchus anatinus*) populations, and spawning and migration of threatened species such as Australian grayling (*Prototroctes maraena*; DEPI 2014). The ecological outcomes of environmental watering have been monitored and reported on across the Murray–Darling Basin through the Long-Term Intervention Monitoring Project. This project includes the Edward–Wakool, Goulburn, Gwydir, Lower Murray, Lower Lachlan and Murrumbidgee river systems, and the junction of the Warrego and Darling rivers. The contribution of Commonwealth environmental water to the environmental objectives of the Murray–Darling Basin Plan is also evaluated at the Basin scale. Together, these monitoring and evaluation activities provide examples of closing the management loop for use of water for environmental purposes, whereas feedback from activities is used to inform future management decisions.

Inland water: 2011–16 in context

The past 5 years opened with widespread heavy rainfall and extensive flooding in Queensland, New South Wales and Victoria, and closed with some areas having record-breaking temperatures from October to December 2015. Most states and territories experienced record low rainfall in some areas for 1–36 months.

A massive expansion in national-scale water information occurred under the Bureau of Meteorology, as flagged in SoE 2011. This includes delivery of National Water Accounts, Australian Water Resources Assessments,

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1 The Convention on Wetlands (Ramsar, Iran, 1971) is an intergovernmental treaty whose mission is ‘the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world’. As of January 2013, 163 nations have joined the convention as contracting parties, and more than 2060 wetlands around the world have been designated for inclusion in the Ramsar List of Wetlands of International Importance.
extensive national surface-water and groundwater data and information systems, and a variety of services and products. These have contributed to overall situational awareness of our water resources that was unavailable in 2011, with improvements in the comparability and quality of available water information (ANAO 2014). They also provided consistent reporting to support better assessment of trends, both against the 2011 assessment and across longer terms that are more appropriate to ecological systems. In some ways, Australia’s water reporting is approaching the levels that our weather and climate reporting has demonstrated for quite some time. Assessment has also expanded to cultural considerations of water, and the impact that the state of our inland waters can have both culturally and socially.

The operation of our water markets has matured during recent years, as has the level of associated water information. Annual national water market reporting, however, has somewhat diminished. The functionality of state water registers has improved, albeit in the absence of a national water market system. Many barriers to water trade have been removed, and carryover arrangements have supported effective management of water across multiple years. Accountable environmental water arrangements have advanced across all jurisdictions, with a mix of rule-based and held environmental water entitlements in place (NWC 2014).

Groundwater management, although not entirely coming of age during 2011–16, has certainly emerged into the spotlight during the past 5 years. On the back of the millennium drought, where reliance on groundwater increased in many areas of Australia, investigations of managed aquifer recharge and the water resource implications of coal-seam gas mining have shifted focus towards groundwater management. Through the work of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, and the subsequent Bioregional Assessment Programme, groundwater information, understanding and assessment have increased. Although focused on the bioregions, there are likely to be spin-off advantages for other groundwater ecosystems arising from general improvements in groundwater data quality and accessibility.

Lake Kununurra, Western Australia
Photo by Helen McFadden
Long-term developments affecting water resources and aquatic environments have continued, from urban growth, and social and cultural pressures—Australia’s population has grown by about 1.5 million people in 5 years, with consequential pressures on water demand and aquatic environments. Agriculture, especially irrigated agriculture, remains the greatest consumer of water in Australia (see Box WAT1 for an example of market-driven irrigation). Urban water consumption per person has shown multiyear rises after declining or fluctuating for most of the past decade.

The Murray–Darling Basin Plan came into effect in late 2012. This plan guides governments, regional authorities and communities in sustainably managing and using the surface and underground waters of the Basin. Under the Water Act 2007 (Cwlth), the Murray–Darling Basin Authority was charged with developing the plan, as a significant step in ongoing management of the Basin’s water for the benefit of all its users and the environment. The Basin Plan sets new ‘sustainable diversion limits’ on the amount of water allocated to consumptive use. It also specifies plans and frameworks covering water trading, water quality, environmental water provisions, community access to potable water, and implementation and monitoring of the Basin Plan.

Other (broader) water management and policy factors during the past 5 years that have shaped and are shaping the inland water environment include:

- significant changes in impetus, support and governance of the National Water Initiative, which is the key framework for improving Australia’s water knowledge, planning and management during the past decade
- policy shifts towards developing northern Australia
- increasing our nation’s agricultural competitiveness and productivity.

However, much of the water reform agenda is yet to be achieved. Challenges include improving the conjunctive management of surface-water and groundwater resources; and protecting groundwater quality and yield under potential impacts of coal-seam gas and large mining developments, and the northern Australian development plans.

**Box WAT1  Tasmanian irrigation: market-driven irrigation development**

Tasmania has not been viewed traditionally as an area of significant irrigation activity, relying more on rain-fed agriculture. However, developments during the past decade have proven the long-held view that irrigation can add significant value in supplementing water supply and supporting investment in higher-value crops.

Tasmanian Irrigation Pty Ltd (TI) was established in 2008 to develop, own and operate irrigation schemes in Tasmania and, where feasible and appropriate, to facilitate local community management of these schemes. TI develops schemes as public–private partnerships, whereby TI works with landholders to work out how much water is wanted and then shares the cost of building a scheme with the private sector.

TI planned 10 initial Tranche 1 irrigation schemes, which were funded under the Australian Government’s Water for the Future initiative and by the Tasmanian Government. All 10 schemes were operational by mid-2015. Tranche 2 development continues, including schemes at Scottsdale, North Esk, Swan Valley and the Southern Highlands. All schemes developed by TI are designed to last 100 years, deliver water at an average reliability of more than 95 per cent, and satisfy demand in each region. Farm Water Access Plans ensure that irrigation is applied sustainably, and are audited for compliance. Irrigation development has also been assessed under environmental protection legislation to minimise environmental impacts.

The TI Tranche 1 and 2 projects will enable Tasmania to store and distribute around 160,000 megalitres of water across almost 250,000 hectares of arable land. This is viewed as revolutionising agriculture in Tasmania, with the potential to establish Tasmania as the most reliable source of high-quality food and fibre in a continent challenged by climate change.

Sources: Tasmania Irrigation; Australian Government strategic assessments
At a glance

Overall, the key pressures affecting inland water environments have changed little since 2011, with climatic and pest-based pressures increasing, land-use and management pressures remaining largely stable, and some stabilisation occurring in the pressure of water resources development.

This period provided the first cooler than average year since 2001, along with the warmest, third warmest and fifth warmest years on record for Australia. It also included 2011 as the second wettest year on record, whereas recent years have produced significant record rainfall deficiencies in parts of Australia.

Invasive species pressures include those from cane toads, common carp, gambusia, goldfish, and various Weeds of National Significance. Cane toads have reportedly spread into the Kimberley and upper reaches of the Fitzroy River in Western Australia, while 2 aquatic weeds (sagittaria/arrowshead and water hyacinth) were added to the Weeds of National Significance list in 2012.

No recent water-affecting land-use or management changes have been observed on a nationally significant scale. The broadest land-cover effects on water quality since 2010–11 are likely to have arisen from post–La Niña fires in savanna and rangeland areas. About 50–70 million hectares of the northern savannas burn each year, contributing to the ongoing tropical aquatic ecosystem pressures. In addition, Queensland’s land-clearing rate of nearly 300,000 hectares per year exceeds all other states and territories combined.

Urban water consumption figures from larger centres have generally increased. To assist in meeting demands, Australia’s climate-resilient water sources (desalination and recycled water plants) produced more than 440 gigalitres (GL) in 2012–13, amounting to approximately 25 per cent of the estimated production capacity of 1821 GL. More than two-thirds of this was for urban use. Groundwater use for urban demand is not a large proportion of the total water supply for the country, although it continues to be a key supply resource for Perth and for many rural areas.

The primary pressures on our inland water environments have not changed significantly since 2011, although—as noted in the Drivers report—there has been movement in some of the drivers of environmental change during that period, particularly when compared with the decade leading up to 2011. The twin drivers of economic growth and population growth have continued to increase pressure on the supply and use of water.

The few wetter years that followed the millennium drought eased the pressure on total water available to the environment in some areas. Land-use and management pressures—such as irrigation and cropping, and stocking changes—continued to influence inland waters. Pest species have responded to both climate and management efforts. Mining development, particularly of coal-seam gas, has the potential to increase pressure in coming years, as does the promise of accelerated development and growth in northern Australia.
Recent climate

The period since 2010–11 provided the first cooler than average year since 2001 (i.e. 2011), along with the warmest (2013), third warmest (2014) and fifth warmest (2015) years on record for Australia (BoM 2012, 2014a, 2015a). (See the Atmosphere report for more details.) This period included 2011 as the second-highest rainfall year on record. If 2010 is considered, then 2010 and 2011 form the wettest 2-year period on record. Surprisingly, the years 2012–15 were near median at a national scale, although significant local and regional variations occurred. January 2011 was the wettest January on record for Victoria, whereas February 2011 was the wettest on record for South Australia (BoM 2012). January–March 2011 rainfall contributed to some of the most significant flooding seen in Australia, with notable flooding events in the Kimberley, the Northern Territory, Queensland, Tasmania and Victoria.

Conversely, recent years have produced continuing rainfall deficiencies in parts of Australia. Following the end of the most recent La Niña period in autumn 2012, rainfall has been very much below average for large areas of eastern Australia. These areas started 2015 with long-term rainfall deficiencies in place; these deficiencies persisted across Queensland and worsened in south-eastern Australia during the year. Figure WAT3 shows rainfall deficiencies for the 36 months to December 2015, with the lowest decile values in much of Queensland, western Victoria, south-west Western Australia and parts of Tasmania, including areas with the lowest 36-month rainfall on record.
Rainfall deficiencies, 2013–15

Source: Archive—thirty-six-month rainfall deficiency for Australia; © Commonwealth of Australia (Bureau of Meteorology) 2016
Although Australia has seen near-median total annual rainfalls in recent years, the distribution of higher than average rainfall has been largely in drainage divisions with little or no major water storage infrastructure (Figure WAT4). Consequently, the amount of water held in storage across Australia decreased, year on year, from 2012 to 2015 (Figure WAT5).

Source: Daily rainfall totals for Australia; © Commonwealth of Australia (Bureau of Meteorology) 2016

Figure WAT4  Australian rainfall deciles, 2012–15
Figure WAT5  Water in storage, 2011–16

Source: Water storage: © Commonwealth of Australia (Bureau of Meteorology) 2016
During 2015, a decreasing trend in water storage was apparent across all but one drainage division (Table WAT1), increasing the pressure for all water users, including environmental water delivery from managed water distribution systems.

### Water resource development

After a few years of moderate change in urban water demand, recent years (2013–14) have seen an increase in water demand from larger urban water-consuming areas across Australia. National Water Account figures for Melbourne, Sydney, Brisbane and Perth generally saw increases in water abstraction, urban claim and household water supply.

For Sydney, the urban water supply in 2013–14 was 557,820 megalitres (ML), a marginal increase from 543,311 ML in 2012–13 and 502,296 ML in 2011–12 (Figure WAT6; Table WAT2). In the latter 2 years, this demand was supplied primarily from surface-water sources, whereas in 2010–11 and 2011–12, some 12–15 per cent was supplied by the Kurnell desalination plant.

For Melbourne, south-east Queensland (including Brisbane) and Perth, similar moderate growth is seen in urban water supply (Table WAT2; BoM 2013a, 2014b, 2015b). This growth reflects the combined effects of population and per-person consumption.

### Table WAT1  Water held in major public storages across Australia’s drainage divisions

<table>
<thead>
<tr>
<th>Drainage division</th>
<th>Jan 2015</th>
<th>Jan 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(% full)</td>
<td>(% full)</td>
</tr>
<tr>
<td>Carpentaria Coast</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Lake Eyre Basin</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Murray–Darling Basin</td>
<td>52.6</td>
<td>40.4</td>
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<tr>
<td>North East Coast</td>
<td>73.5</td>
<td>65.8</td>
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<td>North Western Plateau</td>
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<td>N/A</td>
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<td>Pilbara–Gascoyne</td>
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<td>South Western Plateau</td>
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<td>N/A</td>
</tr>
<tr>
<td>Tanami–Timor Sea Coast</td>
<td>98.5</td>
<td>77.7</td>
</tr>
<tr>
<td>Tasmania</td>
<td>48.0</td>
<td>38.0</td>
</tr>
</tbody>
</table>

N/A = not applicable

a Only one major public water storage in this division.
b No major public water storages in this division.
c Combined South East Coast (NSW) and South East Coast (Victoria) storages

Source: Bureau of Meteorology, January 2016
At June 2015, an estimated 4.53 million people were residing in Greater Melbourne, an increase of 91,600 from June 2014. This was the largest growth of all greater capital cities in Australia (Table WAT3). The Australian Bureau of Statistics reported that, for 2014–15:

Melbourne’s population grew by 2.1 per cent in 2014–15, down slightly from 2.2 per cent last year, but still higher than the next-fastest growing capital, Darwin (1.9 per cent). Perth, which has been one of the fastest-growing capital cities since the mid-2000s, grew by 1.6 per cent in 2014–15 (down from 1.9 per cent last year) and now sits equal fourth with Brisbane, behind Sydney (1.7 per cent). (ABS 2015b)

Urban water consumption is reported in a series of national performance reports now published by the Bureau of Meteorology. The 2013–14 report detailed average residential water supplied (kilolitres per property) that, in general, showed a change from a downwards or steady trend at the end of the millennium drought to an increasing trend in the 4 years to 2013–14 (Figure WAT7).

Urban demand is only one of the demands for water arising from the twin drivers of population and economic growth. Agriculture consumes around 7000–13,000 GL per year, depending on the water available from climate and storage. This equates to some 50–65 per cent of Australian water consumption (ABS 2014a, 2015a). Recreational pressures occasionally come into play for surface-water resources, such as in maintaining high water levels during summer holiday periods, although these pressures are minor compared with the overall balance of water moving through managed systems.

As noted in SoE 2011, in recent decades, meeting water demand has shifted away from a large focus on building new water storage infrastructure. New approaches combine development of dams and climate-resilient water sources, such as desalination plants, with changes in the management of water, such as demand management (reducing per-person consumption) and increased water use efficiency. Note that the latter can be achieved through both infrastructure and management actions.

The annual production capacity of the 360 desalination and recycled water plants captured in the Bureau of Meteorology’s climate-resilient water sources dataset is more than 1821 GL, with actual production in 2012–13 exceeding 440 GL or approximately 25 per cent of

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>502,296</td>
<td>543,311</td>
<td>557,820</td>
<td>543,588</td>
</tr>
<tr>
<td>Melbourne</td>
<td>374,198</td>
<td>408,878</td>
<td>415,436</td>
<td>420,391</td>
</tr>
<tr>
<td>South-east Queensland (including Brisbane)</td>
<td>243,213</td>
<td>251,897</td>
<td>261,247</td>
<td>267,792</td>
</tr>
<tr>
<td>Perth</td>
<td>283,027</td>
<td>284,058</td>
<td>289,114</td>
<td>291,026</td>
</tr>
</tbody>
</table>

ML = megalitres

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Sydney</td>
<td>4,921,000</td>
<td>83,300</td>
<td>1.7</td>
</tr>
<tr>
<td>Greater Melbourne</td>
<td>4,529,500</td>
<td>91,600</td>
<td>2.1</td>
</tr>
<tr>
<td>Greater Brisbane</td>
<td>2,308,700</td>
<td>35,200</td>
<td>1.6</td>
</tr>
<tr>
<td>Greater Perth</td>
<td>2,039,200</td>
<td>31,100</td>
<td>1.6</td>
</tr>
<tr>
<td>Greater Adelaide</td>
<td>1,316,800</td>
<td>12,100</td>
<td>0.9</td>
</tr>
<tr>
<td>Australian Capital Territory</td>
<td>390,700</td>
<td>5,400</td>
<td>1.4</td>
</tr>
<tr>
<td>Greater Hobart</td>
<td>221,000</td>
<td>1,700</td>
<td>0.8</td>
</tr>
<tr>
<td>Greater Darwin</td>
<td>142,300</td>
<td>2,600</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Source: ABS (2015b)
estimated capacity. More than two-thirds of this was for urban use. Across Australia, the production capacity for climate-resilient sources has risen by more than 360 GL since 2011, including large desalination plants at Dalyston, Victoria (162 GL), and Binningup, Western Australia (111 GL).

**Dams**

There has been a range of levels of development of dams during recent years. Although states and territories generally have good processes for approval and licensing of dam construction, public reporting of construction is less clear. One of the larger dam infrastructure projects completed since 2011 is the Cotter Dam enlargement in the Australian Capital Territory, which, when completed in 2013, increased the reservoir capacity from 4.0 to 79.4 GL, with an accessible volume of 76.2 GL. Victoria has listed no new significant licensed or permitted dam sites since the construction of the Woodglen No. 2 Dam in 2009. In Tasmania, where the Department of Primary Industries, Parks, Water and Environment has ‘number of new dam works permits’ as a key performance indicator, 40 dams were approved in 2013–14 (Tasmanian Government 2015). This was the lowest annual total number of permits since 2000. The total storage capacity of the new dam works (including new dams and enlargements) approved was 11.3 GL, with an average of 284 ML, down from a 5-year peak of 550 ML per permitted development in 2012–13.

In Queensland, the Nathan Dam and pipeline approval process entered its 8th year in 2016. The dam, with a proposed capacity of 888 GL, was gazetted in 2008, and a supplementary environmental impact assessment (EIS) is under consideration, following an initial EIS developed in 2012. The Nathan Dam is just one dam in a proposed new era of national water infrastructure development announced in mid-2015, as part of an overall strategy to boost the competitiveness of Australia’s agricultural sector and to develop northern Australia. The envisaged water infrastructure developments may build or augment existing water infrastructure, including dams,
pipelines or managed aquifer recharge. Augmentation considerations include existing projects in the Murray–Darling Basin, the Great Artesian Basin and Tasmania.

**Groundwater**

Groundwater is a key component in water supply across much of Australia. In many ways, less is known about groundwater, and groundwater is considered less often than supply from surface-water and climate-resilient sources. (See Box WAT2 for an example from one of the more studied aquifers in the country.)

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**Box WAT2  New groundwater resources for Perth, August 2015**

‘Billions of litres of extra water could be made available to Perth households and businesses after a breakthrough discovery in a study of the Gnangara groundwater system—the city’s most important water source. More than halfway into a 4-year, $7 million investigation of Perth’s groundwater resources, the Department of Water said it had identified an aquifer to the north that appeared to be separate from the main system.

*The finding is one of the most significant in years for the understanding of Perth’s groundwater network, which provides about half its drinking water and hundreds of billions of litres a year for horticulture and industry. Largely untapped, the aquifer lies to the west of the Gnangara Mound and is separated by a geological formation known as the Badaminka fault line, which runs north of Yanchep and is more influential than scientists had thought. Its discovery was made after the department used advanced scientific techniques, including seismic and electromagnetic surveys, to produce the clearest pictures yet of Perth’s extensive network of aquifers.*  
(West Australian 2015)

Groundwater replenishment is also set to become part of Perth’s water resource solutions, with construction of a replenishment system slated for completion in 2016 (Water Corporation 2016).

In recent years, groundwater use across large urban areas has fluctuated, reflecting year-to-year variability in supply and demand factors. Overall, groundwater for urban demand (Table WAT4) is not a large proportion of the total water supply reported in the National Water Account, although investigations of managed aquifer recharge may see this grow in future. In many rural areas, groundwater already provides most of the water supply.

A small—but potentially relevant—groundwater and surface-water issue is that of the water extracted during coal-seam gas production. This has been reported to vary from 5 to 300 ML per well per year (NSW Office of Water 2013; Queensland Government 2016). Also, because of the natural and human-sourced chemicals used (such as fracking fluids), coal-seam gas production needs to be managed carefully to minimise environmental impacts. The Queensland Government (Queensland Government 2016) is also periodically assessing underground water impacts of coal-seam gas production in the Surat Cumulative Management Area.

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**Table WAT4  Groundwater abstraction for some areas,a 2011–12 to 2014–15**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Perth</td>
<td>514,995</td>
<td>486,741</td>
<td>479,618</td>
<td>483,191</td>
</tr>
<tr>
<td>Melbourne</td>
<td>13,173</td>
<td>15,478</td>
<td>14,414</td>
<td>19,166b</td>
</tr>
<tr>
<td>Adelaide</td>
<td>17,379</td>
<td>54,287</td>
<td>43,699</td>
<td>51,461</td>
</tr>
<tr>
<td>South-east Queensland (including Brisbane)</td>
<td>3,925</td>
<td>5,300</td>
<td>7,516</td>
<td>6,911</td>
</tr>
</tbody>
</table>

ML = megalitres

*a Groundwater store information is not available for the Sydney National Water Account region, because volumes related to groundwater store could not be quantified in a way that is complete, neutral and free from material error. Also, groundwater is generally not recognised in the water accounting statements, because its contribution is very minimal.

b Additional data were available in 2015.

