Appendix E: Wentworth Group 2017 Review of Water Reform in the Murray-Darling Basin

WENTWORTH GROUP

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REVIEW OF WATER REFORM IN THE MURRAY-DARLING BASIN

NOVEMBER 2017

Wentworth Group of Concerned Scientists

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Summary

It has been thirteen years since the historic National Water Initiative was signed, and five years since the Australian Parliament agreed to the Murray-Darling Basin Plan. Since then, nearly $8 billion of taxpayers' money has been spent largely to address the chronic over-allocation of water in the river systems of the Murray-Darling Basin.

This report is the first independent and comprehensive review of the Basin Plan. Its purpose is to evaluate progress towards the social, environmental and economic objectives of the reforms, with the view to setting out steps necessary to deliver the Basin Plan in full by 2026. This report also looks further into the future and sets out a suite of long-term reforms that are necessary if the nation is to achieve its ultimate goal of restoring the health of river systems in the Murray-Darling Basin.

Overall, the review finds there has been significant progress since 2004, but this progress has slowed to a trickle since the Basin Plan was adopted in 2012. Without major changes in implementation, it is almost certain that the Basin Plan will fail.

A healthy working Murray-Darling Basin is vital for the wellbeing and livelihoods of more than three million people who live in the Basin or rely on its water resources. It is also of great importance to Australia. A healthy working Basin means communities with reliable fresh water for growing food and fibre, an open Murray mouth with sufficient water to export salt, and healthy populations of water-dependent species and ecosystems, including 16 wetlands of international conservation significance.

Since Federation, successive governments have grappled with the challenge of managing water resources in the Murray-Darling Basin. More than a century of growth in water use has resulted in significant environmental degradation, where 21 of the 23 catchments in the Basin are now in poor or very poor health.

In 2004, a major intergovernmental agreement - the *National Water Initiative* - was signed by all governments of Australia. It represented a once-in-a-generation opportunity to restore the health of river systems in a way that promotes economic prosperity while using less water.

In 2007, the *National Plan for Water Security* provided a legislative framework (the *Commonwealth Water Act 2007*) and what amounted to a $13 billion public investment to deliver these reforms. The 2007 Water Act required the newly created Murray-Darling Basin Authority to produce a Basin Plan to *"*ensure the return to environmentally sustainable levels of extraction for water resources that are over-allocated or overused*"*.[1]

The Basin Plan was established by the Australian Parliament in 2012 to recover 3,200 GL of water for the environment from an annual consumptive use of 13,623 GL, or implement projects which deliver 'equivalent' outcomes. This volume fell substantially short of the Murray-Darling Basin Authority's best estimate that between 3,856 GL (high uncertainty) and 6,983 GL (low uncertainty) was required for a healthy river. The Basin Plan also allowed for significant increases in groundwater extractions, and did not take into account the likely future impact of climate change, particularly in the southern Basin where the latest projections show reduced river flows are likely to have significant impacts on water availability.

In this review, we find that national water reform has improved water trade which has provided greater flexibility for irrigators to manage risks and adapt with less water. Water is now moving to higher value uses, assisted by permanent and temporary water trade. The Basin's economy as a whole has grown since 2002 and has been maintained in the five years since the Basin Plan has been in place.

Since the 2004 National Water Initiative, there has also been substantial progress towards the recovery target, with two thirds of the water recovered (2,107 GL) and with almost two thirds of the funding spent ($7.9 billion). While no overall improvement in the condition of river systems has been observed yet, there have been local improvements in salinity, water quality, and the condition of freshwater species in river reaches receiving additional water.[2] The Ramsar-listed Coorong is still in poor condition due to inadequate freshwater flow, however the condition of the Lower Lakes, also an internationally recognised environmental asset, has improved through the combination of the return of wetter conditions since the millennium drought and the delivery of environmental flows.[3]

Notwithstanding these important achievements, strong political pressure has resulted in national water reform slowing to a trickle. This pressure has been exerted on governments to halt water purchase and unwind water recovery targets. Only one quarter of the water recovered so far (530 GL) has been acquired since the Basin Plan was adopted, while the cost of water recovery has doubled.

One of the reasons for this pressure is that in some districts, water recovery has compounded the many other economic pressures facing rural and regional Australia, and governments have failed to support communities in these districts. Whilst individual irrigators have benefited from the reforms, less than one percent of the $13 billion was made available to assist communities affected by the reforms to adapt to a future with less water.

This review finds that even with the Basin Plan implemented in full, it will be impossible to achieve the objective that the "mouth of the River Murray is open without the need for dredging in at least 95% of years"[4] without significantly more river flow, permanent dredging or other major interventions.

This review also finds that some Basin states are retarding progress and proposing changes which are inconsistent with the objectives of the Basin Plan: some have put forward projects as substitutes for environmental water, most of which do not satisfy the requirements of the Basin Plan;[5] some are failing to remove constraints which prevent environmental water from flowing downstream; and some are attempting to adjust river management rules and change computer model settings in a way that will allow larger volumes of water to be legally pumped for private use (including water that has been recovered for the environment).

A series of institutional changes since 2012 have eroded regulatory oversight of the national water reforms: in 2013, the Murray-Darling Basin Ministerial Council abolished the Sustainable Rivers Audit, a program that was established to measure the condition of the river systems in the Basin; in 2014, the Commonwealth Government abolished the National Water Commission; and in 2017, revelations of possible water theft and meter tampering exposed inadequate monitoring and compliance regimes.