Source: National Water Account
Changing land use and management

Land use and land management can produce pressures on aquatic environments that include changes to flow, water quality and the availability of habitat. As noted in SoE 2011, point sources of pollutants no longer significantly affect the aquatic environment. Diffuse sources, such as large-scale land clearing or changes to land cover, have left a legacy of changes in quality and flow regimes, such as changes in biota and sediment, and nutrient concentrations in streams. As an example, an extensive study of macroinvertebrate assemblages in Tasmanian streams confirmed the significant and widespread effects of livestock grazing on community structure (Magierowski et al. 2012). Elsewhere, a review of how forest cover affects flow found that, in catchments undergoing a permanent change in forest cover, it takes between 8 and 25 years for a catchment to reach a new equilibrium. Flow changes arising from the effects of water use patterns of different forests included uniform changes in all flows, changes in numbers of zero flow days, and proportionally larger changes in low, compared with high, flows (Brown et al. 2013).

Since 2011, there have been no land-use changes or changes to management practices on a nationally significant scale. Land clearing continues across all Australian states, although at a much lower rate and with far more controls in place than in previous decades. Queensland’s land-clearing rate, which has risen from below 100,000 to nearly 300,000 hectares per year since 2010 (OSITI 2015), exceeds that of all other states and territories combined. Queensland’s clearing in recent years is dispersed across the state; no reports have been found of significant widespread hydrological impacts. See Box WAT3 for an example of best management practices in Queensland.

The broadest land-cover effects on water quality since 2010–11 are likely to have been those occurring across the Australian savannas and rangelands during the La Niña years following the millennium drought (see the Land report for details). This produced a spike in central Australian fires in late 2011 (Bastin 2011), including more than 5 million hectares burned in Tanami, Northern Territory. It is estimated that some 50–70 million hectares of the northern savannas burn each year, contributing to the ongoing pressures on tropical aquatic ecosystems arising from fire regime changes from cool early-season burns to hot late-season burns.

| Box WAT3 | Great Barrier Reef catchments: best management practices |

Farming practices in reef catchments have received significant attention in recent years as part of an initiative to improve reef water quality, and to slow or stop declines in the condition of coral reefs and seagrass meadows. The Queensland and Australian governments are committed to reducing the pollutant load flowing to the Great Barrier Reef, aiming to reduce nitrogen loads by up to 80 per cent and total suspended sediment load by up to 50 per cent in key Reef catchments by 2025.

Initiatives to improve water quality target grazing and sugar cane farming, as well as coastal wetland management. Regulations cover fertiliser application rates, herbicide practices, nutrient management and training for chemical handling. Best management practices (BMPs) for grazing and cane farming have been developed, and farmers are being applauded for their adoption. BMPs for sugar cane include:

- soil health and nutrient management
- irrigation and drainage management
- weed, pest and disease management.

The grazing BMPs cover:

- animal health and production
- land management
- soil health
- people and business.

A review of these efforts concluded that ’recent efforts in the Great Barrier Reef catchments to reduce land-based pollution are unlikely to be sufficient to protect the Great Barrier Reef ecosystems from declining water quality within the aspired time frames’ (Kroon et al. 2016).
In temperate zones since 2011, there were no bushfires on the scale of the 2009 Victorian Black Saturday fires. The largest fires, or series of fires, burned around:
- 300,000 hectares in South Australia in 2014
- 166,000 hectares in Victoria in 2014
- 100,000 hectares in New South Wales in 2013
- 100,000 hectares in Tasmania in early 2016.

The Black Saturday fires, which burned about 28 per cent of Melbourne’s forested water supply catchments, are predicted to reduce post-fire streamflow after 100 years by 1.4 per cent (around 12 GL per year) to 2.8 per cent (around 24 GL per year) under average climatic conditions. This low number is largely because of the low mortality of trees that were burned (Feikema et al. 2013). Other post-fire effects on inland water environments include increased sediment loads, and changes in nutrient, carbon and oxygen dynamics.

Other land use–related pressures on inland aquatic ecosystems include cover changes in areas of farmed land in Australia. This, and the area given to cropping, fluctuate by a few million hectares per year (Table WAT5; ABS 2014b, 2016).

This follows a general decline during recent decades in the total Australian farm area, which, when combined with the adoption of best-practice farm management, lessens pressure from land use.

<table>
<thead>
<tr>
<th>Type of area</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmed</td>
<td>409.7</td>
<td>405.5</td>
<td>396.6</td>
<td>406.2</td>
<td>384.6</td>
</tr>
<tr>
<td>Cropped</td>
<td>32.1</td>
<td>32.0</td>
<td>31.6</td>
<td>25.6</td>
<td>26.1</td>
</tr>
</tbody>
</table>

Pests and invasive species

SoE 2011 provided information on the pressure of invasive species, including cane toads (*Rhinella marina*, formerly *Bufo marinus*), common carp (*Cyprinus carpio*), eastern gambusia (*Gambusia holbrooki*), goldfish (*Carassius auratus*) and various Weeds of National Significance. Other invasive species exerting pressure on inland waters include pigs and buffalo, redfin perch (*Perca fluviatilis*), various tilapia species, oriental weatherloach (*Misgurnus anguillicaudatus*) and redclaw crayfish (*Cherax quadricarinatus*).

Cane toads have now spread into the Kimberley and upper reaches of the Fitzroy River in Western Australia (Pusey & Kath 2014), and inland western Queensland, with estimates of expansion of around 10–50 kilometres per year. Expansion in the cane toad range has been found to reflect a shift in the species’ realised niche (i.e. a shift aided by the presence of novel biotic and abiotic conditions in the invaded range), as opposed to the evolutionary shifts in range-limiting traits that affect the range of any species (Tingley et al. 2014).

The challenge of managing feral freshwater fish, and understanding their extent and impact has spawned a national online information resource, Feral Fish Scan. Feral Fish Scan is taking a crowdsourcing approach to provide a community resource for mapping feral fish, which, over time, will provide further support for management. A heat map of carp extent in Australia shows areas similar to those reported in 2011. Increases have occurred in western South Australia, and central and southern Victoria (Figure WAT8). Detailed local monitoring may provide more accurate assessment of the presence and extent of feral species; for example, the Lake Eyre State of the Basin Committee found no carp in a survey of an area that may have formerly contained carp. There is also some evidence that carp numbers have increased since the 2010–11 flooding of the Murray River (Koehn et al. 2016).

The eastern gambusia is one of the more widespread invasive freshwater fish species in Australia, with sightings in all mainland states and territories (Figure WAT9). They are also known to be present in the Tamar River and nearby constructed water bodies in Tasmania (Coleen Cole, Department of Primary Industries, Parks, Water and Environment [DPPIPWE], pers. comm., 10 June 2016). However, data from the Atlas of Living Australia show no significant expansion in eastern gambusia extent since 2011 (DPPIPWE, peer review comments).

The problems of invasive ornamental fish have gained the attention of the Senate Environment and Communications References Committee. The committee...
European carp (Cyprinus carpio) distribution

- Lowest density
- Highest density

Source: Atlas of Living Australia; used under CC BY 3.0 AU

Figure WAT8   Heat map of observed carp extent, 2016 (number of records)
Observed extent of eastern gambusia, 2016 (number of records)

Source: Atlas of Living Australia; used under CC BY 3.0 AU
produced an environmental biosecurity report in 2015 that identified a focus within committee submissions on the threat posed by ornamental fish, noting that ‘of 40 exotic fish species known to have established in Australian waterways, up to 30 were imported as aquarium fish’ (SECRC 2015). The known pressures of invasive fish species include impacts on both native freshwater fish and native frogs. Other pressures, such as on habitat and invertebrate species, are largely unknown.

Two aquatic Weeds of National Significance were added to the list in 2012, as part of an update that added 12 new weeds (Australian Weeds Committee 2012):

- Sagittaria or arrowhead (*Sagittaria platyphyllla*), an emergent aquatic plant native to the southern areas of North America, was introduced as an ornamental pond plant. Mature plants grow up to 1 metre tall and can produce up to 20,000 seeds, which are mostly dispersed by water.

- Water hyacinth (*Eichhornia crassipes*), a free-floating aquatic plant native to South America, was introduced as an ornamental pond plant in the late 1800s. Under favourable conditions, plants can double in size in as little as 8 days, and seeds can remain viable for up to 20 years.

The distribution of these plants is shown in Figures WAT10 and WAT11.
Inland water | Pressures affecting inland water environments

Arrowhead (Sagittaria platyphylla) distribution

- Blue: Lowest density
- Green: Lower density
- Yellow: Intermediate density
- Orange: Higher density
- Red: Highest density

Source: Atlas of Living Australia; used under CC BY 3.0 AU

Figure WAT10  Distribution of arrowhead
Figure WAT11  Distribution of water hyacinth

Source: Atlas of Living Australia; used under CC BY 3.0 AU
Many factors influence water quality

Multiple interactions of factors over varying timeframes, with a range of responses to management actions, need to be considered when assessing the state of the environment.
## Assessment summary 1

### Pressures affecting inland water environments

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressures resulting from climate variability and climate change</td>
<td>Australia had near-median rainfall in recent years; areas of WA and NT had above average rainfall; areas of Qld, Vic, Tas, NSW, SA and WA had rainfall deficiencies. Average temperatures included the warmest, third warmest and fifth warmest years on record. Climate projections for Australia include increasing temperatures and numbers of hot days. Water storage started at a high level and decreased during the past 4 years.</td>
<td>Very high impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water resource development</td>
<td>Urban water use has increased; demand was met through addition of climate-resilient water sources and management of existing supplies, rather than dam building. Agricultural water use, which can vary significantly each year because of water availability and management controls, has remained relatively steady. Small developments of dams and irrigation areas continue to increase pressure on resource development and effective management.</td>
<td>Very high impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use and management</td>
<td>Land clearing continues at minor levels, except in Queensland. Adoption of best management practice is improving run-off and nutrient load pressures. Moderate areas of bushfire activity occurred in temperate environments. Northern Australian tropical savanna and rangelands had generally typical levels of burning, with a peak in 2011. Impacts of farming are ongoing, with small decreases in farmed area each year.</td>
<td>Very high impact</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Assessment summary 1 (continued)

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Very high impact</td>
<td>In grade</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High impact</td>
<td>In trend</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low impact</td>
<td>To 2011</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very low impact</td>
<td>assessment</td>
<td></td>
</tr>
</tbody>
</table>

**Pests and invasive species**

- Increasing areas of inland water systems are affected by vertebrate pests
- Additional Weeds of National Significance are affecting mainland waterways

**Recent trends**

- **Improving**
- **Deteriorating**
- **Stable**
- **Unclear**

**Grades**

- **Very low impact**: There are few or negligible impacts, and predictions indicate that future impacts on the environmental values of regions are likely to be negligible
- **Low impact**: There are minor impacts in some areas, and predictions indicate that future impacts on the environmental values of regions are likely to occur, although they will be localised
- **High impact**: The current and predicted environmental impacts are significantly affecting the values of regions, and predictions indicate serious environmental degradation within 50 years
- **Very high impact**: The current and predicted environmental impacts are widespread, irreversibly affecting the values of regions, and predictions indicate widespread and serious environmental degradation across the region within 10 years

**Confidence**

- **Adequate**: Adequate high-quality evidence and high level of consensus
- **Somewhat adequate**: Adequate high-quality evidence or high level of consensus
- **Limited**: Limited evidence or limited consensus
- **Very limited**: Limited evidence and limited consensus
- **Low**: Evidence and consensus too low to make an assessment

**Comparability**

- **Comparable**: Grade and trend are comparable to the previous assessment
- **Somewhat comparable**: Grade and trend are somewhat comparable to the previous assessment
- **Not comparable**: Grade and trend are not comparable to the previous assessment

For additional information and an accessible version of the assessment summary, see SoE Digital.
State and trends of inland water environments

At a glance

Online availability of flow data and water resources information has increased substantially since 2011, including:

- various state-based data portals
- a national repository with flow and other data for more than 3400 sites
- a national set of 222 long-term, high-quality reference flow gauging stations
- monthly updates of rainfall patterns and streamflow status
- regional information on the state and trends of streamflow, groundwater and major water balance components.

Surface and groundwater conditions have varied considerably since 2011, largely in response to climate. National water storage levels varied from above 80 per cent to below 50 per cent during the period. State-level variations in storage have ranged from above 75 per cent to below 45 per cent for New South Wales and Tasmania, whereas South Australia’s water storage has remained constant at between 80 and 100 per cent, supported by water from the Murray River. Following dry conditions in the northern and southern extremities of the Murray–Darling Basin since 2012, Basin rainfall during the 18 months leading up to 2016 was largely in the median range. Basin streamflows in early 2016 were mostly around average in southern and central areas, with a mix of above average and below average flows in the north. The South West Coast was one of the few wetter-than-normal areas of Australia leading into 2016, with 55 mm of total rainfall in January 2016; this was 224 per cent higher than the 1980–2015 average. Conversely, total rainfall across the Carpentaria Coast division was 98 mm, 52 per cent lower than the 35-year average.

This 2016 report includes a new assessment of the state of groundwater, based on national aggregated information. Groundwater condition is mostly graded as poor across Australia’s drainage divisions, reflecting historical groundwater use, significant numbers of bores and low knowledge of the impacts on groundwater-dependent ecosystems. Trends were mostly assessed as deteriorating or stable.

Unlike the extensive site-based assessment of the SoE 2011 report, water quality assessment for 2016 was based on a range of sources at the state, region or river scale. At a regional level, Lake Eyre Basin water quality monitoring, for example, revealed results generally consistent with previous reporting, the period sampled and the hydrological conditions. Some improving trends were noted for the Murray–Darling Basin, but no assessment was possible for more remote areas, including the South Western Plateau, North Western Plateau and Pilbara–Gascoyne drainage divisions.

Finally, the state and trends of ecological processes and key species populations ranged from very poor, with deteriorating trends across the Murray–Darling, to poor to good condition, with stable trends for southeastern and south-western regions, to good for much of the rest of the country.

The pressures discussed previously influence the state and trends of inland water environments in multiple ways, and the pressure–state interactions are further affected in many areas of the country by our management responses. Climate and land use largely control much of the state of both surface-water and groundwater resources, and these are further modified by water resources infrastructure and operational management. Pests and invasive species then interact with the groundwater and surface-water hydrological regimes to influence the state of inland water environments.
Australia’s surface-water and groundwater conditions have varied considerably during the past 5 years, largely in response to the varying climatic conditions mentioned previously. In 2012, after the strong 2010–12 La Niña event, many regions of the country had experienced recent high streamflows and floods, groundwater levels were stable or rising, and Australia’s aggregated water storage holdings were around or above 80 per cent of capacity. After the millennium drought, this wetting of the country was welcome, with positive responses for water quality and ecological processes. More recently, with the pressures of historically warm years and significant regional drying, the condition of our inland water environments has been more varied.

Four condition assessments of Australia’s inland waters are provided in this report, considering the state and trends of:
- inland water flows and levels
- groundwater resources—a new assessment for 2016
- inland water quality, focusing primarily on surface water
- ecological processes and species populations.

The 2011 state and trends assessments were based, to a greater degree, on analyses undertaken specifically for SoE 2011, including a highly detailed site-based report for water quality. For 2016, the assessments are based on publicly available data and information, including state-based SoE assessments, and specific national or regional assessments, such as for the Great Barrier Reef catchments, the Lake Eyre Basin and the Murray–Darling Basin.

One of the challenges of assessing states and trends is determining the baseline against which the assessment is made. For this report, SoE 2011 provides the baseline, although there is some uncertainty about the methods that were used to reach a particular grade. The Wentworth Group of Concerned Scientists has been leading work since 2008 to provide more comprehensive and uniform baselines and assessments of environmental condition (see information on environmental economic accounting in the Drivers report). Under the National Plan for Environmental Information, the Bureau of Meteorology published a Guide to environmental accounting in Australia (BoM 2013b), which describes water accounts and their purpose, the risks and issues to be considered in accounts, and pathways for implementing accounts. Additionally, the Australian Bureau of Statistics has published annual economic-focused environmental accounts since 2014. Such approaches offer future opportunities, including aligning data with current assessment methodologies and increasing the use of readily available monitoring data.

## Water flows and levels

The Australian surface hydrological network has significant unregulated areas, with flows that reflect the combined effects of climate, and land use and management. There are also significant areas where water management interventions affect the flows in ways that can be beneficial, neutral or detrimental to the aquatic environment. Furthermore, the surface-water system and the broader landscape influence subsurface flows, supporting recharge and discharge of groundwater resources and, thus, the quality of both surface and subsurface resources.

Short-term and long-term changes in flows and water levels produce a range of primary and secondary effects on ecological systems. Increased low-flow and zero-flow days during droughts decrease environmentally important hydrological connectivity and increase pressure on refuge areas such as pools. Long periods of regulated flows and contraseasonal flows (e.g. high flows in dry periods to meet needs such as irrigation) disrupt the timing and nature of ecological events, such as plant growth, and fish or bird breeding. Increases in groundwater recharge above long-term values have raised groundwater levels and produced dryland salinity, whereas drainage of acid sulfate soils has acidified local waterways and caused ecological damage. Finally, although periods of flooding replenish wetlands and provide opportunities for animal breeding and plant growth, extended flooding waterlogs plants, leading to poor plant health, failed regeneration and, eventually, death. Thus, the ecological value of the state and trends of inland water flows and levels must be viewed through a variety of lenses regarding ecological consequences.

Compared with previous assessments, this assessment of the state and trends of inland water flows and levels focuses more on unregulated than on regulated flows. It is intended that this approach best represents the effects of the pressures of climate, and land use and management, without a large influence of water resources development and management intervention.
Available data

A major increase in the online availability of flow data and information on water resources assessment has occurred in Australia since 2011. The Bureau of Meteorology’s 2010 and 2012 Australian Water Resources Assessments provide detailed analyses of the water resources situation in each of the 13 national drainage divisions, and the Bureau’s 2013–14 Water in Australia report was the first in an annual series that highlights key issues related to water resources and their use at a national scale. Additionally, the Bureau’s annual National Water Accounts provide detailed information on water resource management for 10 nationally significant water regions. This includes information on Australia’s billion-dollar water market, such as volumes of water traded, extracted and managed for economic, social, cultural and environmental benefit. Many state agencies have increased online access to streamflow data in recent years, and a national repository of flow data and other information for more than 3400 sites is available at the Bureau’s Water Data Online site.

A further national source of information on surface-water resources is the Geoscience Australia – CSIRO data cube; this is a resource based on a time series of satellite data that, when integrated and calibrated with high-quality surface observations, has the potential to reveal the state of water volumes in surface storage areas and to shed light on water quality (Dekker & Hestir 2012). Remote sensing of water balance components across large areas has been found to be feasible. An analysis of remotely sensed precipitation, evapotranspiration and terrestrial water storage changes for the Lake Eyre Basin closed the water balance, with an error of around 2.1 per cent, or 6.2 mm, of the 300 mm annual average water input through precipitation. This equated to a continental-scale average run-off of 144.7 ± 11.3 mm per year, which is comparable with the national values determined by the Bureau of Meteorology (Wang et al. 2014). The Water Observations from Space (WOfS) product is one example of application of the data cube to water resources. WOfS provides a historical summary of inundation for each grid cell across Australia, based on 27 years of Landsat images. Combining this history with local-scale information of topography and land cover could provide insight into the local ecological effects of historical inundation.

Water quality observations from space have also been investigated, looking at the use of reflected light to inform indicators such as chlorophyll, coloured dissolved organic matter, total suspended matter and the light environment of the water column. These indicators could provide estimates of important ecological factors such as trophic status and aquatic carbon content. Investigations have concluded that there is potential to use such approaches, although more in situ data are needed to support parameterisation and validation of the Earth observation–derived water quality information products (Dekker & Hestir 2012).

The Bureau of Meteorology’s Hydrologic Reference Stations and Monthly Water Update reports provide information for assessing the state and trends of water flows and levels across much of the country. The Hydrologic Reference Stations are a set of 222 long-term, high-quality flow gauging stations, all of which have no major flow-regulating structures upstream of the gauge. The gauging stations are managed by various, mostly state, water agencies. The data recorded at these stations are used to identify streamflow trends, and to analyse long-term variability and change in streamflow. Most stations—located in 10 of the 13 national drainage divisions—have data available to at least the end of December 2014.

The Monthly Water Update provides an online overview of rainfall patterns and streamflow status across Australia, updated for each month early in the following month. Updates have been produced since May 2015 and are available for 9 of the 13 national drainage divisions. Updates are not available for the North Western Plateau, Pilbara–Gascoyne or South Western Plateau because of observing network issues. The Monthly Water Update interprets the hydrological status of surface-water flows each month using provisional information from data providers. Gauging stations have been selected to best represent the spatial variation of flows across each drainage division. Data are presented as deciles to support comparison (e.g. Figures WAT12 and WAT13), and data for individual sites can also be viewed.

In addition to the above, the Regional Water Information online resource provides an array of options for examining the state and trends of streamflow, groundwater and major water balance components—precipitation, potential and actual evaporation, and run-off. This portal allows users to examine information at monthly and annual scales from more than 3500 gauging stations across Australia.
Figure WAT12  Rainfall deciles for the Lake Eyre Basin, January 2016
Figure WAT13  Monthly streamflow for the Lake Eyre Basin, January 2016

Source: Monthly Water Update; © Commonwealth of Australia (Bureau of Meteorology) 2016
Triennial (i.e. every 3 years) reporting on Australia’s implementation of the Ramsar Convention on Wetlands provides a further source of information, covering wetland condition and management. The most recent report was prepared for the 12th Meeting of the Conference of the Contracting Parties, held in 2015 (Australian Government 2014). In addition to information on management planning and effectiveness, ecological value and condition, and social and cultural aspects, the most recent report stated that the condition of 59 of 65 of Australia’s Ramsar wetlands did not change.

**Regional results**

The Carpentaria Coast drainage division is represented in both the Monthly Water Update and the Hydrologic Reference Stations. In January 2016, more than half of the division had lower than average rainfall, with some areas reporting the lowest rainfall on record. Total rainfall across the division was 98 mm, 52 per cent lower than the 1980–2015 average of 206 mm. January rainfall was the ninth lowest in the past 117 years, and streamflows for most of the area were in the median range. Reference flow gauging stations within the division showed no significant trends for the 4 years from 2011 to 2014, with only the Wenlock River at Moreton showing a significant increasing trend in flow since 1967. Eight stations—2 in the Northern Territory and 6 in Queensland—showed significant step changes in their flow history, with the dates for these changes falling between 1970 and 1998. Annual flows for the past 4 years showed no trends towards either higher than average or lower than average values.

The Lake Eyre Basin has 5 high-quality reference flow gauges—2 in South Australia and 3 in the Northern Territory. The Monthly Water Update reports on 6 stations—5 in Queensland. Average to lower than average rainfall conditions in much of the Queensland area of the Lake Eyre Basin in mid-2015 to late 2015 produced lower than average flows in January 2016, except for the Bulloo River at Autumn Vale, which had above average flows because of some local high rainfall at the end of 2015. The region showed a small but insignificant trend towards lower than average flows in recent years, with 2 gauges reporting zero flows for 2013 and 2014.

Following periods of moderately extensive dry conditions in the northern and southern extremities of the Murray–Darling Basin during much of the period since 2012, rainfall in the 18 months leading up to 2016 was largely in the median range (decile 4–7) across the Basin. Basin streamflows in early 2016 were mostly around average in the southern and central areas, with a mix of above average and lower than average flows in some northern catchments. Stations on the Gwydir, Namoi and Macquarie rivers reported below average to very much below average flows, with the Gwydir River downstream of Copeton Dam having the lowest flow since 1980. The Copeton Dam was less than 17 per cent full at that stage, having fallen from 100 per cent full during the previous 40 months. The Basin contains 75 reference stations, with data to the end of 2013. Given the significant level of water resources development in the Basin, the stations are largely spread around the southern and eastern periphery. Of these 75, 56 had more years of below average than above average flows during 2011–13, with 28 (37 per cent) having all 3 years with below average flows.

The North East Coast drainage division covers the eastern coastal catchments of Queensland, including all those that flow to the Great Barrier Reef lagoon. The Monthly Water Update gives readings for 42 flow stations, from Pascoe River at Garraway Creek, at 12.7°S, to Logan River at Forest Home, at 28.2°S. The high-quality reference set also contains 42 stations for this division, 8 of which coincide. The tropical nature of the division and the moderate size of most of the coastal catchments mean that it is possible for adjacent catchments to have very much below average and very much above average rainfall in a given period. In early 2016, one area of the division, north of Cooktown, had above average rainfall in the previous 6–12 months, while the rest of the division had average to below average rainfall. Above average flows occurred at 16 per cent of the sites, mostly in the south, whereas average and below average flows occurred at 53 and 29 per cent of the sites, respectively, spread across most of the division. Long-term downwards flow trends are evident at 7 gauges in the Burrun, Brisbane and Logan–Albert catchments, with downwards step changes in 22 gauges across the catchment; the dates of these changes ranged from 1960 to 2007. Recent-year annual flows have not been dominated by either higher than average or lower than average values.
The North Western Plateau and Pilbara–Gascoyne divisions have insufficient river gauges or data to support either long-term, high-quality reference site trend analyses or a Monthly Water Update. Streamflow data for the De Grey River catchment showed annual flows in the past 5 years to be generally lower than in the previous decade. Streams in the Pilbara–Gascoyne have showed no consistency in annual flows in recent years, reflecting the variable nature and influence of the different rainfall pressures in the region.

Long-term and high-quality river gauging in the South Australian Gulf focuses on the less dry and more densely populated areas of the drainage division, around Adelaide. Periodic data summaries for various catchments in the Gulf are published by the South Australian Government, through its WaterConnect portal. Leading into 2016, the division saw above average rainfall in the southern half, and mainly average conditions in the north. The exception is for the end of 2015, when below average to very much below average rainfall occurred across 75 per cent of the division. Consequently, early 2016 streamflows were average to very much below average. Very much below average flows occurred at 2 sites north of Adelaide, with the Broughton River at Mooroola having its third lowest January streamflow since 1980. Falling flow trends across 3 of the 5 long-term gauging stations aligned with more broadly observed trends across much of south-eastern and south-western Australia.

As noted previously, the combined South East Coast drainage division used in SoE 2011 is now more commonly broken into two divisions: South East Coast (New South Wales) and South East Coast (Victoria), the latter of which includes parts of the Snowy and East Gippsland catchments in New South Wales, and the South Australian areas of the Glenelg River and Millicent Coast catchments.

Similar to the North East Coast, the South East Coast (New South Wales) division covers a narrow strip of coastal catchments that extend south from the Gold Coast and Tweed River to the Towamba River. The latitudinal range of rainfall pressures—for example, through systems such as east coast lows—played out clearly on streamflow in early 2016. Flow for sites around and south of Newcastle was mostly higher than average, with the highest January flows since 1980 recorded for 3 sites. Much of this was because of the above average to very much above average rainfall falling across 62 per cent of the division. Conversely, 27 per cent of streamflow sites, all north of Newcastle, experienced below average flows. Flow trend data from long-term Hydrologic Reference Stations are largely equivocal for the division, with only 6 of the 17 stations having sufficient data to support a trend analysis, and only 1 of those (the Goulburn River at Coggan) showing a trend, which was falling. Across 2014–15, 7 of 14 sites available in the Regional Water Information service showed no trend; 5 showed a strong negative trend and 2 a weak negative trend in the medium range of flows. This was a slight degradation compared with 2013–14 conditions, when there were 9 sites with no significant trend and 5 with a strong negative trend.

Similarly, the South East Coast (Victoria) region had 10 of 19 reported sites with no significant trend in 2014–15; 3 sites had weak negative trends, and the remaining 6 sites had a strong negative trend. The latter 6 months of 2015 produced significant areas of very much below average and lowest-on-record rainfall across the western and central southern regions of Victoria, which contributed further to very low flows. The south-eastern areas of the state had mostly average conditions. The long-term, high-quality reference flow sites for this division have a range of above average and below average annual flows during the period, with 6 of 27 sites having all years above average for 2011–13, and 5 sites having all years below average. The former sites were in Gippsland and the latter near the South Australian coast, emphasising the climatological variability along the coast in the past 5 years.

One of the few wetter-than-normal areas of Australia leading into 2016 was the South West Coast. This was in stark contrast to the previous 36 months, when significant areas of the south-west experienced below average, very much below average and lowest-on-record rainfall. This region has 13 Hydrologic Reference Stations and 23 stations suitable for Monthly Water Updates, with 2 sites (Deep River at Teds Pool and Harvey River at Dingo Road) in common, meeting the differing requirements of these 2 online information products. Regional Water Information for 2014–15 reported on-flow trends for 9 sites, with the other 475 sites in the division having insufficient data to support analysis. Six of these 9 sites had a strongly significant falling trend for 2014–15, and 3 showed no trend. Early 2016 results showed above average to very much above average flows.
for 65 per cent of sites. Regarding longer-term trends, 9 of 11 reference sites had significant falling trends, with 8 sites showing significant step reductions in flow from 1975 to 2000.

The Tanami–Timor Sea Coast division has 13 reference stations, with 10 in the Northern Territory. Eight of the stations show significant trends during the long term, all rising. Rainfall conditions during the latter months of 2015 ranged from very much above to very much below average across different parts of the division. Eleven flow stations normally report in the Monthly Water Update. In December 2015, 10 of these were reported to have flows exceeding average conditions, with 7 showing the highest-on-record flows for December since 1980. January 2016 conditions returned to largely average, with 7 sites having average flows, 3 below average and 1 (Daly River at Mount Nancar) very much above average.

Serious rainfall deficits affected all of Tasmania for much of 2015, with some areas in the west having the lowest 12-month rainfall on record. Four of 12 reference stations show long-term declines in flow, and declines in flow during 2015 saw the division’s 46 major water storages drop from a cumulative 46.1 to 35.6 per cent full. Streamflows for stations located mainly in the north of the state were reported in January 2016 as below average. Lowest-on-record flows occurred at 44 per cent of sites, located in the north and central east. At 7 sites, streamflows were the lowest for January since at least 1980, because of low rainfall in the previous 3 months.
### Assessment summary 2

State and trends of inland water flows and levels

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carpentaria Coast (formerly Gulf of Carpentaria)</strong></td>
<td>Largely median streamflows across the region, reflecting recent variability in climate pressures. No significant trends in flows evident since 2011</td>
<td>Poor</td>
<td>In grade</td>
<td>In trend</td>
</tr>
<tr>
<td><strong>Lake Eyre Basin</strong></td>
<td>Streamflow gauging indicates below average flows in recent years. No significant trends in flows evident since 2011</td>
<td>Poor</td>
<td></td>
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<tr>
<td><strong>Murray–Darling Basin</strong></td>
<td>Predominance of below average annual flows during recent years, with monthly flows around average early in 2016. Longer-term downwards trends in flows seen in nearly 50% of stations, with no change in trends evident since 2011</td>
<td>Poor</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>North East Coast</strong></td>
<td>State and trends of flows showing no evidence of significant changes since 2011</td>
<td>Poor</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>North Western Plateau</strong></td>
<td>Low data availability, with no discernible significant change in state or trends</td>
<td>Poor</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pilbara–Gascoyne (formerly Indian Ocean)</strong></td>
<td>Low data availability, with no discernible significant change in state or trends</td>
<td>Poor</td>
<td></td>
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<tr>
<td><strong>South Australian Gulf</strong></td>
<td>Observations largely focused on a small part of the region, dominated by below average flows in recent years</td>
<td>Poor</td>
<td></td>
<td></td>
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<tr>
<td><strong>South East Coast (NSW)</strong> (Note: In 2011, South East Coast [NSW] and South East Coast [Vic] were combined in South East Coast)</td>
<td>A range of below average to above average monthly streamflows across the division in recent years, with many sites showing a decreasing trend in annual medium flows</td>
<td>Poor</td>
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</tbody>
</table>
### Assessment summary 2 (continued)

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>South East Coast (Victoria) (Note: In 2011, South East Coast [NSW] and South East Coast [Vic] were combined in South East Coast)</td>
<td>A range of annual flows from very much below average to above average in recent years, dominated by below average to average. Nearly half the reported sites showing weakly to strongly falling trends</td>
<td>Very poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>South West Coast</td>
<td>Mostly average to below average annual flows, with some very much below average. Reference sites dominated by negative annual flow anomalies. Trends largely weakly to strong falling</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>South Western Plateau</td>
<td>Low data availability</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Tanami–Timor Sea Coast</td>
<td>Mostly above average flows in recent years, with some strongly significant rising trends, offset by recent lower flows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tasmania</td>
<td>A mix of above average and below average annual flows to 2013, transitioning to average to very much below average. Flows recently trending down</td>
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</tbody>
</table>

For additional information and an accessible version of the assessment summary, see SoE Digital.
Groundwater resources

Groundwater systems are important in providing water resources for much of the country, and are subject to the pressures of climate (McFarlane et al. 2012), development and growth. Groundwater is also an important and often overlooked component of aquatic ecosystems, both by itself and in conjunction with surface water.

Groundwater and surface-water interconnections have myriad hydrological and ecological effects, and disconnection of groundwater from surface water has potential implications for ecological function and resilience. For example, an investigation of the disproportionately high reductions in streamflow arising from reduced rainfall in Western Australia found that, when groundwater was connected, it played a key role in streamflow generation (Kinal & Stoneman 2012). Groundwater was an effect magnifier; the contribution of connected groundwater to streamflow generation was mostly indirect and magnified other streamflow-generating processes, such as surface run-off and throughflow. As connectivity decreased, this magnifying effect declined.

Even as late as 2012, saturated groundwater ecosystems were considered one of the ecological research frontiers (Larned 2012), with many unexplored processes and issues. Research issues included:

- field and access logistics
- ecosystem boundaries and other spatial information
- habitat, taxonomic and biogeographic knowledge.

This new assessment summary area is based largely on the national integrated information sources available from the Bureau of Meteorology, aided by state-level analysis and reporting. Supporting information came from investigations associated with the Bioregional Assessment Programme that aim to improve understanding of the potential impacts of coal-seam gas and large coal mining developments on water resources and water-related assets.

Available data

Nationally collated groundwater data were not available for consideration and inclusion in SoE 2011, although at that time significant investments were being made in the collation and assessment of groundwater data. These were driven by both the growing interest in coal-seam gas exploration and production, and the Bureau of Meteorology’s commitment to extending the national water information focus under the ground.

Spatial and informational heterogeneity is a challenge in assessing groundwater observations across Australia. Each state and territory uses localised terminology to describe hydrogeological units (e.g. sediments and rocks with similar hydraulic characteristics), causing problems for cross-jurisdictional regions such as the Great Artesian Basin and the Lake Eyre Basin bioregions. Since 2011, the Bureau of Meteorology has led development of a National Aquifer Framework, used for consistent naming and grouping of hydrogeological units across Australia.

The National Aquifer Framework is used to standardise terminology in the Bureau’s National Groundwater Information System (NGIS)—Australia’s national groundwater information system. The NGIS is a specialist spatial database containing a broad range of groundwater information contributed by states and territories. It contains more than 850,000 bore locations across Australia, with associated lithology logs, bore construction logs and hydrostratigraphy logs. For some areas, 2D and 3D aquifer geometries are also available.

The NGIS forms a large component of a national suite of groundwater information products available from the Bureau; the others are Australian Groundwater Insight, Australian Groundwater Explorer and the Atlas of Groundwater Dependent Ecosystems. The Insight tool provides broadscale, nationally consistent information on groundwater, including hydrogeology, entitlements, management plans and zones, and levels and trends. The Explorer supports in-depth examination of bore locations, bore logs, groundwater levels and landscape characteristics, including visualisation, analysis tools and data download. Finally, the Atlas shows ecological and hydrogeological information on known groundwater-dependent ecosystems, and ecosystems that potentially use groundwater.

Additional resources exploring the state and trend of groundwater resources are available from some states and territories, often tied to local resource management planning and monitoring. The South Australian Government, for example, has implemented a robust and consistent method to report on State Natural Resource Management Plan 2012 targets, using a report...
card approach. The report cards provide statewide information on the condition of natural resources and their management. The information is also presented at the scale of natural resource management (NRM) regions. In total, 56 report cards summarise statewide information, and 242 are regional snapshots of the same information. For groundwater assessment, the report cards provide summary assessments that focus on groundwater extraction, annual rainfall, current salinity and changes in groundwater level for the past 12 months. The report cards include traffic-light indicators of aquifer condition at the scale of groundwater management units.

Recent additions to the CSIRO-led national series of water resource and yield assessments have used a range of approaches to consider groundwater. In the Flinders (Petheram et al. 2013a) and Gilbert (Petheram et al. 2013b) assessments, for example, groundwater was not assessed as a resource. Instead, the assessments focused on the potential for groundwater processes and, hence, associated ecological processes, to change under irrigation development. Elsewhere, in the Pilbara assessment (McFarlane 2015), significant attention was paid to groundwater-dependent ecosystems and their ecological, cultural, social and tourism values.

A major recent initiative to improve groundwater information and understanding in selected areas is the Australian Government’s Bioregional Assessment Programme. The bioregional assessments focus on areas across Queensland, New South Wales, Victoria and South Australia, specifically the Lake Eyre, Gippsland, Sydney and Northern Sydney basins, and the Clarence–Moreton and Northern Inland Catchments bioregions. The assessments provide a risk analysis that identifies areas where potential impacts are likely, or unlikely, to occur. They consider potential impacts, particularly focusing on regional-scale and cumulative impacts, of coal-seam gas, and open-cut and underground coalmining developments. They produce a range of products, including registers of data and water-dependent assets, conceptual models, outputs of numerical and analytical models, and descriptive reports. The assessments have limited reporting on the impacts of recent development, but, with regard to groundwater levels and trends, they do offer the opportunity to clearly set baseline conditions and to identify the types of changes in condition that may occur, thereby informing ongoing monitoring programs.

Surface-water drainage divisions have been used elsewhere in this theme as the assessment components, and Australia’s water resource assessments consider groundwater in this context. Alternative organising approaches for assessment are to consider the principal or other hydrogeology (Figure WAT14), or possibly groundwater management units. However, the challenges of undertaking assessment across multiple hydrogeological layers in one area, along with the desire for spatial consistency across condition assessments, led to selection of the surface drainage divisions as the assessment components. Within these areas, the assessment considers the range of groundwater aquifer layers for which information is available.

Groundwater level status is available in the Groundwater Insight tool for many of the more than 800,000 bores in the national database. Trend information is also available for many of the bores that are monitored on a regular basis, and that meet criteria for both frequency and continuity of monitoring. Levels are categorised by percentile, based on a 20-year water level history; below average conditions are below the 25th percentile, above average conditions are above the 75th percentile, and average conditions are in between.

Regional results

Carpentaria Coast bore information mostly comes from upper aquifers, and from two primary regions: the Roper River in the Northern Territory and the Mitchell–Coleman rivers system in Queensland. More than 100 bores had timeseries data, with some 70 having sufficient data to support a 5-year trend analysis. Of these, around 40 showed a rising trend, 20 were stable, and the remainder showed a declining trend. Water level status was mostly average, with an equal minor mix of below average and above average levels.

Groundwater data for the Lake Eyre Basin come mostly from the Diamantina–Georgina rivers system, with a small number of sites in the Cooper Creek – Bulloo system to the east of the basin. Reasonable coverage of upper, middle and lower aquifers is available. Sixty sites supported decile analyses of levels, with just over half having below average values and one-third being average. Of the 48 sites with sufficient data for timeseries trends, 27 were declining, and the remainder were equally distributed between stable and rising
Principal hydrogeology

- **Fractured or fissured; extensive aquifers of low to moderate productivity**
- **Fractured or fissured; extensive, highly productive aquifers**
- **Local aquifers; generally of low productivity**
- **Porous; extensive aquifers of low to moderate productivity**
- **Porous; extensive, highly productive aquifers**

Source: Bureau of Meteorology Groundwater Insight

**Figure WAT14** Principal hydrogeology of Australia
trends. This counters some of the information available from the mid-term review for stage 3 of the Great Artesian Basin Sustainability Initiative (Sinclair Knight Merz 2013), which reported anecdotal evidence of increasing bore pressure and increasing flow from bore springs. Similarly, a recent water resource assessment for the Great Artesian Basin (Smerdon et al. 2012) indicated that, when considering the 20 years up until 2010, there was clear evidence of recovery of groundwater levels arising from bore-capping and water-piping activities.