The consequence of this systematic weakening of the 2004 reforms and undermining of the Murray-Darling Basin Plan has now placed water reform at great risk, leaving Australia's most productive basin seriously compromised. It will be the people living downstream and future generations that carry the cost of the degraded river system.

What is needed is to return to a genuine spirit of cooperation that existed when the nation's governments signed the National Water Initiative in 2004. Cooperation among states and the Commonwealth is essential to restoring public trust in the integrity of the Basin Plan and ensuring water reform is both fair and effective.

In December 2016, in response to growing concerns of the commitment of governments to reform, all Murray-Darling Basin First Ministers agreed to ensure the Basin Plan is delivered "on time and in full".[6] We welcome this statement. On the basis of this review, we put forward five actions that we believe are necessary to deliver the Murray-Darling Basin Plan if governments are to deliver on this promise:

1. Rebuild trust with greater transparency;
2. Guarantee recovery of the full 3,200 GL or genuinely equivalent outcomes;
3. Ensure that water recovered achieves measurable improvements to the river system;
4. A regional development package that puts communities at the centre of reform; and
5. Prepare for the prospect of a future with less water.

The Basin Plan agreement to recover 3,200 GL is an important step in the journey of water reform. With these actions and with the $5 billion remaining, it is possible to restore public trust, complete these reforms and in doing so, put Australia on a path towards restoring the health of the Murray-Darling Basin. When these reforms are in place, environmental assets will be in better condition, the Basin's economy will be more prosperous in the long-term, and communities will have greater confidence in their future.

Key findings

Progress towards recovering 3,200 GL or equivalent outcomes

1. Two thirds (2,107 GL) of the surface water target has been recovered as of September 2017, and nearly two thirds ($7.9 billion) of the $13 billion has been spent. Three quarters (1,577 GL) of this water was acquired prior to the Basin Plan, between 2009 and 2012.
2. Since 2014, water recovery has stalled and is no longer on a trajectory to meet the Basin Plan target (Figure 8). Water has been recovered through a combination of water purchase (57%), infrastructure efficiency upgrades (34%) and other mechanisms (8%). Recovered volumes may be less than claimed because of the reduction in runoff into rivers and leakage into groundwater as a result of upgrading and consolidating of irrigation systems.
3. The Murray-Darling Basin Authority has put forward a draft determination to increase the sustainable diversion limits by 605 GL on the basis of 37 projects put forward by state governments. Our asssessment of these projects found that only one project should be approved, eleven projects (representing in the order of 150 to 270 GL water savings) require additional information before a proper assessment can be undertaken, and twenty five projects (in the order of 316 to 436 GL) do not satisfy Basin Plan requirements and should be rejected.
4. Governments have listed water use efficiency projects to contribute to recovering 450 GL of water to enhance the health of the Basin's environment without harming communities and the economy overall, but there has been no reported recovery of this water to date.
5. Winter rainfall and streamflow in the southern Basin have declined since the mid-1990s and the Basin has warmed by around a degree since 1910. The Basin is likely to experience significant changes in water availability due to human-caused climate change, particularly in the southern Basin where annual rainfall is projected to change by -11 to +5% by 2030. Any reduction in precipitation is likely to have significant impacts on water flows in rivers, in some cases driving a threefold reduction in runoff, with implications for water recovery under the Basin Plan.

Environmental outcomes

1. Water recovered for the environment has assisted export of nearly 1 million tonnes of salt each year, more than would have been exported without the Basin Plan, but less than the Basin Plan target of 2 million tonnes.
2. Rivers and wetlands that received environmental water are in better condition, with measured improvements in water quality, salinity and fish. However, there are many more sites across the Basin which have not received sufficient environmental flow and there is no evidence yet to demonstrate improvement across the Basin as a whole. Environmental water recovered so far has not been sufficient to arrest the long-term deterioration in key river condition indicators (e.g. waterbirds and ecological processes). While localised improvements have been made in some Ramsar wetlands of the Basin, e.g. in the Gwydir wetlands, most remain in a state that is more degraded than the ecological character for which they were listed under the treaty. River operating constraints, inadequate environmental flow protection and non-compliance are still impeding the delivery of water downstream and onto floodplains.
3. Environmental water and natural flows have contributed to the improved environmental condition of the Lower Lakes, a Ramsar wetland of international significance, following the millennium drought. The Coorong is still in poor condition due to inadequate freshwater flow.
4. Even when the 3,200 GL or equivalent outcomes is delivered in full, it will not be possible to achieve the Basin Plan target of maintaining an open Murray mouth in 95% of years without continued dredging of the mouth, except during flood events.