More than half of the bore timeseries available from the national information system are for bores in the Murray–Darling Basin, with bores in all 28 of the Basin’s river regions. More than 7000 of the 10,400 sites are for upper aquifers, and the remainder are evenly split between middle and lower aquifers. More than 5000 bores have sufficient data to support decile

Hancock Gorge to Kermits Pool, Western Australia
Photo by Phil McFadden
analyses of water level, with most showing average levels, and the remainder fairly evenly distributed between below average (1202 bores) and above average (1231 bores). Groundwater trends were mostly (3429 out of 5518) rising, with slightly more than 1500 bores stable and nearly 600 declining.

The North East Coast division is well represented, with groundwater data for most areas south of Cairns. Data are available for nearly 5000 sites, with 3500 of these reporting on the upper aquifers and 3600 reporting on water level status. Of the 5000 sites, 2000 had above average water levels, and most of the rest were in the average range. Clusters of below average values are evident near Atherton and west of Toowoomba, and clusters of above average levels occur near Ayr, near Bowen, near Mackay, inland of Bundaberg, west of Toowoomba and at North Stradbroke Island. Groundwater trends are largely rising (50 per cent) and stable (37 per cent), with clusters of rising trends around Toowoomba and inland of Bundaberg.

No groundwater observations are available in the national database for the North Western Plateau. Only a small set of bore data is available for the Pilbara–Gascoyne division, all but 3 of which are in the Greenough River region, to the south. Most bores have average to above average levels, with trends mostly stable.

Nearly 1000 bores have data available across the South Australian Gulf division, the bulk of which are located towards the coast, south of the Lake Torrens – Mambray Coast river region. Nearly 750 bores have sufficient data to support decile analysis, with around 43 per cent of bores above average and 38 per cent in the average range. Trends are available for 800 bores, and are mostly rising (322 bores) or stable (349 bores). A minority are declining.

Although 300 bores are recorded in the national database for the South East Coast (New South Wales) division, fewer than 25 have data suitable for analysis; these are dominated by average groundwater level status and stable trends.

The South East Coast (Victoria) division has been the focus of considerable groundwater investigation, being a trial area for development of a standardised groundwater information model and database (Sinclair Knight Merz 2013). More recently, it has been an area for investigation of a multi-annual timeseries analysis approach to assess the effects of pumping and climate drivers on groundwater levels (Shapoori et al. 2015). Data from more than 1500 bores are available, mostly for the upper aquifers, spread from the Mitchell–Thomson river region in the east to the Millicent Coast at the Victoria – South Australia border. Average range groundwater levels exist for 46 per cent of bores, and the remainder are evenly distributed between above average and below average levels. Trends are reported for 1259 bores, with the majority being stable.

Bores within the South West Coast division are located predominantly in the coastal and near-coastal regions, mostly between Busselton and Joondalup–Yanchep. Levels are in the average (54 per cent) or below average ranges (38 per cent), with trends mostly being stable or declining. Very few bores show a rising trend.

There are 165 bores reported in the South Western Plateau division, all of which are in the Gairdner River region, and most of which are east of Penong, thereby limiting the relevance of the bore information for the whole division. Of the 95 bores supporting decile analysis of levels, nearly two-thirds have groundwater levels in the average range. Trends are reported for 130 sites, with most being stable during the past 5 years.

The Tanami–Timor Sea Coast division has data available for 263 bores, most of which are in the Adelaide, Daly, Finniss and Victoria River – Wiso river regions. Data are available for a good range of lower, middle and upper aquifers, with a significant majority of bores showing levels in the average range. Trends are less evenly distributed, with 53 per cent of bores having a rising trend, 27 per cent stable and 40 per cent declining. A small cluster of rising trends is evident west of Katherine.

Six bores from Tasmania have timeseries data available in the national database, although around 2000 bores are included in the NGIS. Data in the national database are currently insufficient to support reporting of either levels or trends, although work to increase available data is progressing.
## Assessment summary 3
State and trends of groundwater resources

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpentaria Coast</td>
<td>Mostly average levels, with stable to rising trends in upper aquifers. Limited information or no dominant condition for middle and lower aquifers</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>Lake Eyre Basin</td>
<td>Mostly below average levels, with others mostly stable. Trends mostly declining</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>Murray–Darling Basin</td>
<td>Mostly average, with a moderate number of above average and below average levels. Most bores have a rising trend</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>North East Coast</td>
<td>Mostly above average levels, with a large minority of average values. Trends mostly rising, with a large minority of stable values</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>North Western Plateau</td>
<td>Little monitoring data available. Minimal groundwater exploitation</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>Pilbara–Gascoyne</td>
<td>Few bores in limited areas. Average to above average groundwater levels, with mostly stable trends</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>South Australian Gulf</td>
<td>A significant density of bores, with mostly rising to stable levels, and trends above average to average</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>South East Coast (NSW)</td>
<td>The limited data available indicate average levels and stable trends</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
</tr>
<tr>
<td>South East Coast (Victoria)</td>
<td>Good data coverage across upper, middle and lower aquifers, with an even distribution of levels and mostly stable trends</td>
<td><img src="#" alt="Assessment" /></td>
<td><img src="#" alt="Confidence" /></td>
<td><img src="#" alt="Comparability" /></td>
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</tbody>
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### Assessment summary 3 (continued)

<table>
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<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>South West Coast</td>
<td>Data coverage is mostly around the coast, with average and below average levels, and stable and declining trends</td>
<td>Poor</td>
<td>Moderate</td>
<td>Not previously assessed</td>
</tr>
<tr>
<td>South Western Plateau</td>
<td>Data are limited to the eastern portion of the division, showing average levels and stable trends</td>
<td>Poor</td>
<td>Moderate</td>
<td>Not previously assessed</td>
</tr>
<tr>
<td>Tanami–Timor Sea Coast</td>
<td>A limited spatial distribution of bores, largely with average levels and a little over half with rising trends</td>
<td>Good</td>
<td>Very limited</td>
<td>Not previously assessed</td>
</tr>
<tr>
<td>Tasmania</td>
<td>Moderate numbers of bores and groundwater use. Insufficient data to support report</td>
<td>Very poor</td>
<td>Low</td>
<td>Not previously assessed</td>
</tr>
</tbody>
</table>

**Recent trends**
- **Improving**
- **Deteriorating**
- **Stable**
- **Unclear**

**Grades**
- **Very good**: No significant impacts on groundwater as a result of human activity
- **Good**: Groundwater levels have changed in some areas, but not to the extent that changes are significantly affecting the function of groundwater-dependent ecosystems
- **Poor**: Groundwater levels have changed substantially in some areas, to the extent that the function of groundwater-dependent ecosystems is significantly affected in some areas
- **Very poor**: Groundwater levels have changed substantially across a significant area, to the extent that the function of groundwater-dependent ecosystems is seriously affected. Ecosystem function is seriously affected

**Confidence**
- **Adequate**: Adequate high-quality evidence and high level of consensus
- **Somewhat adequate**: Adequate high-quality evidence or high level of consensus
- **Limited**: Limited evidence or limited consensus
- **Very limited**: Limited evidence and limited consensus
- **Low**: Evidence and consensus too low to make an assessment

**Comparability**
- **Comparable**: Grade and trend are comparable to the previous assessment
- **Somewhat comparable**: Grade and trend are somewhat comparable to the previous assessment
- **Not comparable**: Grade and trend are not comparable to the previous assessment

For additional information and an accessible version of the assessment summary, see [SoE Digital](#).
Water quality

Water quality in SoE 2011 was assessed as a significant one-off activity, involving collection, collation, analysis and assessment of water quality data from thousands of sites across Australia. A comprehensive report considered water quality at the river-region scale, and information was aggregated to the drainage-division scale. Such an analysis was not done for the 2016 update, and assessment is based on consideration and collation of a range of sources at state, region or river scale.

Available data

Assessment of water quality, including groundwater quality, is more complicated than assessing groundwater levels and trends, and much more complicated than assessing surface-water flows and levels. A wide variety of water quality parameters are collected using a range of methods, for sometimes disparate purposes. Available water quality data and metadata were evaluated in the context of supporting Australian Water Resources Assessments. It was found that the potential existed for more than 1,500,000 combinations of site and water quality parameters across the country, and many hundreds of other parameters, with multiple names for seemingly similar parameters. Thus, development of a national data model and collation of a comprehensive national database, as done for groundwater data, would be many years’ work.

A challenge in assessing water quality is selecting an analysis method. Methods continue to develop as our understanding of the potential uses of water quality data develops. Penev et al. (2014) investigated a statistical method to analyse water quality trends in the Shoalhaven region of New South Wales. A mixed data sampling regression method was used, accounting for some of the mixed frequency of data collection used in water quality sampling, as well as the mixed contributions of rain and flow. The authors concluded that the method could distinguish between these contributions, and that the effects of flow on water quality are likely to be more complicated than the effects of rainfall. These types of methodological developments offer the potential to better inform our management around water quality and aquatic ecosystems.

Spatial representativeness is another challenge faced for this and other assessments that use point-sampling data. For some environmental variables, such as rainfall, a local observation is sometimes quite different from regional or synoptic values. Surface-water quality measured at a point integrates many of the processes occurring in upstream catchments, whereas groundwater salinity or acidity can also be a measure of larger-scale factors. Thus, the approach used here focuses on larger, more comprehensive reports that include water quality, with a few individual cases to provide emphasis or counterpoint.

There is no single national repository of data on surface-water quality, nor are there any regular national or state-scale assessments. As part of its national role in water information, the Bureau of Meteorology is investigating the provision of continuous water quality data alongside flow data on the web. Although this is significantly more complicated than collating, standardising and publishing flow data, it is possible that a first tranche of reporting will be available in 2016–17. The Bureau’s Groundwater Insight tool provides information on groundwater salinity for Australia.

States and territories manage water quality monitoring and associated databases for a variety of business purposes. Associated ‘data portals’ offer access at the site level, with very limited support for aggregating and summarising data at the basin and drainage-division level. State and territory monitoring often focuses on key common parameters of water quality, such as sediment, salinity, electrical conductivity, phosphorus, nitrogen and dissolved oxygen, although many individual sites have a full spectrum of water quality parameters. Other parameters, such as organic carbon, are also of major relevance to aquatic ecosystems, as is acidity, particularly in areas with acid sulfate soils. One other area of surface-water quality that has gained attention in recent years is that of blackwater events, including investigation of drivers and effects on aquatic fauna (King et al. 2012, Whitworth et al. 2012, McCarthy et al. 2014).

Regional results

The Queensland ambient network of surface-water quality has some 18 sites located in the Carpentaria Coast division. The most recent Queensland SoE report, which provides some assessment of water quality, is from 2011. The bulk of the division has nonsaline groundwater, with
areas of saline groundwater along the Rosie and nearby rivers, and inland in the south-western areas of the Nicholson – Leichhardt River region.

The Lake Eyre Basin Rivers Assessment 2013–14 monitoring report was released in 2015 and provides the most recent division-wide assessment. Water quality observations were collected from 44 fish-monitoring sites, and various parameters (temperature, dissolved oxygen, conductivity, pH and turbidity) were also measured at gauging stations in the Cooper, Diamantina, Finke, Georgina, Macumba and Neales catchments. For 47 sites, 226 stream water quality samples of each parameter were reported. Many sites across the basin had zero flow at various periods during 2013–14. Water quality was assessed at each fish-monitoring site and was found to be within the range of tolerance for fish species in the Lake Eyre Basin. For in situ sites, water quality parameters in the Diamantina, Warburton, Cooper and Barcoo catchments were within the range of previous reporting rounds. Overall, water quality was generally consistent for the sample period and hydrological conditions (Mathwin et al. 2015).

Basin-scale water quality assessment for the Murray–Darling Basin division can be gained from multiple sources, including state and territory SoE reports; Basin-wide assessments, such as the Sustainable Rivers Audit and Basin-focused water quality assessments (e.g. Henderson et al. 2013); monitoring and reporting as part of implementation of the Basin Plan; and individual multicatchment or sub-basin reports. The 2013 Victorian SoE report (Victorian Government 2013a) was unable to obtain a water quality assessment for the Victorian Murray–Darling Basin catchments, whereas the 2015 New South Wales report (NSW EPA 2015) marked nitrogen and phosphorus levels as moderate, with both having a decreasing impact and reasonable information availability. The most recent SoE report for Queensland is from 2011. The 2015 Australian Capital Territory SoE report (Commissioner for Sustainability and the Environment 2015) rates most water quality indicators as either good or very good, with total nitrogen the only very poor indicator. Trends in the Australian Capital Territory are mostly for improving water quality. The 2015 water report card for the Murray River in South Australia (DEWNR 2015) identified that, in 2014, 75 per cent of the water quality targets for drinking water, 67 per cent for recreation, 87 per cent for flow management and 100 per cent for irrigation were met. Trends in meeting water quality targets were stable during 2010–14.

The Sustainable Rivers Audit is the most comprehensive Basin-wide river health assessment available; however, the most recent report (MDBA 2012) covers 2008–10, so is not relevant to condition assessment after 2011. The Long-Term Intervention Monitoring Project may support broadscale water quality assessment in the future, although reporting at this early stage is focused largely on the water quality impacts of individual environmental flow events. For salinity, the Basin Salinity Management Strategy (BSMS) 2013–14 annual implementation report states that:

When considered over the climatic conditions during 1975–2000, mitigation works and measures put in place to 2014 have delivered an average daily salinity outcome at Morgan of less than 800 EC (electrical conductivity units) for 98 per cent of the time, compared with an outcome of less than 800 EC for 72 per cent of the time that would have occurred with the works and measures that were in place in 2000. In other words, irrespective of climatic conditions, the incidence of salinity exceedance of 800 EC at Morgan has substantially declined as a consequence of BSMS implementation. (MDBA 2015)

An assessment of trends in physical and chemical aspects of water quality for the Murray–Darling Basin was released in 2013 (Henderson et al. 2013), covering 1978–2012, and including trend assessment for 2003–12. There were broad decreases in nutrients across the period, and increases at some sites for some parameters. The floods of 2010–11 increased most nutrients across most sites—except for nitrogen oxides—and conductivity, turbidity and dissolved organic carbon also increased. Most of these have returned to pre-flood values in the years after the floods, leading to an overall improving water quality trend.

Many of the water quality considerations for the North East Coast division focus on the effects of outflows to the Great Barrier Reef, with Brisbane and the surrounding south-east Queensland region also receiving considerable attention. A recent study of sediment load in Great Barrier Reef catchments investigated errors in load estimation and the predictive power of trends in water quality (Wang et al. 2015). A combination of new regression methods and sampling strategies to increase the predictive power resulted in detection of trends of
20 per cent in the past 20 years, which—although longer than the assessment increment for SoE reporting—offers opportunities to better assess trends and the effectiveness of management across decades.

The 2014 Great Barrier Reef report card estimated nutrient and sediment load reductions of more than 10 per cent from 2009 to 2014, and pesticides decreased by more than 30 per cent (GBRMPA 2014). These reductions are somewhat on track to meet 2018 targets. Within these, all catchments were reported as having reductions in catchment loads, with Fitzroy representing the highest risk because of load reductions generally below 5 per cent (Queensland Government 2015). Figure WAT15 shows part of the 2014 ecosystem health report card for the Fitzroy Basin, reporting on nutrient conditions in the Theresa catchment. Extensive ecosystem report card information is available online for catchments of south-east Queensland, where catchment water quality ranges from excellent to poor.

Information supporting water quality assessment for the North Western Plateau, Pilbara–Gascoyne and South Western Plateau is scarce. The most recent SoE report for Western Australia was in 2007, and the most recent statewide river water quality assessment was in 2008.

The South Australian Government has increased online reporting of water quality in recent years, including a range of specific site information and an extensive series of NRM report cards, as mentioned above. Data reported from 2012 for sites in the South Australian Gulf, drawn largely from the Northern and Yorke region, included many sites with enriched levels of nutrients and some with sediment arising from erosion. Saline water was also present at some sites. It was also reported that ‘best land management practices are not being widely implemented and despite some improvements in recent years, much remains to be done to reduce the movement of nutrients into streams’ (EPA SA 2012). The 2013 South Australian SoE report indicated that surface and groundwater water quality in the Northern and Yorke region were in variable condition, with variable trends (EPA SA 2013).

Assessments of inland water quality for the South East Coast (New South Wales) division consider streams, groundwater and coastal lakes. The 2015 New South
Wales SoE report shows moderate nitrogen and phosphorus levels, with an overall decreasing impact on river health. The 2014–15 annual summary of coastal estuary and river water quality (Dakin 2015) contains temperature and salinity data from 21 monitoring stations, spread from the Richmond catchment in the north to the Shoalhaven catchment, providing information that reflects interactions between coastal rainfall, streamflow and marine influences. At a catchment level, the 2013 Clarence River Estuary report card reported water quality mostly in the poor to very poor categories. The Sydney Catchment Authority (2014) reported that, in 2013–14, nutrients for catchments with significant agricultural or urban development regularly exceeded water quality guidelines, whereas those in unaffected catchments generally did not.

Assessment of water quality for the South East Coast (Victoria) division can be considered across three distinct areas:

- the east, encompassing Gippsland Lakes and nearby catchments
- the central area around Port Phillip Bay and Western Port
- areas west of Geelong.

The Victorian Catchment Management Council (2012) reported groundwater and surface-water condition in Gippsland to be moderate to good, while that for Port Phillip Bay and Western Port was in the poor to moderate range. The western Victorian coastal catchments also had groundwater and surface-water quality in the poor to moderate range. The 2012–13 Yarra River and Port Phillip Bay report card (Victorian Government 2013b) provided a broader range of results, ranging from 23 per cent of sites in poor condition to 13 per cent in very good condition, with a slow general trend towards improved conditions.

For the South West Coast division, water quality in the middle and upper sections of the Swan Canning river system was reported to be moderate to poor. For 2011–15, 53 per cent of monitoring sites met long-term nitrogen targets developed for the Swan Canning system, whereas 80 per cent (increasing to 87 per cent in 2015) of sites met long-term phosphorus targets (Swan River Trust 2015). Reports from the Peel–Harvey streams show high to very high nutrient levels during 2011–13, with no discernible trend. Many local water quality improvement plans are being enacted at present, offering hope for future water quality improvements. The most recent statewide assessment of water quality for Western Australia was completed in 2008.

Most information on water quality in the Tanami–Timor Sea division focuses on Darwin. Darwin Harbour Region report cards (DLRM 2016) provide a snapshot of water quality and the health of aquatic ecosystems across the harbour and its catchment. The 2013 report card indicated that water quality mostly ranged from good to excellent, with grades mostly stable in recent years. Water quality in the Daly River in 2012–13 was similar to that in previous years, with known high nitrogen values in the Katherine and Douglas rivers, and low values elsewhere.

Similar to most other states and territories, comprehensive assessment and reporting of Tasmania’s surface-water quality or river condition have not been completed in recent years, with efforts focused on online data portals, guidelines, targets and plans. In the future, the Tasmanian River Condition Index may fill this gap. A few local assessments are available that give some indication of the state and trend of water quality in Tasmania. The 2015 Tamar Estuary report card noted high pollutant loads in the upper estuary because of high inflows from the North and South Esk rivers, in addition to sewage-plant and power-station contributions. In 2014, Hydro Tasmania reported that water quality was mostly good in the lakes and rivers monitored in that year.
## Assessment summary 4

State and trends of water quality

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Very poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Carpentaria Coast (formerly Gulf of Carpentaria)</td>
<td>No division-scale assessment available. Minimal new development since 2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake Eyre Basin</td>
<td>Observations generally consistent with sampling period and hydrological conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray–Darling Basin</td>
<td>Recent local improvements in some water quality parameters, against a background of values exceeding guidelines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North East Coast</td>
<td>Water quality concerns, including nutrients, sediment and pesticides. Significant development of coordinated monitoring and reporting schemes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Western Plateau</td>
<td>Very little water quality data available; no comprehensive assessments available</td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilbara–Gascoyne (formerly Indian Ocean)</td>
<td>Very little water quality data available; no comprehensive assessments available</td>
<td>Not assessed</td>
<td></td>
<td></td>
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<tr>
<td>South Australian Gulf</td>
<td>Broadscale enriched levels of nutrients and sediment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South East Coast (NSW) (Note: In 2011, South East Coast [NSW] and South East Coast [Vic] were combined in South East Coast)</td>
<td>Widespread exceedance of nutrient guidelines</td>
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<td></td>
<td></td>
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</table>
### Assessment summary 4 (continued)

<table>
<thead>
<tr>
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<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>South East Coast (Victoria)</td>
<td>Majority of sites in moderate to poor condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South West Coast</td>
<td>Continuing exceedance of water quality guidelines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Western Plateau</td>
<td>Very little water quality data available; no comprehensive assessments available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanami–Timor Sea Coast</td>
<td>Limited data, mainly from Daly River and Darwin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tasmania</td>
<td>Local areas of high nutrient values; otherwise moderate to very good condition</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For additional information and an accessible version of the assessment summary, see SoE Digital.
Ecological processes and species populations

Assessing water-related ecological processes and species populations further indicates the health of aquatic ecosystems. Processes and populations add a layer of assessment that integrates many of the individual parameters assessed in previous sections.