Socio-economic outcomes

1. Irrigation businesses across the Murray-Darling Basin have benefited from the conversion of annual entitlements to permanent property rights and the capacity to trade those rights, a capital injection of $2.7 billion of public investment to purchase water entitlements, and $3.6 billion in irrigation infrastructure subsidies.
2. The gross value of irrigated agricultural production has risen since the early 2000s and has been maintained in the past 5 years. Money paid to irrigators by the Commonwealth to recover water and the ability to trade water has helped some irrigators adjust to the drought and cope with other pressures.
3. While agricultural production has been maintained, employment in agriculture in the Basin has declined by nearly 26% in the past 15 years. This decline has slowed considerably in the past 5 years, but has not increased in line with the rise in agricultural employment nation-wide. Most of the decline in agricultural employment in the Basin occurred in dairy farming and growing cotton, grapes, fruit and livestock grain. Despite this, there was a 2% increase in the overall number of people employed in the Basin from 2011 to 2016, largely due to increases in employment in other sectors such as education and training, health care and social assistance.
4. Employment and economic production in some regional centres, such as Griffith and Shepparton, have grown significantly over the past decade while other, usually smaller, communities have experienced declines. More efficient water use and water trade have contributed to these structural changes, including expansion of high-value production in the southern Basin.
5. The total number of agricultural businesses has also declined across the Murray-Darling Basin in line with national trends. Factors behind the decline include drought, technological improvements which have reduced demand for labour, and increasing farm business size to improve profitability. In some districts such as Deniliquin and Moree, water reforms have also been modest contributing factors. In these districts, water purchase have reduced water available for production while improvements in water efficiency and trade have led to rationalisation of agriculture (e.g. automation, out-sourcing and consolidation) and reduced demand for labour.
6. A major failure of water reform has been insufficient investment in structural adjustment to support communities affected by water reforms to adapt to a future with less water. Less than one per cent of the $13 billion has been made available to assist these communities.

Recommendations: Five actions necessary to deliver the Basin Plan "on time and in full"

COAG should agree to the following five actions to deliver the Murray-Darling Basin Plan 'on time and in full'. Future payments by the Commonwealth should be contingent on states delivering these actions, with annual audits of progress by COAG.

1. Rebuild trust with greater transparency, by:

- **Improving metering and compliance** by Commonwealth, state and territory governments agreeing to comprehensive measurement of consumptive water use and water interception, including groundwater, across the whole Basin to a standard suitable for compliance action.
- **Improving accountability** with professional water accounting standards and independent auditing against standards, accompanied by annual audits of expenditure of public funds and annual reviews of the Basin Plan's progress by an independent auditor.
- **Reinstating a basin-wide river monitoring program** to measure and report regularly on the overall condition of the 23 river systems across the Basin as well as targeted programs reporting on progress towards specific Basin Plan objectives against what would have occurred without the Basin Plan.
- **Strengthening the capacity of the Murray-Darling Basin Authority to fulfil duties as a regulator**.

2. Guarantee recovery of the full 3,200 GL or genuinely equivalent outcomes, by:

- **Securing the remaining 1,093 GL or equivalent**, including the 450 GL to enhance the Basin's health, through a combination of strategic water purchase, water efficiency programs and on-farm investment, but only where such recovery results in measurable additional water to the river system. Water recovered must account for the reduction in runoff and groundwater recharge that would have otherwise benefitted the environment.
- **Ensuring environmental outcomes are equivalent or better** as a result of any adjustment to the sustainable diversion limit by agreeing to the conditions in Table 10 on page 52. Rivers need water, and 'complementary measures' such as carp herpes virus, are not a substitute for real water.
- **Making sure water recovered for the environment is protected in the river and not being undermined** by changes to state water resource plans, river management and operating rules, changes to baselines or model assumptions (as defined in Table 12 on page 59), and other land use changes that affect water availability in the catchments (e.g. farm dams, plantations, floodplain harvesting).[7]

3. Ensure that water recovered achieves measurable improvements to the river system, by:

- **Removing constraints (physical and policy)** that restrict the use or passage of environmental water to target floodplains and wetlands, by re-configuring infrastructure and enforcing planning restrictions in designated floodways (see Table 13 on page 62), and where appropriate, compensating for any third party impacts.
- **Ensuring sufficient water reaches the Lower Lakes, Coorong and Murray Mouth** to export salt from the Basin, reduce water quality risks, and deliver freshwater to maintain the ecological character of the Ramsar wetlands.
- **Aligning the Basin Plan targets, the Basin-wide environmental watering strategy, and water resource plans,** at the catchment level as part of the accreditation process to achieve outcomes.

4. A regional development package that puts communities at the centre of reform, by:

- **Assisting communities most affected by water recovery to restructure their economies to adapt to a future with less water.** Assigning for example, 10% of the remaining $5.1 billion would release up to $500 million for regional development initiatives.
- **Linking public funding directly to the Basin Plan**, by the Commonwealth working directly with community leaders, local government, regional development boards and natural resource management agencies to recover the water in a manner that optimises regional development opportunities for those communities.

5. Prepare for the prospect of a future with less water, by:

- **Improving scientific understanding of the potential future stresses** caused by extreme weather events (e.g. more frequent and more severe drought and higher evaporation from rising temperature) and long-term changes in climate including water availability, supported by a climate change adaptation program for environmental assets, industries and public infrastructure.
- **Expanding the mandate of the Basin Plan** to integrate water planning with broader natural resource management to improve the overall environmental condition of the Basin.
- **Investing in knowledge and capacity** to enhance agricultural productivity, sustainable production and food and water security, and protect the natural resource base in a variable and changing climate.
- **Ensuring water reform** remains a permanent item on the COAG agenda, and recognising the long-term nature of national water reform via the establishment of an independent expert body to undertake regular reviews of progress.

Water reform is crucial to the future of the Basin

Benefits of a healthy and productive Murray-Darling Basin

The Murray-Darling Basin is Australia's largest river system, spanning one seventh of the continent and traversing four states and a territory (Figure 1). It is home to 2.2 million people and it supplies freshwater to a further 1.3 million, including the cities of Adelaide, Whyalla and Port Augusta. The Basin has become the nation's food bowl, generating a third of the national food supply and nearly half of all irrigated agricultural production in Australia.[8, 9] The Basin also contains a number of nationally significant environmental assets, including 16 internationally recognised Ramsar wetlands including the Coorong, Lower Lakes and Murray mouth (Figure 1).

A healthy Murray-Darling Basin is vital for the wellbeing and livelihoods of these people, and of great importance to the whole of Australia. A healthy Murray-Darling Basin means:

- Clean water for drinking and for growing food and fibre, with flows that flush salt, sediment and excess nutrients out of the Basin;
- Economic benefits from recreation, fishing, tourism and education;
- Reduced risk of algal blooms, hypoxic blackwater events, acidification, salinisation and erosion which pose significant health risks and impacts farming, fishing and tourism;
- Improved soil fertility and enhanced pastures in grazing landscapes as a result of the natural wetting cycles of floodplains;
- Improved water security for farmers during dry periods, improved capacity of wetlands to buffer floods and refuge for animals during droughts;
- Cultural and economic benefits for indigenous nations;
- Resilience to climate extremes with greater capacity to adapt to a changing climate in the future; and
- Habitat, food, migration pathways and breeding opportunities for native fish, waterbirds and other native wildlife that rely on water in the Basin, some of which are nationally threated and/or recognised by international agreements.

Healthy river systems are a pre-requisite for delivering all these benefits. Water is key to protecting and restoring the health of the Basin's ecosystems that provide these benefits.

Surface water in the Murray-Darling Basin is highly variable and there is strong competition over its use. Through past mistakes, many rivers are over-allocated or overused.[7] Without sufficient quality and quantity of flow, the Basin cannot support important environmental assets that depend on water, nor can it sustain the basic functions such as safe drinking water, reducing salinity for viable irrigation industries, as well as discharging salts and sediments to the sea through an open Murray mouth.

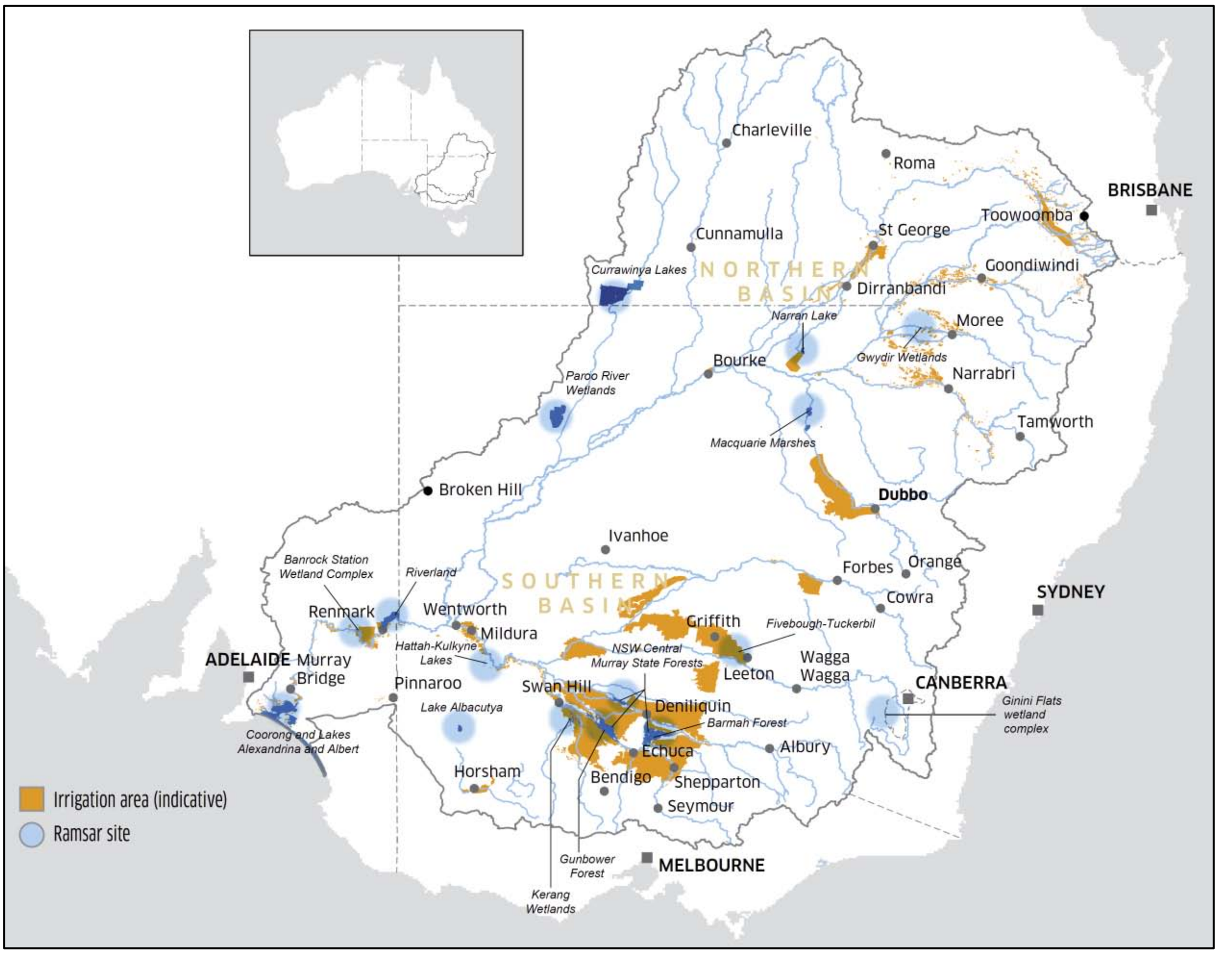

Figure 1. Map of the Murray-Darling Basin showing rivers, towns, major irrigation areas and Ramsar wetlands of international importance (Source: MDBA, 2016)[10]