State and trends of ecological processes

Broadscale health assessment for aquatic ecological processes relies on a background of compliance monitoring, overlaid by programs at the level of individual regions, initiatives or issues. Reporting across the country varies in scale, scope, timing and nature, although standard or common methodologies—such as the Australian River Assessment System and stream condition indices—assist in collating and comparing assessments. Several new and updated assessments have been released since 2011, providing support for this report.

Bunn et al. (2014) produced a landmark assessment of the ecological responses to altered flow regimes for the Murray–Darling Basin, based on 5 research questions:
1. What are the different types of freshwater ecosystems and where are they?
2. What are the flow-related threats to freshwater ecosystems, and how do they differ across the Murray–Darling Basin?
3. How do freshwater ecosystems respond to these flow-related threats, and what is the likelihood they will respond to environmental flows?
4. Can river managers optimise the delivery of environmental flows to improve environmental outcomes?
5. How can river managers measure the success of the application of environmental flows?

A Basin-scale classification of freshwater ecosystems was developed to help address these questions. This classification was used to assess how ecosystems were affected by threats such as water resource development and land-use change. Impacts were found to vary across the Basin—some freshwater ecosystems were affected more by water resource development than others, whereas the cumulative effect of bores, farm dams and levees posed a greater threat to freshwater ecosystems than that posed by large dams in some regions. The assessment demonstrated that provision of environmental flows can, to some extent, be used to address ecosystem degradation, and an approach was developed to improve the environmental benefit of flows released from environmental water holdings.

Another recent formalised approach for assessing ecological responses to altered flow regimes is the ‘eco evidence’ method of Webb et al. (2013). Their analyses found strong support for many hypotheses regarding ecological impacts, with a consistent sensitivity to changes in flow regime for fish and riparian vegetation across a variety of performance metrics. Macroinvertebrate responses were more varied, although largely consistent with these performance metrics. The ecology associated with different flow regimes has also been investigated in Tasmania (Warfe et al. 2014), and Bice et al. (2014) further investigated responses of a range of small-bodied and large-bodied Murray River riverine fish species, highlighting the species-specific responses that occur with different components of a managed flow regime. Other recent flow–ecology investigations have considered fish (Vilizzi et al. 2014, Wedderburn et al. 2014, Rayner et al. 2015), macroinvertebrates (Chessman 2015), vegetation (Campbell et al. 2014), and carbon and energy (Cook et al. 2015). Ecological and water quality responses of floodplains and wetlands have also received attention (Beesley et al. 2012, Jardine et al. 2012, Pettit et al. 2012).

The South Australian NRM report cards indicate that aquatic ecological condition is assessed as good to fair in the north-east of the state (in the Lake Eyre Basin division), and fair to poor in the south-east. Aquatic ecological condition is reported as unknown across the west of the state, in the South Western Plateau division, and no trend information is available.

In addition to analysis of future risks from development and climate change, the Northern Australia Water Futures Assessment (Close et al. 2012) characterised surface-water and groundwater regimes, and ecological processes for northern Australia. Overall, the northern Australian catchments were reported to have a relatively low level of disturbance, with catchments such as the Mitchell and Gilbert in good ecological health. It was noted, however, that for regions in
northern Australia there is a general lack of quantitative information on relationships between flow, and floral and faunal responses.

In Tasmania, the upper Tamar Estuary was assessed in 2015 as being in poor health, partly because of urbanised catchments, and poor-quality agricultural, stormwater and wastewater treatment plant run-off. Elsewhere, Hydro Tasmania reported that its monitoring of Woods Lake detected eggs and mature adults of the Arthurs paragalaxias fish (*Paragalaxias mesotes*), previously thought to be locally extinct. Rehabilitation of the Lagoon of Islands achieved success, with zero toxic algal blooms, development of a diverse algal community and wetland vegetation recolonisation.

The condition of Victoria’s aquatic ecosystems, reported in 2013, was largely based on assessments made before 2011. Planned dates for the next group of assessments of Victorian wetlands, streams, estuaries and rivers are likely to be known in late 2016. The Living Murray’s 2013–14 assessment of icon sites, which range from the Barmah–Millewa Forest to the Murray Mouth, showed that ecological conditions had either improved or remained stable, benefiting from both natural floods and environmental watering. Future condition assessments will be available as part of monitoring of implementation of the Basin Plan’s Environmental Watering Strategy. The results of the first year of the Commonwealth Environmental Water Office’s Long-Term Intervention Monitoring Project show ecological benefits for stream metabolism, macroinvertebrates, vegetation, frogs and fish that generally range from probable to strong, with a small number of negative responses such as reduction in slack water area.

The 2015 New South Wales SoE report describes the overall condition of rivers across New South Wales as moderate, and gives the same rating for the condition and extent of wetlands. Coastal rivers in the South East Coast (New South Wales) division are in better ecological health than those of the Murray–Darling and Lake Eyre basins, whereas fish communities are in poor condition across the state, with continuing declines in the Murray–Darling Basin. Wetland condition is noted as having improved in areas benefiting from environmental watering, which has helped to maintain waterbird diversity. As an example at a local catchment scale, the Clarence catchment was reported in 2013 as having ecosystem health across subcatchments ranging from very poor to good, with a majority in fair condition, leading to an overall fair rating.

The Fitzroy Basin (Queensland) is the largest catchment delivering outflows to the Great Barrier Reef. Overall freshwater ecosystem condition reported across the basin for 2013–14 ranged from fair to good (Queensland Government 2015). Within this, ecological condition assessment included consideration of macroinvertebrates, PET (Plecoptera, Ephemeroptera, Trichoptera), taxa richness, SIGNAL (Stream Invertebrate Grade Number—Average Level) index and the percentage of tolerant taxa. Ecological condition assessments were only available for the Mackenzie, Theresa and Upper Isaac catchments, with most identified as having poor condition.

The South-East Queensland Healthy Waterways Partnership similarly reported most catchments to have poor to fair environmental condition, where poor indicates that many key ecological processes are not functional and most critical habitats are affected. No catchments were given a ‘fail’ grade, and Noosa—at the extreme north of the region—was rated as having an excellent environmental condition.

Queensland’s Q-catchments condition reports of 2012 included coverage of the Bulloo (Negus et al. 2013a), Nebine (Negus et al. 2013b), Paroo (Negus et al. 2013c) and Warrego (Negus et al. 2013d) catchments. The overall condition of riverine ecosystems in the Bulloo catchment was assessed as ‘slightly disturbed’, whereas the condition of the other 3 catchments was assessed as ‘moderately disturbed’.

Box WAT4 describes the success of a wetlands management program in Queensland.

The South West Index of River Condition (SWIRC) has been used to assess river condition across a range of areas in southern Western Australia, with most assessments for periods leading up to 2011. A 2015 assessment of the river health of the lower Blackwood reported that, overall, ‘the ecological health of the waterways was good, with most SWIRC theme scores for each system categorised as largely unmodified and slightly modified’ (White et al. 2015). The assessment was based on short-term monitoring, precluding commentary on trends.
Pink Lake Sunrise, Victoria
Photo by Helen McFadden
The Biodiversity report provides further and broader information on the state and trends of species and ecosystems.

State and trends of key species populations

Waterbirds

The 2014 aerial survey of waterbirds in eastern Australia (Porter et al. 2014) noted mostly dry wetland conditions across much of the survey area, reflecting a long period of below average rainfall. Trend analysis indicated a continuation of long-term declines in abundance, wetland area and breeding species richness. Environmental flows in areas such as the Macquarie Marshes were noted as delivering wetland benefits, albeit on scales much smaller than in years with above average rainfall. Overall, given the general drying conditions, waterbirds were concentrated in a small number of important sites. Lowest-on-record values of total breeding index and breeding species richness (Figure WAT16) were recorded, reflecting both the poor and declining state of waterbird populations across the region. The most recent aerial survey of waterbirds for the whole of Australia was completed in 2008, as part of the national waterbird survey led by the University of New South Wales.

Frogs

Frog numbers in Australia continue to decline, in line with international trends, with significant threats arising from disease (e.g. chytridiomycosis) and loss of habitat. Since 2011, 3 species of frog have been added as critically endangered to the list of threatened species under the Environment Protection and Biodiversity Conservation Act 1999. The iconic southern (Pseudophryne corroboree) and northern (P. pengilleyi) corroboree frogs are under threat, with status either critically endangered or endangered at various administrative levels. Surveys of known sites for these frogs suggest that they are very close to extinction in the wild. A January 2014 survey of southern corroboree frog sites found only 6 males, with no eggs in their nests. Results are similar for northern corroboree frogs, although good population numbers have been observed in the Fiery Range area of New South Wales. Chytridiomycosis is also known to be present in South Australia, although the extent and effects on frogs are unknown.

Environmental watering has been used to some benefit for frog populations. Under The Living Murray program, environmental flows were found to provide benefits to frog populations in the Chowilla Floodplain, including a significant breeding response by southern bell frogs (Litoria raniformis). Similarly, the Long-Term Intervention Monitoring Project recorded benefits of environmental watering for frogs in the Warrego–Darling (Commonwealth Environmental Water Office 2014) and Murrumbidgee (Commonwealth Environmental Water Office 2016) regions.

Fish

The 2013–14 Lake Eyre Basin assessment of fish populations reported that fish species richness for the major river systems varied from 3 species in the Macumba River to 18 species in Cooper Creek. Total
abundance of fish was 4–5 times greater than in previous years, largely because of high catches of Lake Eyre hardyhead (*Craterocephalus eyresii*) in the lower Cooper and Diamantina catchments. Exotic species accounted for less than 1 per cent of the total catch, with the Neales catchment having the highest proportion of exotic species. No exotics were caught in the Finke, Macumba and Georgina catchments (Mathwin et al. 2015).

In Western Australia, the 2014 values of the Fish Community Index showed that fish communities in the Swan and Canning rivers had improved since the mid-2000s, although the 2014 values were consistent with the pattern of good to fair condition assessments in recent years, indicating a stable trend. The results indicate high and stable salinity in the Swan and Canning rivers, along with higher oxygen levels and an absence of significant toxic algal blooms. The Western Australian Government’s strategic assessment of Perth and the Peel region, a draft of which went to public consultation from December 2015 to May 2016, may provide a platform for future ecological improvements in the region.

For Murray–Darling icon sites, the Living Murray results from 2013–14 and previous years reflect recovery of fish populations after a significant blackwater event in 2011.

**Stygofauna**

Little is known at a national level about state and trends in stygofauna since 2011. Stygofauna have been noted as being of relevance to the Bioregional Assessment Programme, with the Independent Expert Scientific Committee’s methodology noting that stygofauna ‘are recognised as a factor for environmental consideration under the *Queensland Environmental Protection Act 1994*; are valued as indicators of ancient aquifers and their water quality by the Western Australian Department of the Environment and Conservation; and are being actively researched in South Australia, New South Wales and the Northern Territory’ (Barrett et al. 2013). Active research is also under way in Western Australia (A Pinder, Western Australian Department of Parks and Wildlife, pers. comm., 7 July 2016).
## Assessment summary 5

State and trends of inland water ecological processes and key species populations

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpentaria Coast (formerly Gulf of Carpentaria)</td>
<td>Moderate changes to ecological processes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake Eyre Basin</td>
<td>Moderate changes to ecosystem functioning</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Murray–Darling Basin</td>
<td>Widespread loss of ecosystem function. Species populations declining. Some point-scale success in ecosystem restoration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North East Coast</td>
<td>Many ecological processes and many species affected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Western Plateau</td>
<td>Limited ecological information available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Australian Gulf</td>
<td>Many riverine ecological processes affected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South East Coast (NSW) (Note: In 2011, South East Coast [NSW] and South East Coast [Vic] were combined in South East Coast)</td>
<td>River and wetland ecological processes affected. Declining populations of some species</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South East Coast (Victoria) (Note: In 2011, South East Coast [NSW] and South East Coast [Vic] were combined in South East Coast)</td>
<td>River, lake and wetland ecological processes affected. Declining populations of some species</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South West Coast</td>
<td>Some species populations declining; many ecological functions affected</td>
<td></td>
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<td></td>
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</tbody>
</table>
### Assessment summary 5 (continued)

<table>
<thead>
<tr>
<th>Component</th>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Western Plateau</td>
<td>Very little ecological information. Conditions largely unknown</td>
<td>Not assessed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanami–Timor Sea Coast</td>
<td>Limited to moderate changes to ecological pressures</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Tasmania</td>
<td>Ecological function affected in some areas. Some endangered species</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For additional information and an accessible version of the assessment summary, see SoE Digital.
Effectiveness of inland water management

At a glance

The National Water Initiative has driven water policy, planning and management reforms in Australia for the past decade, which have delivered significant benefits for all Australians. It is critical that there should be no backsliding from reform principles. During a similar or longer period, river research and management communities in Australia have moved more towards integrated and ‘ecosystem-based’ considerations.

Indigenous management of water resources has re-emerged, and Indigenous knowledge of water management is gaining increased recognition for the values that it can add to better inform decisions. Indigenous perspectives on water markets also offer insight into ongoing water resource management.

The Murray–Darling Basin Plan was finalised in late 2012. Some elements of the Basin Plan that have been implemented are producing and encouraging efficient water use, and positive economic, social and environmental outcomes. However, other elements and associated implementation are having negative impacts on economies and communities in the Basin.

The Great Barrier Reef 2013–14 report card reported mostly poor to very poor progress towards 2018 catchment targets for factors directly affecting catchment run-off. Across central and northern regions, a review of the Great Artesian Basin Sustainability Initiative found that it had produced many significant achievements, including some evidence that it is helping to achieve commitments from the National Water Initiative.

Aspects of the effectiveness of inland water management were assessed across each of the 4 key pressures—development, land and water management, climate, and pests. Generally, understanding of the context of management and planning was rated as being at a higher level than inputs, processes and outcomes; inputs were the lowest ranked, with either stable or deteriorating trends.

Water management in Australia

We have significant and expanding knowledge of the relationships between water management actions and ecological condition that are essential for effective management. Much of the focus of action has been on manipulating or providing flows for environmental good, and our knowledge in this area is as diverse as spawning requirements (Cockayne et al. 2013), seed dispersal (Greet et al. 2012), flow regime optimisation (Beesley et al. 2014), requirements of Indigenous populations (Jackson et al. 2015) and risks of benefiting invasive species (Conallin et al. 2012). Other efforts have been directed towards floodplain corridor revegetation, wetland health, pest control, translocations, and engineered river works (e.g. Ellis et al. 2013, Hammer et al. 2013, Lintermans 2013, Pittock et al. 2013).
In the past 2 decades, river research and management communities in Australia have moved gradually from traditional single discipline–based approaches to more integrated and ecosystem-based considerations, including at the whole-of-catchment scale. However, it has been noted that ‘although river management has been transformed in recent decades, much remains to be done to create a holistic foundation for river restoration that links biophysical science to social science and economics’ (Fryirs et al. 2013). Broader considerations in management of inland waters include systematic multidiscipline planning (Hermoso et al. 2012a), greater incorporation of spatiotemporal connectivity (Hermoso et al. 2012b, Linke et al. 2012), and assessment of methods or benchmarks such as the Limits of Acceptable Change applied to wetlands (Newall et al. 2015) or the Ecological Limits of Hydrologic Alteration framework (Mackay et al. 2014). Investigation of catchment-scale governance across 3 catchments in northern Australia (Dale et al. 2014) has highlighted the challenges to effective governance, including the challenges of balancing Indigenous, economic and conservation interests (see Box WAT5).

As noted in the SoE 2011 inland water theme chapter, Indigenous management of water resources has re-emerged. Ecological health of wetlands, for example, is important to Indigenous communities for both aquatic fauna and flora species. Indigenous knowledge of water management is gaining increased recognition for the values that it can add to better inform decisions (Woodward et al. 2012, Liedloff et al. 2013), and there is broader recognition of Indigenous use of water resources (e.g. Jackson et al. 2012). In terms of effective management of inland waterways, Indigenous perspectives about water markets offer insight into ongoing water resource management (Nikolakis et al. 2013). Overall, the National Water Initiative provides a useful and usable framework for Indigenous management of water resources.

Groundwater management and surface-water–groundwater co-management have also emerged in recent years, including social aspects (Mitchell et al. 2012), management of groundwater-dependent ecosystems (Adams et al. 2015) and management to conserve baseflow contributions to streamflow regimes. Water management planning and plan implementation, including under the reforms of the National Water Initiative, have continued across Australia in recent years, with varying effectiveness because of the complexity of planning processes and competing priorities. For example, of the Northern Territory’s 9 water allocation plans—5 of which have been declared—only 1 has been declared in the past 5 years, and 3 others have been in draft for more than 4 years. A key element in water allocation planning for northern Australia is ensuring equitable participation of Indigenous people in the water reform process. This was advanced by the Indigenous Water Policy Group in 2010–12, with achievements that included quantifying Indigenous access to water in the Ooloo (Northern Territory), Mataranka (Northern Territory),

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**Box WAT5**  
**Ngarrindjeri Regional Authority wins the 2015 Australian Riverprize for Murray River basin management**

The Ngarrindjeri Regional Authority won the 2015 Australian Riverprize (now Australasian Riverprize), Australia’s top award for effective and sustainable river basin management. The Riverprize recognises, rewards and supports those who have developed and implemented outstanding, visionary and sustainable programs in river management.

The Ngarrindjeri’s Kungun Ngarrindjeri Yunnan Agreement established a new and positive relationship between the Ngarrindjeri and the South Australian Government, which has seen an innovative and integrated approach to river basin management for the Murray River. In particular, the agreement emphasised a participatory approach with the land’s traditional custodians—moving past historical barriers to Aboriginal involvement in integrated river basin management—which has led to opportunities to develop Aboriginal-led wetland management plans for land owned by the Ngarrindjeri people.

The Ngarrindjeri Regional Authority river management team received the award for its long-term commitment to integrated river basin management, including Aboriginal involvement, equitable government relationships and international partnerships.

Source: International River Foundation: Australasian Riverprize
Nicholson (Queensland) and Mitchell (Queensland) water planning processes.

In New South Wales, 2012 planning controls for riparian land have been found to be not predicated on scientific evidence, and to be likely to compromise the environmental health of rivers and riparian systems (Ives et al. 2013). Water management issues have, however, been included in the management strategies of other sectors, such as the horticultural sector (Horticulture Australia 2006).

Recent national assessments of management performance

The National Water Initiative has set the water policy reform agenda for the past decade, following on from the Council of Australian Governments (COAG) Water Reform Framework of 1994. In recent years, National Water Initiative activities such as a National Water Market System and various national frameworks have either ceased or have less momentum because of changes in focus and competing priorities. A review of the policy and legal framework for collaborative water planning in Australia (Tan et al. 2012) found some key gaps relating to community engagement, including:

- tools for engagement
- procedural fairness, such as using independent experts
- clear documentation and language
- the development of comprehensive policy
- a legislative framework that allows a systems approach to consensus building
- information on how much water is needed and where.

Some of these themes were picked up in 2014 in the 4th assessment of the National Water Initiative—the last assessment completed by the former National Water Commission. In summary, the assessment concluded that:

> Water reform in Australia is now at a crossroads. Solid progress on managing the nation’s water resources during the past two decades has delivered tangible benefits to governments, communities and industries. The millennium drought tested the reform principles enshrined in the National Water Initiative (NWI) but the principles have proven to be of enduring value, even when confounded by crisis, shorter-term priorities and declining resourcing.

In implementing the NWI, the [National Water] Commission and its partner governments have adopted an adaptive and cooperative approach, recognising the need to learn and adjust when implementing change in complex and dynamic environments. This will become even more important as future reform proceeds during a time when other issues occupy centre stage on the national agenda. The absence of COAG leadership will require progress to be led by state and territory governments and industry.