History of a century of water reform in Australia

Australia is the driest inhabited continent and flows in the Murray-Darling Basin are among the most variable in the world. Water has always been vital to national development and human well-being. For over a century, successive governments have grappled with the challenge of managing water resources in Australia. There are many examples in history where governments have taken decisive action in response to these challenges. The first landmark water reform in Australia was catalysed by the severe drought that gripped the nation at the time of federation (1895 – 1902; Figure 2). After more than a decade of conflict between states, the Murray Waters Agreement in 1915 set out, for the first time, rules for sharing water of the River Murray between state and Commonwealth governments.

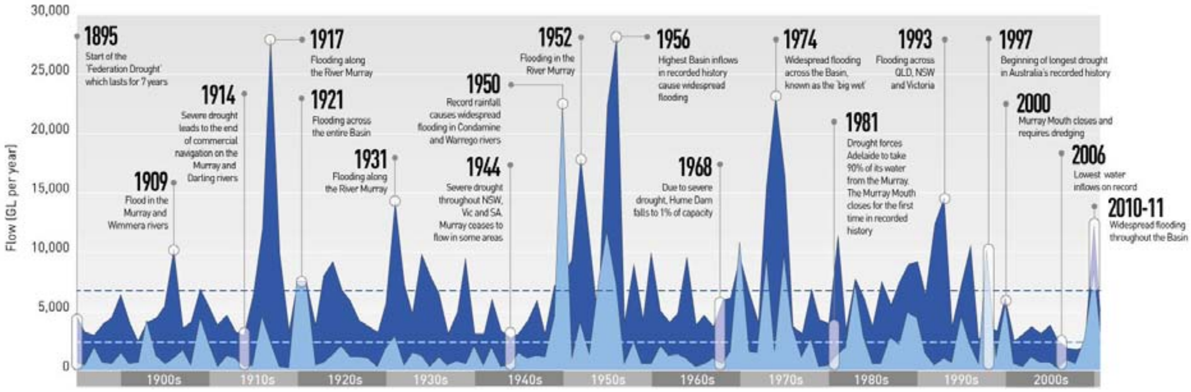

Figure 2. Historical river flows in the Murray-Darling Basin from 1895 to 2011 with major events highlighted. Annual flows are shown for the Southern Basin on the Murray River at Euston (dark blue) and for the Northern Basin on the Darling River at Burke (light blue), with averages shown as dotted lines. Source: MDBA, 2017.[11]

This Agreement, together with the Commonwealth's post-war nation-building agenda, shaped the course of water management through the mid-20th century. The Snowy Mountains Hydro-Electric Scheme constructed from 1949 to 1974 was the largest engineering project in Australia. It employed 100,000 workers in regional communities, of which 65% were immigrants. Governments also invested in the expansion of irrigation into the dry inland plains. By 1988, 84 large dams and weirs had been built in the Basin for regulating the river for water supply, river navigation, flood mitigation and hydro-electricity.[12] Thousands of small dams were constructed on farms for private use, and levees and channels were built to transport water to farms. This infrastructure provided for the rapid expansion of irrigated agriculture. Water use more than doubled in the period between the 1950s and the 1970s, and continued to grow steadily through the 1990s (Figure 3). In 1998, about one third of the annual inflow into the Basin was extracted for irrigation each year, an amount that was approaching the average annual natural flow to the sea (Figure 3).[12]

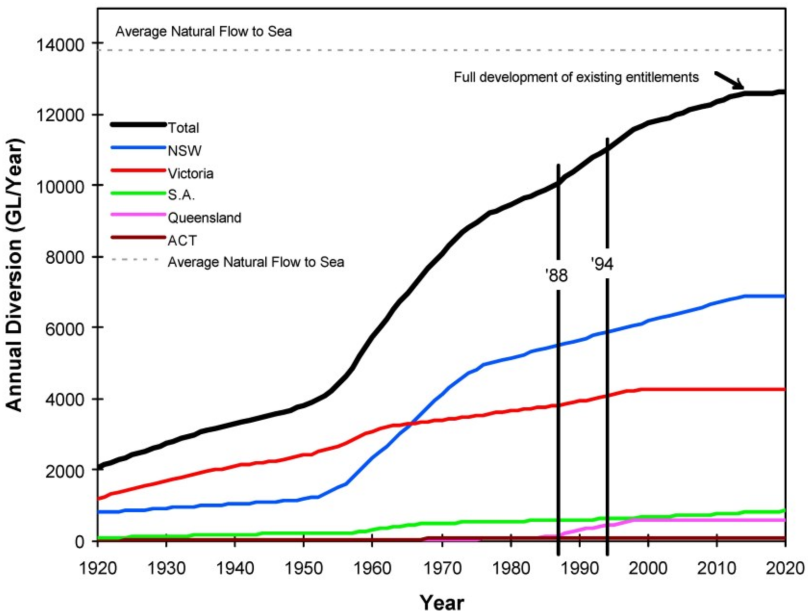

Figure 3. Annual diversions in the Murray-Darling Basin. Source: MDB Ministerial Council, 1995[13]

The 1918 Agreement proved adequate during the period of expansion and growth, but in drier years it failed to manage the problems of water quality. During the 1960s and 1970s, dryland salinity emerged as a problem, prompting investigations into salinity across the Basin. By 1987 it was estimated that 96,000 hectares of the Basin's irrigated land were salt-affected and 560,000 hectares had water tables within two metres of the land surface.[14] The Murray mouth closed for the first time on record in 1981, and dredging commenced to manage salt concentrations in the Coorong. In recognition of these issues, the Murray-Darling Basin Agreement was expanded to address water quality issues in 1987.

The problem of over-allocation of rivers remained. In 1991, a 1,200km blue-green algae bloom formed in the warm, shallow waters of the Darling River. An audit of water use by the Murray-Darling Basin Commission in 1995 revealed that median annual flows through the Murray mouth were only 21-28% of what they would have been in natural conditions.[15] It also found that drought conditions in the lower Murray occurred in 60% of years compared to 5% under natural conditions. In most years, water was so over-allocated, that more water was permitted to be taken than was physically available in the rivers. In 1997, after a century of unrestricted growth in water use, the Commission agreed to place a cap on water diversions from the Murray-Darling Basin.

The millennium drought (1999 to mid-2010) was the next shock to the system. Record low flows caused widespread degradation of the environment across the Basin, hyper-salinisation of the Coorong and Lower Lakes region in South Australia, and the closure of the Murray mouth. Only 2 of the 23 valleys of the Basin remained in moderate to good health by the end of the decade (Figure 4).[16] The impacts had flow-on effects for communities and the regional economy. One in every five jobs in agriculture across the Basin were lost from 2001 to 2011.[17] The crisis of the millennium drought prompted a new generation of water reforms designed to protect the health of rivers, wetlands, estuaries and groundwater systems while securing water supply for people and their livelihoods.

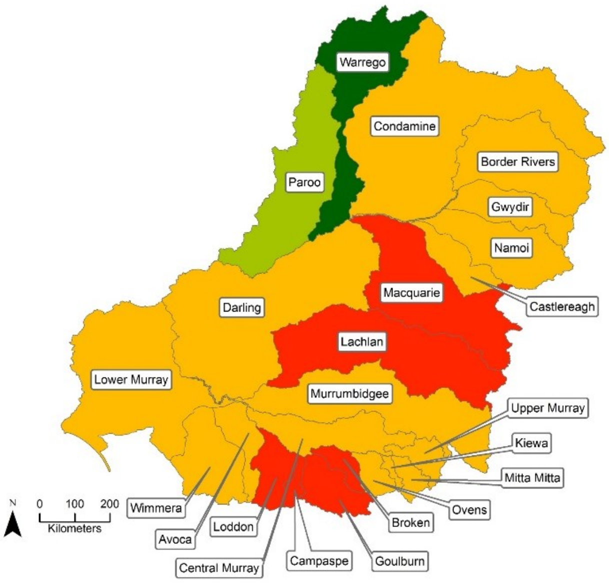

Figure 4. Ecosystem health as reported in the Sustainable Rivers Audit 2, showing valleys in good (dark green), moderate (light green), poor (yellow) and very poor (red) health (2008 - 10).

In the past two decades, governments have responded to these challenges by setting a new agenda for managing water in the Murray-Darling Basin. They have embarked on a series of water reforms aimed at protecting and restoring the health of Australia's rivers, wetlands, estuaries and groundwater systems, in a way that also creates economic opportunities and prosperity for communities in the Basin. The historic *National Water Initiative* in 2004 was described by many at the time, including the Wentworth Group, as one of the most significant agreements in our nation's history. The solution rested on the creation of more wealth using less water, by securing property rights for water users and promoting trade of water to higher value uses, in exchange for restoring over-allocated rivers to sustainable levels of extraction.

On Australia Day in 2007, Prime Minister John Howard announced at the National Press Club a ten billion dollar *National Plan for Water Security* to "once and for all" address over-allocation of water in the Murray-Darling

Basin.[18] In that same year, the then Minister for Environment and Water, Malcolm Turnbull introduced the *Water Act 2007* which set a legislative framework for water planning and management through what amounted to a $13 billion public investment package. In introducing the Water Bill 2007 to Parliament, Minister Turnbull announced "for the first time, the governance of the basin will reflect the hydrology of the basin—one interconnected system managed for the first time in our history in the national interest… We need these reforms to ensure the viability of our water-dependent industries, to ensure healthy and vibrant communities and to ensure the sustainability of the basin's natural environment". The *Water Act 2007* set the foundations for the Murray-Darling Basin Plan which was the key policy for returning a sustainable balance to the Basin. The *Water Act* 2007 also established the Commonwealth Environmental Water Holder tasked with managing the portfolio of environmental water, of what will amount to a quarter of entitlements in the Basin.[19]