Given the substantial government investments and hard-won progress so far, and the valuable but challenging gains yet to be realised, it is critical that there is no backsliding from reform principles. The commission urges all governments to sustain their commitment to enduring water reform, so that Australia continues to optimise water's elemental contribution to our economy, environment and communities. (NWC 2014)

For water quality, Australian governments are revising the 2000 Australian and New Zealand guidelines for fresh and marine water quality. Work has been progressing steadily, with publication of the revised guidelines scheduled for 2017. Although no formal national assessment of performance of the guidelines has been done recently, the state and territory governments cite their constant use in planning, management and regulatory applications.

Reviews of state and regional management

The Murray–Darling Basin Plan included 2750 GL of water to be recovered from consumptive use and returned to the environment each year. In early 2016, a Senate Select Committee found that elements of implementation of the plan are producing and encouraging efficient water use, and positive economic, social and environmental outcomes. Concerns were expressed that elements of the plan, and associated implementation, were having negative impacts on economies and communities in the Basin. The committee made 31 recommendations about implementation of the plan, including cost and benefit analyses, entitlements and water recovery actions, liability for damage from environmental watering, cold-water pollution, salt interception, and expansion of the Long-Term Intervention Monitoring Project. Monitoring
and assessment of plan outcomes will be assisted in future by collaborative agreements on data sharing and knowledge exchange, and use of a common aquatic ecosystem toolkit.

At a state and territory level, a 2014 audit of the effectiveness of catchment management authorities in Victoria found that ‘the existing approaches to catchment management in Victoria are inadequate. In particular, the statewide approach is fragmented and short term in focus, while catchment condition and changes over time are poorly understood’ (Victorian Auditor-General 2014). Victoria’s 2013 SoE report commented that ‘management activities such as fencing, revegetation, weed control and the release of environmental flows have played an important role in maintaining and improving river condition. These activities are likely to have improved river resilience during the long drought period, and will further improve resilience in the future’ (Victorian Government 2013a). The report also noted that it will take some years before these changes are reflected in condition assessments. The Victorian Government’s Our catchments, our communities—integrated catchment management in Victoria 2016–19 (DELWP 2016), released in early 2016, includes a promise of future improvements to catchment ecosystem monitoring, evaluation and reporting.

The Great Barrier Reef 2013–14 report card reported mostly poor to very poor progress towards 2018 catchment targets for factors directly affecting catchment run-off, including low uptake of best management practices by sugar cane growers (e.g. nutrient management at 13 per cent of growing area) and graziers (e.g. pasture management at 28 per cent; 22 per cent in the Fitzroy Basin). Losses of wetlands and forest were reported as continuing, and the overall condition of the inshore marine receiving environment remained poor in 2013–14.

In central Australia, the mid-term review for stage 3 of the Great Artesian Basin Sustainability Initiative was completed in February 2013. The review found many significant achievements arising from the initiative, including some evidence of assisting achievement of National Water Initiative commitments. It was suggested that, although (groundwater mound) spring flows were improving, more work was required to better understand the ecological significance of the springs and the benefits of returning flows to them.
Assessment summary 6
Effectiveness of inland water management

<table>
<thead>
<tr>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water resource development</strong></td>
<td>In grade</td>
<td>In trend</td>
<td>To 2011 assessment</td>
</tr>
<tr>
<td><strong>Understanding of context:</strong> There is good understanding within management of surface-water resources in the context of ecosystem functions and environmental values, and understanding of groundwater in this context is increasing. Regular national water resource accounting and reporting are providing core contextual information</td>
<td>In effective</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Planning:</strong> The Murray–Darling Basin Plan is in place, as are many regional water management plans. Disaggregation of National Water Initiative (NWI) responsibilities and machinery-of-government changes have raised the potential for diminished commitment to the NWI reform agenda. New major policies include consideration of water and the aquatic environment</td>
<td>Partially effective</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Inputs:</strong> Capacity in state and territory agencies for monitoring and implementation has diminished, and future financial support for Water Act 2007 (Cwlth) requirements are not confirmed. A Bioregional Assessment Programme is in place to address impacts of coal-seam gas and large coalmines on water resources</td>
<td>Partially effective</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Processes:</strong> Commonwealth, state/territory, regional and local water resource development has governance, stakeholder engagement and oversight processes. Implementation of these varies in accordance with priorities and available inputs</td>
<td>In effective</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td><strong>Outputs and outcomes:</strong> Moderate assessment of outputs is being undertaken, with some examples of positive environmental outcomes now becoming apparent</td>
<td>Partially effective</td>
<td>▲</td>
<td>▲</td>
</tr>
</tbody>
</table>
### Assessment summary 6 (continued)

<table>
<thead>
<tr>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
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</thead>
<tbody>
<tr>
<td>Land-use and water quality management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Understanding of context:</strong> Understanding of ecosystem functions in this context is reasonable to good, although variable around spatial, temporal and cumulative impacts, particularly with regard to tropical and groundwater aquatic environments</td>
<td>Ineffective Partially effective Effective Very effective</td>
<td>In grade In trend To 2011 assessment</td>
<td>▲</td>
</tr>
<tr>
<td>Planning: Water quality objectives across different scales and jurisdictions, and responsibility for achieving these, are moderately clear. Co-management to meet combined water quality and quantity objectives is limited</td>
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<tr>
<td>Inputs: Resources for implementation of water quality management have been diminishing in some areas, as have monitoring and integrated water quality assessment information. Issue-focused and region-focused programs provide specific information to support management decision-making</td>
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<tr>
<td>Processes: There is significant variability in engagement, implementation and monitoring processes for management of land-use and water quality improvement, without effective high-level frameworks to provide consistency and impetus</td>
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<tr>
<td>Outputs and outcomes: Improvements in land-use practices directed towards water quality outcomes are occurring at a range of levels in different areas</td>
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</tbody>
</table>
Assessment summary 6 (continued)

<table>
<thead>
<tr>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adaptation to climate variability and climate change</strong></td>
<td></td>
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<tr>
<td><strong>Understanding of context:</strong> New regionalised climate change projections, and associated information on impacts and adaptation provide nationally standardised and consistent information for managers and policymakers. Implications are broadly and reasonably well understood.</td>
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<tr>
<td><strong>Planning:</strong> Climate and water outlooks over a range of future timeframes are available and used in planning across some areas. Responsibilities for water resource management responses to climate are generally clear.</td>
<td></td>
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<tr>
<td><strong>Inputs:</strong> There are more online resources and fewer human resources to interpret and integrate climate science into adaptation responses, especially with regard to groundwater and surface-water responses across different regions.</td>
<td></td>
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</tr>
<tr>
<td><strong>Processes:</strong> Good governance and management systems exist for engagement, implementation and reporting on adaptation responses to climate variability and climate change.</td>
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<tr>
<td><strong>Outputs and outcomes:</strong> Inland water management actions to account for climate change and climate variability have been taken and reported variously across the country. There is limited to moderate evidence of positive ecosystem outcomes to date.</td>
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</table>
## Assessment summary 6 (continued)

<table>
<thead>
<tr>
<th>Summary</th>
<th>Assessment grade</th>
<th>Confidence</th>
<th>Comparability</th>
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</thead>
<tbody>
<tr>
<td>Management of pests and invasive species</td>
<td></td>
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</tr>
<tr>
<td><strong>Understanding of context:</strong> There is good understanding nationally of the context of pests and invasive species in the aquatic environment, with good awareness of emerging threats</td>
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</tr>
<tr>
<td><strong>Planning:</strong> Policy and planning for management of significant pests operate well nationally and are well coordinated</td>
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<tr>
<td><strong>Inputs:</strong> Resources are not available to fully manage existing and emerging aquatic pests at a national scale. Resources are effectively engaged on priority pests and regions</td>
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</tr>
<tr>
<td><strong>Processes:</strong> Good and well-coordinated processes are available, including those for stakeholder engagement, governance and management coordination</td>
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</tr>
<tr>
<td><strong>Outputs and outcomes:</strong> Management actions have produced clear on-ground outputs, with priority pest and invasive species being addressed at local scales. There are some demonstrable ecosystem outcomes in some areas</td>
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</tbody>
</table>

For additional information and an accessible version of the assessment summary, see SoE Digital.
### Assessment summary 6 (continued)

#### Management context

**Understanding of context**

Decision-makers and environmental managers have a good understanding of:

- environmental and socio-economic significance of environmental values, including ecosystem functions and cultural importance
- current and emerging threats to values.

Environmental considerations and information have a significant impact on national policy decisions across the broad range of government responsibilities.

**Grades**

- **Very effective**: Understanding of environmental and cultural systems, and factors affecting them is good for most management issues.
- **Effective**: Understanding of environmental and cultural systems, and factors affecting them is generally good, but there is some variability across management issues.
- **Partially effective**: Understanding of environmental and cultural systems, and factors affecting them is only fair for most management issues.
- **Ineffective**: Understanding of environmental and cultural systems, and factors affecting them is poor for most management issues.

#### Planning

Policies and plans are in place that provide clarity on:

- objectives for management actions that address major pressures and risks to environmental values
- roles and responsibilities for managing environmental issues
- operational procedures, and a framework for integration and consistency of planning and management across sectors and jurisdictions.

**Grades**

- **Very effective**: Effective legislation, policies and plans are in place for addressing all or most significant issues. Policies and plans clearly establish management objectives and priorities for addressing major risks, but may not specify implementation procedures.
- **Effective**: Effective legislation, policies and plans are in place, and management responsibilities are allocated appropriately, for addressing many significant issues. Policies and plans clearly establish management objectives and priorities for addressing major risks, but may not specify implementation procedures.
- **Partially effective**: Legislation, policies and planning systems are deficient, and/or there is lack of clarity about who has management responsibility, for several significant issues.
- **Ineffective**: Legislation, policies and planning systems have not been developed to address significant issues.

#### Inputs

Resources are available to implement plans and policies, including:

- financial resources
- human resources
- information

**Grades**

- **Very effective**: Financial and staffing resources are largely adequate to address management issues. Biophysical and socio-economic information is available to inform management decisions.
- **Effective**: Financial and staffing resources are mostly adequate to address management issues, but may not be secure. Biophysical and socio-economic information is available to inform decisions, although there may be deficiencies in some areas.
- **Partially effective**: Financial and staffing resources are unable to address management issues in some important areas. Biophysical and socio-economic information is available to inform management decisions, although there are significant deficiencies in some areas.
- **Ineffective**: Financial and staffing resources are unable to address management issues in many areas. Biophysical and socio-economic information to support decisions is deficient in many areas.

#### Processes

A governance system is in place that provides for:

- appropriate stakeholder engagement in decisions and implementation of management activities
- adaptive management for longer-term initiatives
- transparency and accountability

**Grades**

- **Very effective**: Well-designed management systems are being implemented for effective delivery of planned management actions, including clear governance arrangements, appropriate stakeholder engagement, active adaptive management and adequate reporting against goals.
- **Effective**: Well-designed management systems are in place, but are not yet being fully implemented.
- **Partially effective**: Management systems provide some guidance, but are not consistently delivering on implementation of management actions, stakeholder engagement, adaptive management or reporting.
- **Ineffective**: Adequate management systems are not in place. Lack of consistency and integration of management activities across jurisdictions is a problem for many issues.
### Achievements  
(delivery of expected products, services and impacts)

<table>
<thead>
<tr>
<th>Elements of management effectiveness and assessment criteria</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outputs &lt;br&gt;Management objectives are being met for: &lt;br&gt;• timely delivery of products and services &lt;br&gt;• reduction of current pressures and emerging risks to environmental values</td>
<td>Very effective: Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are being demonstrably reduced</td>
</tr>
<tr>
<td></td>
<td>Effective: Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are understood, and measures are in place to manage them</td>
</tr>
<tr>
<td></td>
<td>Partially effective: Management responses are progressing and showing signs of achieving some objectives. Targeted threats are understood, and measures are being developed to manage them</td>
</tr>
<tr>
<td></td>
<td>Ineffective: Management responses are either not progressing in accordance with planned programs (significant delays or incomplete actions) or the actions undertaken are not achieving their objectives. Threats are not actively being addressed</td>
</tr>
<tr>
<td>Outcomes &lt;br&gt;Management objectives are being met for improvements to resilience of environmental values</td>
<td>Very effective: Resilience of environmental values is being maintained or improving. Values are considered secured against known threats</td>
</tr>
<tr>
<td></td>
<td>Effective: Resilience of environmental values is improving, but threats remain as significant factors affecting environmental systems</td>
</tr>
<tr>
<td></td>
<td>Partially effective: The expected impacts of management measures on improving resilience of environmental values are yet to be seen. Managed threats remain as significant factors influencing environmental systems</td>
</tr>
<tr>
<td></td>
<td>Ineffective: Resilience of environmental values is still low or continuing to decline. Unmitigated threats remain as significant factors influencing environmental systems</td>
</tr>
</tbody>
</table>
Resilience of inland water environments

At a glance

A challenge in assessing resilience of inland water environments is recognising resilience when it occurs, especially because Australian ecosystems have developed to be both resistant and resilient.

We can contribute to resilience by reducing extreme and detrimental ecosystem disturbances, and increasing the ecosystem characteristics needed to increase resilience. Management of streamflow releases, provision of environmental flows, and management to reduce impacts on groundwater levels and quality can all contribute to resilience. The success of these can be assessed after an ecosystem shock—when it is possible to assess whether detrimental changes that we have seen previously or that we expected to occur—were found either to have not occurred or to have been less severe.

Early outcomes of the Commonwealth Environmental Water Office’s Long-Term Intervention Monitoring Project in the Murray–Darling Basin include positive resilience outcomes in improved vegetation condition, recruitment of waterbirds and fish, improved aquatic habitats, support for ecological recovery, natural thinning of seedlings, and improved survival and condition of individuals.

A future opportunity for assessment of resilience in inland water environments lies in the assessment of cumulative impacts of negative or positive factors, especially regarding ecosystem thresholds and tipping points.

Assessing or commenting on the resilience of inland water environments is challenging, because it can be difficult to recognise resilience when it occurs. In Australia’s environment, ecosystems have developed to be both resistant and resilient.

As evidenced in this and other 2016 SoE thematic reports, monitoring, assessing and reporting nationally and comprehensively on ecosystem states and trends are challenging enough once every 5 years, without the added challenge of considering whether a particular change observed in state, such as frog abundance, bears the characteristics of a resilient ecosystem. However, we need to consider whether our management is contributing to both a reduction in extreme and detrimental ecosystem disturbances, and an increase in the ecosystem characteristics needed to increase resilience. Management of streamflow releases, provision of environmental flows, and management to reduce impacts on groundwater levels and quality can all contribute to resilience. These contributions can then be considered when monitoring after an ecosystem shock—when detrimental changes that we have seen previously or that we expected to occur—were found either to have not occurred or to have been less severe.

Resilience is also often associated with active adaptive management (Allan & Stankey 2009). Adaptive management has been applied in various guises in Australian environmental management, although with few outcomes that assist in assessment of resilience.

SoE 2011 suggested that ‘the widespread floods of 2010 in drought-affected areas offer a tremendous opportunity to observe the response of extremely drought-stressed inland water systems, as do the releases of environmental flows in the Murray–Darling Basin and the Snowy River’, particularly as resilience-related ecosystem elements were viewed as compromised (e.g. Nicol 2009, Noell et al. 2009, Zampatti 2010).

As noted earlier, the first outcomes of the Commonwealth Environmental Water Office’s Long-Term Intervention Monitoring Project have been reported. Among these, improved ecological resilience was achieved, envisaged or inferred through:

- improved condition of native vegetation communities in wetlands, including at the expense of exotic species, increasing resilience to future dry weather conditions (SECRC 2015)
• recruitment of waterbirds and fish as part of the larger-scale function of resilient biotic communities (Commonwealth Environmental Water Office 2015)
• multiple years of enhanced spring–summer flow, increasing the resilience of golden perch and silver perch populations in the lower Murray River (Ye et al. 2016)
• maintenance of aquatic habitat and support for ecological recovery (ABS 2014a)
• increased aquatic habitat on the western floodplain (Warrego River), increased productivity and basal food sources, and increased numbers and diversities of higher-level consumers such as frogs and birds (Commonwealth Environmental Water Office 2014)
• improved survival and condition of individuals through provision of individual refuges and improved ecosystem resistance (Commonwealth Environmental Water Office 2014)
• encouragement of natural thinning of river red gum seedlings, preventing river red gum encroachment and promoting re-establishment of aquatic vegetation communities (Commonwealth Environmental Water Office 2016).

In addition to resilience support through environmental flows, the potential for anthropogenic water bodies—such as agricultural ponds, irrigation channels, rural and urban drainage ditches, and transport canals—to offer refuges and increase resilience has been investigated. Chester & Robson (2013) found that freshwater anthropogenic habitats supported biodiversity and that this support could be enhanced through management actions, such as structural modifications and aquatic vegetation control.

In hydrological systems, resilience has been explored in recent years in relation to multiple stable ecosystem states. Various authors identified multiple steady states by conducting simulations from different initial state variables, some using advanced analysis techniques to quantify how the number of steady states may change with a single model parameter. A 2012 study (Peterson et al. 2012) found that switching between steady system states from wet or dry periods, such as with extended rainfall periods after drought, did not occur by crossing the threshold between the steady states. Rather, it occurred by exceeding the 2 steady-state domains, producing hysteresis. Therefore, consideration of stable ecosystem states in the context of resilience must consider the nature of change processes between those states.

A future opportunity for assessment of resilience in inland water environments lies in the assessment of the cumulative impacts of either negative factors, such as development and resource exploitation, or positive factors, such as beneficial co-management of water resources. The relevance of resilience here is that, often, ecosystems can resist or be resilient in the face of one or a few impacts, but this breaks down as impacts of different types and magnitudes accumulate, or as thresholds are reached (Standish et al. 2014). Similarly, recovery actions, such as environmental watering, pest reduction and competition management, may not have significant beneficial outcomes until a cumulative value or threshold is reached.
Hopetoun Falls, Victoria
Photo by Phil McFadden
Risks to inland water environments

At a glance

Risks to inland water environments include direct risks (such as direct water extraction, or changes in run-off and recharge) and indirect risks (such as expansion of invasive species because of increased tourism).

Climate changes may produce both types of risks. Updated climate projections, including rainfall, were released in 2015. For northern Australia, models offer diverse results; natural climate variability remains the major driver of rainfall changes for the next few decades, with variable outlooks thereafter. There is high confidence in future increases in the intensity of extreme rainfall events, so the risk of extreme wet periods and floods seems likely to increase. In the rangelands, there is high confidence in long-term rainfall declines. The direction and magnitude of annual and summer rainfall changes are less certain, whereas the risks of extreme rainfall and time spent in drought will increase. For the southern and south-western flatlands, there is high confidence that winter, spring and annual rainfalls will decrease in both the medium and longer term, and high confidence that extreme rainfall events will intensify. For much of the Murray–Darling Basin, there is a mix of medium and high confidence that, by late in the century, there will be decreases in winter–spring ‘cool-season’ rainfall. Warm-season and summer–autumn rainfall is not projected to change significantly. In other parts of Australia—the south-east and Tasmania—there is high confidence in winter and spring rainfall decreases later this century, except for Tasmania, where there is medium confidence in increases in winter rainfall. There is also high confidence in future increases in the intensity of extreme rainfall events.

Risks from water resource development are ever present. Proposals for significant infrastructure development in the coming decades raise risks of interrupting natural flow regimes, affecting waterscape connectivity and impeding aquatic ecosystem processes that require the run of the river. Risks in developing Australia’s north include surface-water regime change, surface-water pollution, groundwater extraction, seawater intrusion, and accelerated spread of pest plants and animals. However, we have a significant body of practice and knowledge to help avoid the land and water management mistakes of the past.

A range of risks arise from current and proposed coal-seam gas and large coalmining developments, and these will be informed by the Bioregional Assessment Programme.

Risks to the future health of our inland water environments arise across several timeframes, such as:

- development and exploitation risks occurring in the next few years
- accumulation or aggregation of risk factors across decades
- long-term risks (to the end of the century) from changes in climate, and the frequency and severity of extreme events.

Risks include direct and indirect risks, such as direct water extraction or changes in run-off and recharge, expansion of invasive species because of increased tourism and visitors to remote areas, and habitat and range changes arising from climate change. Much of our management and assessment of environmental assets and development proposals use risk-based frameworks, and these need to continue into the future to include potential cumulative impacts on inland waters.