The Murray-Darling Basin Plan

The Commonwealth *Water Act 2007* stated that the purpose of the Murray-Darling Basin Plan is to provide for the integrated management of the Basin's water resources by restoring an environmentally sustainable level of take while optimising economic, social and environmental outcomes. The Murray-Darling Basin Authority is required to prepare a Basin Plan which provides for the purposes summarised below:

a) Giving effect to relevant international agreements, including the Ramsar Convention on Wetlands (shown in Figure 5);
b) Establishment and enforcement of environmentally sustainable limits on the quantities of surface water and groundwater that may be taken (including by interception activities);
c) Basin-wide environmental objectives for water-dependent ecosystems, and water quality and salinity objectives;
d) Use and management of water resources in a way that optimises economic, social and environmental outcomes;
e) Water to reach its most productive use through the development of an efficient water trading regime across the Murray-Darling Basin;
f) Requirements that a water resource plan must meet if it is to be accredited or adopted; and
g) Improved water security for all uses of water resources.[20]

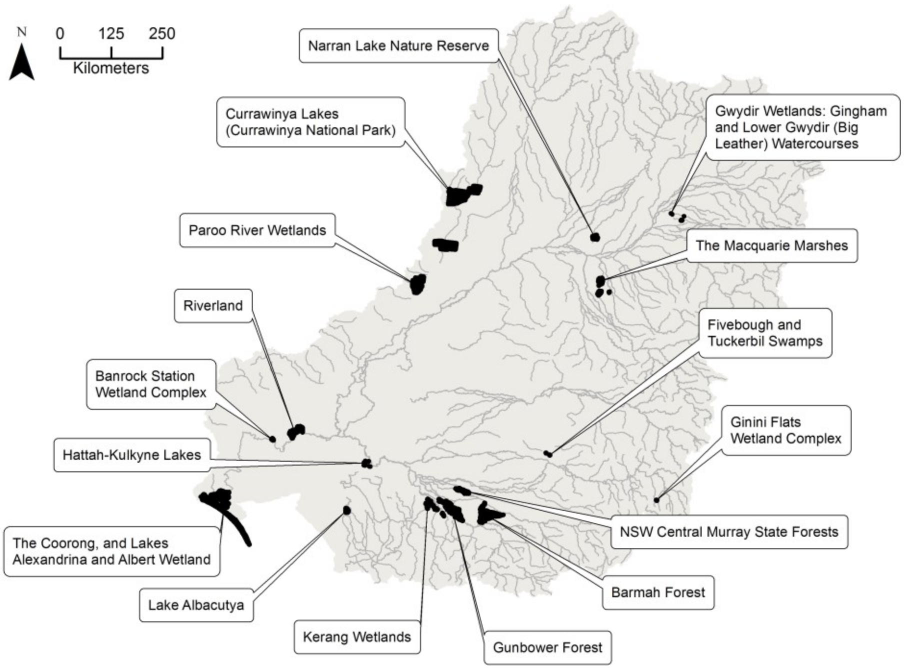

Figure 5. Location of the sixteen Ramsar wetlands in the Murray-Darling Basin.

With respect to the "establishment and enforcement of environmentally sustainable limits on the quantities of surface water and ground water that may be taken from the Basin water resources", the best available evidence produced by the Murray-Darling Basin Authority in 2010 suggested that achieving environmentally sustainable level of extractions would require the recovery of between 3,856 GL (high uncertainty) and 6,983 GL (low uncertainty) of surface water from an annual consumptive use of 13,623 GL.[21]

In 2012, the Authority's Board rejected this advice and instead put to the Australian Government a Basin Plan to recover 3,200 GL of surface water or 'equivalent' outcomes while providing for an increase in groundwater extractions across the Basin by 1,548 GL.[22] This figure was later revised down to 949 GL in the final Basin Plan.[23] In other words, on the evidence provided by the government's own Authority, the reduction amount grossly underestimated the environment water requirements needed.[24] In addition, the Basin Plan also failed to incorporate the impact of increasing groundwater extractions, and did not take sufficient account of the risks to river health from climate change.[24]

While the recovery targets in the Basin Plan failed to meet the minimum requirements for a healthy basin, the Wentworth Group recognised that the Authority's modelling demonstrated that recovery of 3,200 GL or equivalent was capable of producing a substantive improvement in the health of the river system, provided groundwater extraction does not impact on river flows, environmental flows are protected, and river management constraints impeding flows to target wetlands are removed.[25]

The Murray-Darling Basin Plan was passed through Parliament on the 22 November 2012 as a disallowable instrument with bipartisan support and unanimous agreement from Basin states. The long-term annual limits on extractions, known as the sustainable diversion limits, will come into effect in 2019, and the Basin Plan will be reviewed in 2026. In December 2016, all Murray-Darling Basin First Ministers agreed "The Murray-Darling Basin is of vital economic and environmental significance to a large part of Australia and it is critical that the Basin Plan is implemented on time and in full".[6] The Wentworth Group has welcomed this statement.[26] We have also recognised the decision of the Australian Parliament to recover 3,200 GL of environmental water or equivalent outcomes even though this is not sufficient to achieve an environmentally sustainable level of extraction.

Objectives and outcomes of the Basin Plan

There are six categories of management objectives and outcomes to be achieved by the Basin Plan (Table 1). These include objectives and outcomes for the Basin Plan as a whole (s5.02 in Table 1), in relation to environmental outcomes (s5.03), in relation to water quality and salinity (s5.04), in relation to long-term average sustainable diversion limits (s5.05), in relation to the operation of the sustainable diversion limit adjustment mechanism (s5.06), and in relation to trading in the water market (s5.07).