Climate change

Updated projections of climate change in Australia were released in 2015, and are explored in the Drivers and Atmosphere reports. These new projections focus on natural resource management (NRM) areas, dividing...
Australia into 8 regions. The rainfall and temperature projections (CSIRO 2015) can directly inform assessment of the risk to inland waters, although the potential hydrological impacts at the national or regional levels have not been assessed. Part of the Northern Australia Water Futures Assessment (NAWFA) included risks arising from climate change and development (Close et al. 2012). The NAWFA was completed before release of the new projections, and provides catchment-scale profiles on both total risk and major threats.

Until 2012, the South Eastern Australian Climate Initiative (SEACI) undertook a range of impact studies that included long-term and seasonal hydroclimate projections for south-eastern Australia—covering most of the South Australian Gulf, South East Coast (Victoria) and Murray–Darling Basin drainage divisions. At a high level, the Phase 2 SEACI findings were:

There appear to be long-term reductions occurring in cool season rainfall and streamflow across the region. Evidence indicates that these are associated with changes in the global atmospheric circulation ... pushing mid-latitude storm tracks further south and leading to reduced rainfall across southern Australia ... These trends are evident in a range of observational data and can be reproduced by global climate models ... The models also indicate that these trends are expected to continue.

From a water planning and management viewpoint, one implication of these findings is that the traditional ‘filling season’ for water supply systems across most of south-eastern Australia, which historically was considered to run from about May through to November, may not be as reliable in the future. Rather, replenishment of storages (and soil moisture reserves) may in future be more dependent on spring/summer rainfall events.

In terms of the sensitivity of the run-off response to rainfall and other environmental factors, research has shown that changes in rainfall are the dominant influence, with changes in temperature and carbon dioxide concentrations having only a secondary impact. (CSIRO 2012)

Given this latter point, the NRM region projections for rainfall can be used as a guide to future run-off risks. One key risk that is not addressed as rainfall decreases is passing a threshold, such as disconnection of surface-water and groundwater processes, where the response of run-off to declining rainfall may be far from linear.

The Monsoonal North climate projections cover areas of the northern part of the North East Coast (i.e. Burdekin catchment) and Tanami–Timor Sea divisions, and most of the Capricorn Coast division. Global climate models offer diverse results for the Monsoonal North cluster, with shortcomings in resolving some tropical processes. Natural climate variability will likely remain as the major driver of rainfall changes for the next few decades. By late in the century, summer rainfall changes are projected to change by between −15 to +10 per cent and −25 to +20 per cent, depending on the Representative Concentration Pathway scenario, although these have low confidence. Winter rainfall changes are less reliable, partly because winter rainfall is low. However, there is high confidence in a future increase in the intensity of extreme rainfall events, so, although there may be little change in the average water available to the environment, the risk of extreme wet periods and floods seems likely to increase. Similar projections were made for the Wet Tropics NRM cluster, which covers the eastern part of the Capricorn Coast division and the northern part of the North East Coast division, north of Mackay.

The Rangelands NRM cluster area includes the western Murray–Darling Basin, the Lake Eyre Basin, the southern Tanami–Timor Sea Coast, the North Western Plateau, most of the Pilbara–Gascoyne, the South Western Plateau and inland parts of the South Australian Gulf divisions. Winter rainfall trends in the south of the Rangelands NRM are projected to be dominated by natural variability across the next few decades, with a high confidence in longer-term rainfall declines. The direction and magnitude of annual and summer rainfall changes are less certain, whereas extreme rainfall and time spent in drought are both likely to increase. The potential risks to inland water environments include more frequent flooding and groundwater recharge events, as well as longer dry periods when groundwater resources will be of even greater ecosystem value than now. Surface streamflow is generally low for the region, and the risk of extended periods of zero flow days will also increase.

Most of the South West Coast, the near-coastal areas of the South Western Plateau and the southern parts of the South Australian Gulf divisions coincide with the
Southern and South Western Flatlands NRM cluster. There is high confidence that winter, spring and annual rainfalls will decrease in these areas in both the medium (2030) and longer term, with declines of 15 per cent and possibly up to 25 per cent by 2030, and greater reductions thereafter. There is also high confidence that extreme rainfall events will intensify in the future, although the magnitude of this is unclear. Longer times of drought are also predicted that, when combined with drier and more variable conditions, point to lower overall surface-water availability, more groundwater–surface-water disconnection, and significant impacts for water quality and inland water environments.

The East Coast NRM cluster extends from near Wollongong in the south to north of Rockhampton, thereby covering the southern half of the North East Coast and most of the South East Coast (New South Wales) drainage divisions. The models show a range of rainfall outcomes, with no clear predominating effect across much of this cluster (Table WAT6). Only medium–confidence level projections are available, and they are for decreasing winter rainfall in the southern half of the cluster, south of the New South Wales border. There is also medium confidence in the projections for increases in time spent in drought during the next century, and a high level of confidence that there will be future increases in the intensity of extreme rainfall events.

Projections for the remainder of the Murray–Darling Basin drainage division—not covered under the Rangelands NRM projections discussed previously—are included in the Central Slopes and Murray Basin NRM cluster results. These areas hold a mix of medium and high confidence that, by late in the century, there will be decreases in winter–spring cool-season rainfall. Warm-season and summer–autumn rainfall is not projected to change significantly. There is high confidence in projections of increased extreme rainfall intensity, coupled with medium confidence that time spent in drought will increase during the century. For highland areas, snowfall is projected with very high confidence to continue declining over time. Thus, although a detailed hydrological outlook is not available for the eastern and southern Murray—Darling Basin based on these projections, the previously mentioned high-level implications in the SEACI findings appear likely to prevail.

The Southern Slopes NRM cluster includes the Tasmania, most of the South East Coast (Victoria) and the southern areas of the South East Coast (New South Wales) drainage divisions. For these regions, the rainfall outlook is for natural variability to dominate in the early decades of the century. Later decades have high confidence in winter and spring rainfall decreases, except for Tasmania, where there is medium confidence in increases in winter rainfall. There is also high confidence in future increases in the intensity of extreme rainfall events. In Victoria, the Victorian Climate Initiative is looking in more detail at hydrological consequences of climate change, with findings to be made available in mid to late 2016.

### Table WAT6

Table WAT6 shows projected rainfall differences, compared with 1986–2005, for 20-year periods (centred on 2030 and 2090) and 3 Representative Concentration Pathways.

<table>
<thead>
<tr>
<th>Season</th>
<th>RCP4.5 2030 (%)</th>
<th>RCP2.6 2090 (%)</th>
<th>RCP4.5 2090 (%)</th>
<th>RCP8.5 2090 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>-14 to +3</td>
<td>-20 to +6</td>
<td>-18 to +9</td>
<td>-25 to +14</td>
</tr>
<tr>
<td>Summer</td>
<td>-14 to +12</td>
<td>-19 to +15</td>
<td>-16 to +13</td>
<td>-21 to +26</td>
</tr>
<tr>
<td>Autumn</td>
<td>-21 to +15</td>
<td>-27 to +15</td>
<td>-24 to +17</td>
<td>-32 to +27</td>
</tr>
<tr>
<td>Winter</td>
<td>-23 to +8</td>
<td>-22 to +6</td>
<td>-29 to +5</td>
<td>-44 to +6</td>
</tr>
<tr>
<td>Spring</td>
<td>-20 to +12</td>
<td>-25 to +13</td>
<td>-31 to +5</td>
<td>-44 to +7</td>
</tr>
</tbody>
</table>

**RCP** = Representative Concentration Pathway

**Note:** The 10th to 90th percentile range of model results is shown. For 2030, results for all RCPs are similar, so only RCP4.5 values are shown.

**Source:** CSIRO & BoM (n.d.)
In terms of the potential impacts of climate change on aquatic ecosystems, recent research has:

- identified the traits of species likely to be at risk (Chessman 2013)
- studied the impacts of extreme flow variability on aquatic ecosystem populations (Arthington & Balcombe 2011)
- looked at the vulnerability of stream communities at the landscape or catchment scale (Bush et al. 2012)
- considered effects on environmental watering and water-dependent ecosystems (Barron et al. 2012, Kirby et al. 2014)
- investigated the vulnerability of stream and wetland communities (Bush et al. 2012, Filipe et al. 2013, Finlayson 2013).

**Water abstraction and interception**

Three factors contribute to the risk posed by increasing water abstraction and interception:

- the demands of a growing population
- increases in per-person water consumption for this population
- the requirement for extracting more water from an increasingly water-scarce environment to meet consumption, growth and production needs.

The potentially costly approaches to augmenting water supplies through climate-resilient sources, as well as the proven effects of good water-demand management, can offset the factors contributing to risk.

A policy for developing up to 100 dams in Australia, particularly focusing on northern Australia, was released in 2013. Such development risks interrupting natural flow regimes, waterscape connectivity and operation of aquatic ecosystem processes that require the run of the river. Additionally, further development of northern Australia will require a significant difference in both the nature and magnitude of groundwater use, because groundwater provides a potential water resource to support tropical agricultural development, as well as being a primary contributor to dry-season surface flows in some rivers in the north. Changes in groundwater levels arising from abstraction or other pressures also raise risks for groundwater-dependent ecosystems (Box WAT6).

**Box WAT6  Groundwater-dependent ecosystem risk assessment for declining groundwater levels**

The National Climate Change Adaptation Research Facility has developed a risk assessment framework for groundwater-dependent ecosystems under conditions of declining groundwater levels (Chambers et al. 2013).

The framework was developed by a multidisciplinary team of ecologists, modellers and hydrogeologists in south-western Australia—a biodiversity hotspot that has already suffered 3 decades of below average rainfall and declining groundwater levels because of increased groundwater abstraction and land-use change.

The framework integrates a standard risk assessment protocol, and is based on constructing a conceptual model that identifies interrelationships between climate, hydrology, water quality and/or biotic resources, and the biota in an ecosystem. Using the framework, a risk assessment identifies hazards to groundwater-dependent ecosystems; determines exposure and vulnerability, and then assesses causes and effects. The risks are then characterised, including limits and thresholds, and built into management approaches.

Investigations of the vulnerability of 2 fish species—barramundi (*Lates calcarifer*) and sooty grunter (*Hephaestus fuliginosus*)—in the Daly River in the Northern Territory (Chan et al. 2012) identified that full use of current extraction entitlements would have significant impacts on the fish populations; this situation is at risk of exacerbation as pressure mounts to allocate more water to meet agricultural development needs. Risks also extend to impacts on fished species, such as barramundi, where river discharge reductions were found to be likely to affect characteristics that included exploitable biomass, annual catch, maximum sustainable yield and spawning stock size (Tanimoto et al. 2012).

**Land and water use and management**

Risks from changes to land management arise mainly through potential hydrological and water quality changes, whereas those from water management relate
Upper Isdell River, Kimberley, Western Australia
Photo by Helen McFadden
to changes in the timing and nature of flows that may be beneficial or detrimental to aquatic ecosystem health.

As a whole, land-cover or land-use changes are not being made on the same scale as in past decades and centuries. However, some changes may occur anyway because of other factors, such as climate influences on rangeland fire regimes. In expanding extensive land management practices into much of the less-developed areas of northern Australia, we raise the risk of implementing management regimes that are not compatible with either the natural (and increasing) variability of the environment, or the needs of tropical surface-water and groundwater ecosystems—many of which are not well studied or understood. Risks in developing Australia’s north include surface-water regime change, surface-water pollution, groundwater extraction, seawater intrusion, and accelerated spread of pest plants and animals.

However, and conversely, we have a significant body of practice and knowledge to help avoid the land and water management mistakes of the past. These range from practical on-ground management techniques to limit the expansion of pest species (e.g. Florance et al. 2011, Tingley et al. 2013) to policy and process changes that can reduce the risks involved in management of threatened species (McDonald et al. 2015). Projections of the future distribution of pest plants and animals, such as those driven by changes in climate, development and infrastructure, reinforce the requirement for ongoing good monitoring and management of pest species. Operational monitoring and management programs, such as Queensland’s Indigenous Land and Sea Ranger program, provide approaches that can target pest and weed control.

In the short term, coal-seam gas and large coalmining developments pose a range of risks to inland waters. These risks, which will be considered as part of regulatory processes, are intended to be investigated by the Bioregional Assessment Programme, within which individual bioregional assessments will:

- define, characterise and explain conceptual models that establish causal pathways describing the chain of interactions and events connecting depressurisation and dewatering of coal seams at depth with impacts on anthropogenic and ecological receptors located at depth or the surface
- generate quantitative, semi-quantitative or qualitative analyses of the likelihood of impacts of coal seam gas (CSG) and coal mining developments on receptors from the application of ecology, surface water and groundwater hydrology, hydrogeology and CSG or coal resource development models
- develop improved assessments of the likelihood of risks to receptors and the subsequent values of water-dependent assets from CSG and coal mining developments
- provide information on the level of confidence of scientific advice on these impacts
- identify monitoring programs, bioregional assessment review frequency and additional risk assessment studies that could be undertaken outside of the bioregional assessment process to help minimise impacts of CSG and coal mining developments on water resources. (Barrett et al. 2013)

Assessment reports will be progressively available through 2015–17, initially comprising context statements, resource assessments, and receptor and asset registers. Impact reports and risk analyses will be released later.

Disaggregation of responsibility for driving, and resource reductions for implementing, the National Water Initiative raise risks for future water management, especially in light of policy that affects water resources, such as the development of Australia’s north (NWC 2014). These risks include:

- noncompletion of National Water Initiative elements, such as water reform, and lack of national leadership in water
- reduction in independent oversight and public reporting, such as that seen with national water market reporting
- failure of implementation of water quality objectives in water management
- failure of full implementation and auditing of the Murray–Darling Basin Plan.

Assessment summary 7 shows the risks to inland water environments. In addition to those listed, there are many less significant risks, particularly at the local or point scale.
## Assessment summary 7

### Current and emerging risks to inland water environments

<table>
<thead>
<tr>
<th>Almost certain</th>
<th>Major</th>
<th>Moderate</th>
<th>Minor</th>
<th>Insignificant</th>
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<tbody>
<tr>
<td>Warming climate leading to changed flow regime or groundwater condition</td>
<td>Agricultural run-off leading to nutrient pollution and sedimentation of rivers</td>
<td>Flow regime alteration arising from water infrastructure development</td>
<td>Minor chemical pollution events</td>
<td></td>
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<tr>
<td>Increased water extractions leading to changed flow regime or groundwater levels</td>
<td>Invasive aquatic pest animal damage</td>
<td>Urbanisation leading to loss of wetland habitat</td>
<td>Livestock damage to riparian areas</td>
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<td></td>
<td>Major river or aquifer salinisation because of historical land clearance</td>
<td>Changes in fire frequency or intensity</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Aquatic weed invasion leading to habitat loss</td>
<td>Salinisation or contamination of groundwater or rivers because of gas mining or coalmining</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Extreme weather events leading to sedimentation of rivers or coastal aquatic habitats</td>
<td>Warming climate increasing aquatic habitat temperatures</td>
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<td></td>
<td></td>
<td>Blue–green algal outbreaks</td>
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<tr>
<td>Likely</td>
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<tr>
<td>Possible</td>
<td>Major chemical pollution events</td>
<td>Extensive disease outbreak for multiple aquatic species</td>
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<tr>
<td>Unlikely</td>
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<tr>
<td>Rare</td>
<td>Not considered</td>
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</table>
At a glance

Climate and pests remain the largest pressures on our inland water environments. Climate variability and climate change, and associated changes in rainfall regimes, are the primary risks to inland water environments in both the short and long term. Efforts will need to continue to monitor and manage aquatic pests and weeds. As agricultural development spreads and becomes more intensive across northern Australia, the weed and pest outlook will become more uncertain, with more opportunities arising for new pests to establish and flourish.

In addition, the scientific investigation and management controls associated with exploitation of coal-seam gas and large coalmining developments both potentially benefit and threaten the future health of inland waters. In this regard, the Bioregional Assessment Programme offers the most open and accessible data, information and assessment approach in Australian natural resource history.

Australia's water resources information is becoming increasingly available in many forms, supporting broader understanding and more informed debate about the future of our water resources and aquatic environments. It is possible that—with the development of online resources, integrated data and information platforms, machine-to-machine information accessibility, and ready and continuous environmental assessment techniques—future assessments of inland waters could be done on-demand or in near real time, based on semi-automated processing of online data repositories. The current development of Essential Environmental Measures is a step in this direction. This program brings together experts to identify measures that are essential for tracking changes in the state of our environment, and to improve the discovery, access and reuse of data and information under those measures. The increased use of remotely sensed information for widespread water assessment (Ward et al. 2013) may be one of the foundation stones of these new approaches. When combined with management-focused on-ground water monitoring regimes, it provides a positive outlook for our ability to observe, understand and, ideally, respond to changes in timely and effective ways.

Inland waters continue to receive moderate to reasonable attention in national research and policy agendas, such as the national Science and Research Priorities, and the policies on agricultural competitiveness and developing northern Australia (Australian Government 2015a,b), and in research programs, such as the National Environmental Science Programme. The Rural Research and Development...
for Profit program also offers hope for more and better water information to support both productive and environmental uses, with program priorities that include soil, water and managing natural resources.

The addition of 2 new aquatic weeds to the list of Weeds of National Significance in 2012 highlights the efforts that will be needed to continue to monitor and manage aquatic pests and weeds. In areas of prior and existing land development, many of the weed and pest species are known and have defined control regimes. As agricultural development spreads and becomes more intensive across northern Australia, the weed and pest outlook will become more uncertain, with more opportunities arising for new pests to establish and flourish.

The scientific investigation and management controls associated with recent and proposed exploitation of coal-seam gas across most mainland states, along with other large coalmining developments, provide both an opportunity and a threat to the future health of inland waters. The Bioregional Assessment Programme offers the opportunity for the most open and accessible data, information and assessment approaches in Australian natural resource history. The goal of making all assessments publicly available with their background data and models promises to set a benchmark for future large-scale resource developments, such as those on the table for northern Australia. The threat to inland waters lies in the uncertain individual and cumulative impacts on groundwater and surface-water volumes, quality and biota, especially under climatic conditions that have not been experienced previously.

Evidence is emerging about the information impacts of disaggregating responsibility and reducing resources for the National Water Initiative. The future outlook under the National Water Initiative is variable, with reforms around marketisation of water and provision of water for the environment operating well in some areas but having less traction in others. Two emerging areas for the future in which inland water environments will benefit from whole-of-government attention are those of cultural water, and co-management of groundwater and surface water. Indigenous management of water resources, including accounting for environmental needs, receives significant attention in the north and is likely to increase in future in the Murray–Darling Basin and other parts of the country. Conversely, as water resources development increases in the north, and the importance of groundwater within the annual production cycle increases, it will be important to ensure that both surface-water and subsurface-water ecosystems, including stygofauna, are well understood and managed.
# Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym or abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL</td>
<td>gigalitre</td>
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<tr>
<td>kL</td>
<td>kilolitre</td>
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<tr>
<td>ML</td>
<td>megalitre</td>
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<tr>
<td>mm</td>
<td>millimetre</td>
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<tr>
<td>NGIS</td>
<td>National Groundwater Information System</td>
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<tr>
<td>NRM</td>
<td>natural resource management</td>
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<tr>
<td>SEACI</td>
<td>South Eastern Australian Climate Initiative</td>
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<tr>
<td>SoE</td>
<td>state of the environment</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>abstraction</td>
<td>Removal of water from a water store.</td>
</tr>
<tr>
<td>adaptive management</td>
<td>A systematic process for continually improving policies and practices by learning from the outcome of previously used policies and practices.</td>
</tr>
<tr>
<td>algal bloom</td>
<td>A sudden proliferation of algae (microscopic plants) that occurs near the surface of a body of water. Blooms can occur because of natural nutrient cycles, or in response to eutrophication or climate variations. See also eutrophication.</td>
</tr>
<tr>
<td>bioregion</td>
<td>A large, geographically distinct area that has a similar climate, geology, landform, and vegetation and animal communities.</td>
</tr>
<tr>
<td>blackwater event</td>
<td>When organic material is inundated or washed into waterways and consumed by bacteria, leading to a sudden depletion of dissolved oxygen in the water.</td>
</tr>
<tr>
<td>bore</td>
<td>A hole drilled in the ground, a well or any other excavation used to access groundwater.</td>
</tr>
<tr>
<td>chytridiomycosis</td>
<td>A fungal disease that affects amphibians, such as frogs.</td>
</tr>
<tr>
<td>climate change</td>
<td>A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is additional to natural climate variability observed over comparable time periods (under the terms of the United Nations Framework Convention on Climate Change).</td>
</tr>
<tr>
<td>coal-seam gas</td>
<td>A type of natural gas found in coal deposits (coal seams). It largely comprises methane gas.</td>
</tr>
<tr>
<td>condition</td>
<td>The ‘health’ of a species or community, which includes factors such as the level of disturbance from a natural state, population size, genetic diversity, and interaction with invasive species and diseases.</td>
</tr>
<tr>
<td>connectivity</td>
<td>Linkages between habitat areas; the extent to which particular ecosystems are joined with others; the ease with which organisms can move across the landscape.</td>
</tr>
<tr>
<td>drainage division</td>
<td>Representation of the catchments of major surface-water drainage systems, generally comprising a number of river basins. Thirteen drainage divisions are defined for Australia in the Australian Hydrological Geospatial Fabric.</td>
</tr>
<tr>
<td>El Niño</td>
<td>A periodic extensive warming of the central and eastern Pacific Ocean that leads to a shift in weather patterns across the Pacific. In Australia (particularly eastern Australia), El Niño events are associated with an increased probability of drier conditions. See also La Niña.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
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</tr>
<tr>
<td>eutrophication</td>
<td>Excessive richness of nutrients in a body of water, frequently due to run-off from the land, which encourages the growth of algae and other aquatic plants.</td>
</tr>
<tr>
<td>gauging station</td>
<td>A location on a river or steam where instantaneous streamflow is physically measured. Also known as stream gauge or stream gauging station.</td>
</tr>
<tr>
<td>groundwater</td>
<td>Subsurface water in soils and geological formations that are fully saturated. See also surface water.</td>
</tr>
<tr>
<td>hydrogeology</td>
<td>The branch of geology that deals with the occurrence, distribution, movement and effect of groundwater. See also groundwater and surface water.</td>
</tr>
<tr>
<td>hydrology</td>
<td>The branch of science especially concerned with the movement and quality of water in relation to land.</td>
</tr>
<tr>
<td>hydrostratigraphy</td>
<td>The identification of layers of rock and sediment types as they relate to a groundwater bore.</td>
</tr>
<tr>
<td>hysteresis</td>
<td>When the physical effects of something lag behind the cause; a cause that does not have an immediate effect.</td>
</tr>
<tr>
<td>land use</td>
<td>The management and modification of land for various uses, including agriculture, forestry, mining, industry and urban development.</td>
</tr>
<tr>
<td>La Niña</td>
<td>A periodic extensive cooling of the central and eastern Pacific Ocean. In Australia (particularly eastern Australia), La Niña events are associated with increased probability of wetter conditions in eastern Australia. See also El Niño.</td>
</tr>
<tr>
<td>macroinvertebrate</td>
<td>Backboneless animals that can be seen with the naked eye, such as flies, worms, snails and spiders.</td>
</tr>
<tr>
<td>natural resource management</td>
<td>The management of natural resources such as land, water, soil, plants and animals, with a focus on sustainable practices.</td>
</tr>
<tr>
<td>PET (Plecoptera, Ephemeroptera, Trichoptera)</td>
<td>A group of macroinvertebrates that are often used to assess water quality. See also macroinvertebrate.</td>
</tr>
<tr>
<td>pressures</td>
<td>Events, conditions or processes that result in degradation of the environment.</td>
</tr>
<tr>
<td>Ramsar Convention on Wetlands</td>
<td>An international treaty that provides a framework for the conservation and management of important wetland habitats.</td>
</tr>
<tr>
<td>resilience</td>
<td>Capacity of a system to experience shocks while retaining essentially the same function, structure and feedbacks, and therefore identity.</td>
</tr>
<tr>
<td>resistance</td>
<td>Capacity of a system to not change significantly when faced with a common range of natural disturbances.</td>
</tr>
<tr>
<td>riparian</td>
<td>Related to riverbanks or lake shores.</td>
</tr>
<tr>
<td>run-off</td>
<td>Movement of water across the land, including into streams.</td>
</tr>
<tr>
<td>slack water</td>
<td>A state and/or area of reduced water velocity.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>species</td>
<td>A group of organisms capable of interbreeding and producing fertile offspring.</td>
</tr>
<tr>
<td>steady state</td>
<td>A condition in which the state of a system tends to remain unchanged.</td>
</tr>
<tr>
<td>stygofauna</td>
<td>Any animal that lives in groundwater systems. See also groundwater.</td>
</tr>
<tr>
<td>surface water</td>
<td>Water that flows over, or is stored on, the surface of the earth, such as lakes, rivers and streams. See also groundwater.</td>
</tr>
<tr>
<td>taxa</td>
<td>A group of one or more organisms classified as a unit. Taxonomic categories include class, order, family, genus, species and subspecies.</td>
</tr>
<tr>
<td>threshold</td>
<td>A boundary between two relatively stable states; a point where a system can go rapidly into another state, usually because of positive feedback(s).</td>
</tr>
<tr>
<td>turbidity</td>
<td>A measure of the light-scattering properties of water. This is an indicator of the presence of suspended solids.</td>
</tr>
<tr>
<td>water market</td>
<td>A regulatory and planning-based system of managing surface-water and groundwater resources for rural and urban use that aims to optimise economic, social and environmental outcomes.</td>
</tr>
<tr>
<td>watertable</td>
<td>The groundwater surface in an unconfined aquifer or confining bed at which the pore pressure is atmospheric.</td>
</tr>
</tbody>
</table>
Acknowledgements

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Index

Note: An ‘f’ following a page number indicates a figure; ‘t’ indicates a table.

2011–16 in context, 6–8

A
adaptive management, 69
Adelaide, groundwater abstraction, 17t
agricultural competitiveness white paper, 79
agricultural water consumption, vi, 6, 8, 15
anthropogenic water bodies, 70
see also dams
approach for inland water theme, 1
aquatic ecosystems, climate change projections, 75
aquatic pest animals see pests and invasive species
aquatic weeds, 22–24, 80
see also pests and invasive species
aquifers see groundwater
arrowhead (Sagittaria platyphylla), 22, 23f
Arthurs paragalaxias fish (Paragalaxias mesotes), 52
assessment summaries
ecological processes, 56–57
effectiveness of management, 63–68
groundwater, 43–44
pressures, 26–27
risks, 78
water flows and levels, 36–37
water quality, 49–50
at a glance
effectiveness of management, 59
outlook, 79
pressures, 9
resilience, 69
risks, 72
state and trends, 28
Atlas of Groundwater Dependent Ecosystems, 38
Australasian Riverprize, 60
Australian and New Zealand guidelines for fresh and marine water quality, 61
Australian Capital Territory, dams, 16
Australian Groundwater Explorer, 38
Australian Groundwater Insight, 38, 39
Australian River Assessment System, 51
Australian Water Resources Assessments, 30, 45
Australian and New Zealand guidelines for fresh and marine water quality, 61
Australian Water Resources Assessments, 30, 45
Australian Capital Territory, dams, 16
Australian Groundwater Explorer, 38
Australian Groundwater Insight, 38, 39
Australian River Assessment System, 51
Australian Water Resources Assessments, 30, 45

B
barramundi (Lates calcarifer), 75
baseline for assessments, 29
Basin Salinity Management Strategy, 46
Bioregional Assessment Programme, vi, 3, 38, 39, 55, 77, 80
see also coal-seam gas developments
Black Saturday fires, 19
blackwater events, 45, 55
Blackwood River, Western Australia, 52
Brisbane
groundwater abstraction, 17t
urban water supply, 14, 15t
Bureau of Meteorology
data provision, v, 6–7
groundwater data, 38
surface-water data, 30
bushfires, 18, 19

C
cane toad (Rhinella marina), 19
carp (Cyprinus carpio), 19, 20f
Carpentaria Coast drainage division
climate change projections, 73
ecological processes, 56
groundwater, 39, 43
map, 4f
water flows and levels, 33, 36
water quality, 45–46, 49
catchment management authorities, 62
Central Slopes and Murray Basin NRM cluster climate change projections, 74
Clarence catchment, New South Wales, 52
Clarence River Estuary, New South Wales, 48
climate change
risks to inland water environments, 72–75, 79
summary of pressures, 26
water management adaptation, 65
see also Atmosphere report; Drivers report; recent climate

Australia ▪ State of the Environment 2016 ▪ 94
coalmining, 3, 39, 77, 80
coal-seam gas developments, 3, 7, 17, 39, 77, 80
common carp (Cyprinus carpio), 19, 20f
Commonwealth Environmental Water Holder, 6
Commonwealth Environmental Water Office see Long-Term Intervention Monitoring Project
community engagement, 61
Convention on Wetlands (Ramsar, Iran), 6, 33
Cotter Dam, Australian Capital Territory, 16
Council of Australian Governments Water Reform Framework, 61
cropped land, 19
CSIRO water resource assessments, 39
cultural water, 80
Cyprinus carpio (common carp), 19, 20f
D
dams, 16–17, 75
see also anthropogenic water bodies
Darwin Harbour ecosystem health, 48
data and information
groundwater, vi, 38–39
national scale, 6–7, 79–80
online availability, v
variability, 3
water flows and levels, 30, 33
water quality, 45
desalination plants, 14, 15–16
developing northern Australia white paper, 79
drainage divisions, 3–4
groundwater assessments, 39
see also by name of individual divisions
drought, millennium, 3
E
East Coast NRM cluster climate change projections, 74
eastern gambusia (Gambusia holbrooki), 19, 21f
ecological processes, 51–54, 56–57
see also Biodiversity report
ecosystem steady states, 70
effectiveness of inland water management, 1, 59–68
Eichhornia crassipes (water hyacinth), 22, 24f
El Niño, 79
environmental economic accounting, 29
environmental watering, 6, 51, 54, 59, 70
Environmental Watering Strategy (Murray–Darling Basin Plan), 52
Essential Environmental Measures, 79
F
farmed land, 19
feral animals see pests and invasive species
Feral Fish Scan, 19
fire
Black Saturday fires, 19
savannas, 18
fish
feral fish, 19–22
pressures on native species, 75
state and trends, 54–55
Fish Community Index, 55
Fitzroy Basin ecosystem health, 47f, 52
floods, 10, 69
flow regimes
ecological processes, 51
groundwater role, 38
land-use impacts, 18
frogs, 54
G
Gambusia holbrooki (eastern gambusia), 19, 21f
Geoscience Australia – CSIRO data cube, 30
Gnangara groundwater system, 17
Great Artesian Basin Sustainability Initiative, 41, 62
Great Barrier Reef
water management, 62
water quality, 18, 46–47
groundwater
data and information, vi, 38–39
dependent ecosystems, 75
management, 7
pressures on, 17
salinity, 45
state and trends, 1, 38–44
stygofauna, 55
and surface-water co-management, 60, 80
water abstraction, 75
see also Bioregional Assessment Programme; Great Artesian Basin Sustainability Initiative
Guide to environmental accounting in Australia, 29
Gulf of Carpentaria drainage division see Carpentaria Coast drainage division
index

H
Hephaestus fuliginosus (sooty grunter), 75
hydrogeology of Australia, 40f
Hydrologic Reference Stations, 30

I
Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, 7
Indian Ocean drainage division see Pilbara–Gascoyne drainage division
Indigenous Land and Sea Ranger program, 77
Indigenous management of water resources, 60–61, 80
Indigenous Water Policy Group, 60
irrigated agriculture
Tasmania, 8
see also agricultural water consumption

K
key species populations, 54–57
see also Biodiversity report
Kurnell desalination plant, 14

L
Lagoon of Islands, Tasmania, 52
Lake Eyre Basin drainage division
climate change projections, 73
ecological processes, 52, 56
groundwater, 39, 41, 43
map, 4f
rainfall deciles, 31f
streamflow, 32f
water balance, 30
water flows and levels, 33, 36
water quality, 46, 49
Lake Eyre Basin Rivers Assessment 2013–14, 46
fish species richness, 54–55
land clearing, 18
land use and management, 18–19
risks to inland water environments, 75, 77
summary of pressures, 26
water quality, 64
see also Land report
Lates calcarifer (barramundi), 75
Litoria raniformis (southern bell frog), 54
livestock grazing impacts, 18
Living Murray program, 6, 52, 54, 55
Long-Term Intervention Monitoring Project, 6, 46, 52, 54, 69–70

M
management effectiveness of inland water, 1, 59–68
Melbourne
groundwater abstraction, 17t
urban water supply, 14, 15
methodology, water quality, 45
millennium drought, 3
mining see coal-seam gas developments
Monsoonal North NRM cluster climate change projections, 73
Monthly Water Update, 30
Murray–Darling Basin
ecological processes, 51
environmental watering, 6
fish species richness, 55
resilience, 69–70
Murray–Darling Basin drainage division
climate change projections, 73, 74
ecological processes, 52, 56
groundwater, 41–42, 43
map, 4f
water flows and levels, 33, 36
water quality, 46, 49
Murray–Darling Basin Plan, v, 8, 61–62
see also Long-Term Intervention Monitoring Project

N
Nathan Dam, Queensland, 16
National Aquifer Framework, 38
national assessments of water management, 61
National Climate Change Adaptation Research Facility, 75
National Environmental Science Programme, 79
National Groundwater Information System, 38
National Water Accounts, 30
National Water Commission, 61
National Water Initiative, v, 6, 8, 59, 61
Indigenous management of water resources, 60
risks from disaggregation of responsibility, v, 77, 80
National Water Market System, 61
New South Wales
aquatic ecological condition, 52
water management, 61
Ngarrindjeri Regional Authority, 60
North East Coast drainage division
climate change projections, 73, 74
ecological processes, 56
groundwater, 42, 43
map, 4f
water flows and levels, 33, 36
water quality, 46–47, 49
Northern Australia Water Futures Assessment, 51–52, 73
northern corroboree frog (*Pseudophryne pengilleyi*), 54
Northern Territory
pressures on fish species, 75
water management, 60
North Western Plateau drainage division
climate change projections, 73
ecological processes, 56
groundwater, 42, 43
map, 4f
water flows and levels, 34, 36
water quality, 47, 49

**O**
ornamental fish, 19–22
see also pests and invasive species
outlook, 79–80

**P**
Paragalaxias mesotes (Arthurs paragalaxias fish), 52
Peel–Harvey streams, Western Australia, 48
Perth
groundwater resources, 17
urban water supply, 14, 15f
pests and invasive species, 19–24, 80
key findings, vi
management, 66, 77
summary of pressures, 27
Pilbara–Gascoyne drainage division
climate change projections, 73
groundwater, 42, 43
map, 4f
water flows and levels, 34, 36
water quality, 47, 49
policies, 6, 8, 59, 61, 79–80
see also National Water Initiative
pollution, 18
see also water quality
population growth, 8, 15
pressures, 1
at a glance, 9
influencing state and trends of inland water, 28
land use and management, 18–19
pests and invasive species, 19–24
recent climate, 10–14
summary, 26–27
water resource development, 14–17
see also Drivers report
*Pseudophryne corroboree* (southern corroboree frog), 54
*Pseudophryne pengilleyi* (northern corroboree frog), 54

**Q**
Queensland
aquatic ecological condition, 52
dams, 16
land clearing, 18
Queensland Wetlands Management Program, 54

**R**
rainfall
annual averages, 5
climate change projections, 72–75
deciles, 12
deficiencies, 10–11
recent climate, 10–14, 26, 29
Ramsar Convention on Wetlands of International Importance, 6, 33
Rangelands NRM cluster climate change projections, 73
recent climate, 10–14, 26, 29
see also Atmosphere report
recreation, water for, 15
recycled water plants, 15–16
refuges, 70
Regional Water Information, 30
remote sensing for water assessments, 79
residential water supplies, 16f
resilience of inland water environments, 1, 69–70
*Rhinella marina* (cane toad), 19
risk assessment framework for groundwater-dependent ecosystems, 75
risks to inland water environments, 1
climate change, 72–75, 79
at a glance, 72
land and water use, 75, 77
summary, 78
water abstraction and interception, 75
run-off risks, 73
Rural Research and Development for Profit, 79–80

**S**
*Sagittaria platyphylla* (arrowhead), 22, 23f
salinity
groundwater, 45
Murray–Darling Basin, 46
satellite data, 30
savannas, 18
Science and Research Priorities, 79
snowfall, 74
sooty grunter (*Hephaestus fuliginosus*), 75
South Australia
aquatic ecological condition, 51
reporting methods, 38–39
South Australian Gulf drainage division
climate change projections, 73
ecological processes, 56
groundwater, 42, 43
map, 4f
water flows and levels, 34, 36
water quality, 47, 49

South East Coast (New South Wales) drainage division
climate change projections, 74
ecological processes, 52, 56
groundwater, 42, 43
map, 4f
water flows and levels, 34, 36
water quality, 47–48, 49

South East Coast (Victoria) drainage division
climate change projections, 73, 74
ecological processes, 56
groundwater, 42, 43
map, 4f
water flows and levels, 34, 37
water quality, 48, 50

South Eastern Australian Climate Initiative, 73
South-East Queensland Healthy Waterways Partnership, 52

South Eastern Australian Climate Initiative, 73
South-East Queensland Healthy Waterways Partnership, 52
Southern and South Western Flatlands NRM cluster climate change projections, 74

South West Coast drainage division
climate change projections, 73
ecological processes, 56
groundwater, 42, 44
map, 4f
water flows and levels, 34–35, 37
water quality, 48, 50

South Western Plateau drainage division
climate change projections, 73
ecological processes, 51, 57
groundwater, 42, 44
map, 4f
water flows and levels, 37
water quality, 47, 50

South West Index of River Condition, 52
state and territory responsibilities, v
see also National Water Initiative
state and trends of inland water
ecological processes, 51–54, 56–57
at a glance, 28
groundwater, 38–44
key species populations, 54–57
water flows and levels, 29–37
water quality, 45–50

steady states, 70
streamflow see flow regimes
stygofauna, 55
Surat Cumulative Management Area, 17
surface-water and groundwater co-management, 60, 80
surface-water network, 29–37
Sustainable Rivers Audit, 46
Swan Canning river system, Western Australia, 48
Sydney urban water supply, 14, 15t

T
Tamar Estuary, Tasmania, 48, 52
Tanami–Timor Sea Coast drainage division
climate change projections, 73
ecological processes, 57
groundwater, 42, 44
map, 4f
water flows and levels, 35, 37
water quality, 48, 50

Tasmania
aquatic ecological condition, 52
dams, 16
irrigated agriculture, 8
Tasmania drainage division
climate change projections, 74
ecological processes, 57
groundwater, 42, 44
map, 4f
water flows and levels, 35, 37
water quality, 48, 50

Tasmanian River Condition Index, 48
threatened species, 54
tropical aquatic ecosystems, 18

U
urban water consumption, vi, 6, 8, 14–16

V
Victoria
aquatic ecological condition, 52
dams, 16
water management, 62
Victorian Climate Initiative, 74
Victorian Environmental Water Holder, 6
W

water abstraction and interception, 6, 75
  see also dams
water accounts, 29
waterbirds, 54, 55f
water consumption see agricultural water consumption; urban water consumption
water data and information see data and information
water flows and levels, 29–37
water hyacinth (Eichhornia crassipes), 22, 24f
water infrastructure see anthropogenic water bodies; dams; desalination plants
water management effectiveness, 1, 59–68
water markets, 6, 7
Water Observations from Space, 30
water policies, 6, 8, 59, 61, 79–80
  see also National Water Initiative
water quality, vi, 1
  data and information, 30, 45, 61
  influences on, 25f
  land use, 18, 64
  state and trends, 45–50
water reform see National Water Initiative
Water Reform Framework, 61
water resource development, 14–17
  summary of effectiveness, 63
  summary of pressures, 26
  see also dams; water abstraction and interception
water storage, 12, 13–14
water use see agricultural water consumption; urban water consumption
weather patterns see recent climate
weeds, 22–24, 80
Weeds of National Significance, 22
Western Australia
  aquatic ecological condition, 52
  fish species richness, 55
wetlands, 54
Wet Tropics NRM cluster climate change projections, 73
Woodglen No. 2 dam, Victoria, 16
Woods Lake, Tasmania, 52
Australia state of the environment 2016 (SoE 2016) is an independent national assessment of the state of the Australian environment. It includes 9 thematic reports on atmosphere, built environment, heritage, biodiversity, land, inland water, coasts, marine environment and Antarctic environment. It also includes a synopsis of the detailed theme assessments (Overview), highlighting what they mean for the outlook for the Australian environment; a report on the drivers of change in the Australian environment (Drivers); and a report detailing the approach to SoE 2016 (Approach).

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