Table 1. Objectives and outcomes of the Basin Plan, as set out in Chapter 5 of the Basin Plan.

Objectives	Outcomes
Section 5.02: Objectives and outcome for Basin Plan as a whole	
a) Give effect to relevant international agreements through the integrated management of Basin water resources (including the 16 Ramsar sites in the Basin; Figure 1); b) Establish a sustainable and long-term adaptive management framework for the Basin water resources, that takes into account the broader management of natural resources in the Murray-Darling Basin; and c) Optimise social, economic and environmental outcomes arising from the use of Basin water resources in the national interest; and	a) Communities with sufficient and reliable water supplies that are fit for a range of intended purposes, including domestic, recreational and cultural use; and b) Productive and resilient water-dependent industries, and communities with confidence in their long-term future; and c) Healthy and resilient ecosystems with rivers and creeks regularly connected

d) Improve water security for all uses of Basin water resources.	to their floodplains and, ultimately, the ocean.
Section 5.03: Objectives and outcome in relation to environmental outcomes	
a) Protect and restore water-dependent ecosystems of the Murray-Darling Basin; and b) Protect and restore the ecosystem functions of water-dependent ecosystems; and c) Ensure that water-dependent ecosystems are resilient to climate change and other risks and threats; and d) Ensure that environmental watering is co-ordinated between managers of planned environmental water, owners and managers of environmental assets, and holders of held environmental water.	a) Restoration and protection of water-dependent ecosystems and ecosystem functions in the Murray-Darling Basin with strengthened resilience to changing climate.
Section 5.04: Objective and outcome in relation to water quality and salinity	
a) Maintain appropriate water quality, including salinity levels, for environmental, social, cultural and economic activity in the Murray-Darling Basin.	a) Basin water resources remain fit for purpose.
Section 5.05: Objective and outcomes in relation to long-term average sustainable diversion limits	
a) establish environmentally sustainable limits on the quantities of surface water and groundwater that can be taken for consumptive use from Basin water resources, having regard to social and economic impacts, and in doing so: i) Inform environmental water recovery measures, including water purchasing and infrastructure that improves water use efficiency; and ii) Provide greater certainty for all water users, including in times of drought and low water availability; and iii) Provide time for water access entitlement holders and communities to transition and adjust to long-term average sustainable diversion limits.	a) Restoration and protection of water-dependent ecosystems and ecosystem functions in the Murray-Darling Basin; b) Well-informed water recovery measures, including water purchasing and infrastructure, enable a transition to long-term average sustainable diversion limits; and c) Greater certainty of access to Basin water resources; and d) Water access entitlement holders and communities of the Murray-Darling Basin are better adapted to reduced quantities of available water.
Section 5.06: Objective and outcome for operation of the SDL adjustment mechanism	
a) Adjust SDLs in a way that increases environmental outcomes while maintaining or improving social and economic outcomes.	a) A healthy and working Murray-Darling Basin that includes the outcomes specified in subsection 5.02(2).
Section 5.07: Objectives and outcome in relation to trading in the water market	
a) Facilitate the operation of efficient water markets and the opportunities for trading, within and between Basin States, where water resources are physically shared or hydrologic connections and water supply considerations will permit water trading; and b) Minimise transaction cost on water trades, including through good information flows in the market and compatible entitlement, registry, regulatory and other arrangements across jurisdictions; and c) Enable the appropriate mix of water products to develop based on water access entitlements which can be traded either in whole or in part, and either temporarily or permanently, or through lease arrangements or other trading options that may evolve over time; and d) Recognise and protect the needs of the environment; and e) Provide appropriate protection of third-party interests.	Creation of a more efficient and effective market that: a) facilitates water reaching its most productive use; and b) enhances the productivity and growth of water-dependent industries; and c) enables water-dependent industries to: i. better manage through extreme events under current climate variability; and ii. strengthen their capacity to adapt to future climate change.

The outcomes for key environmental components under the Basin Plan are described in the Basin-wide environmental watering strategy developed by the Murray-Darling Basin Authority in 2014. The strategy identifies the expected outcomes for river flows and connectivity, native vegetation, waterbirds and fish (Table 2). Additional 'enhanced' environmental outcomes are to be pursued under a Commonwealth program to recover 450 GL of environmental water (Schedule 5). These enhanced environmental objectives relate to salinity levels in the Coorong and Lower Lakes, water levels in Lake Alexandrina, an open Murray mouth, export of 2 million tonnes of salt, increasing barrage flows, watering of floodplains and outcomes in the Southern Basin.

Table 2. Expected outcomes of the Basin Plan after 2019 for key environmental components, as described in the Murray-Darling Basin Authority's Basin-wide environmental watering strategy.[27]

Component	Expected outcome
River flows and connectivity: Improved flow connections along rivers, and between rivers and their floodplains	1. Maintain base flows at least 60% of natural levels 2. Improve overall flow by 10% more into the Barwon–Darling, 30% more into the River Murray and 30–40% more to the Murray mouth which opens to the sea 90% of the time 3. Maintain connectivity in areas where it is relatively unaffected, between rivers and floodplains in the Paroo, Moonie, Nebine, Warrego and Ovens 4. Improve connectivity with bank-full and/or low floodplain flows by 30–60% in the Murray, Murrumbidgee, Goulburn and Condamine–Balonne, and by 10–20% in remaining catchments 5. Maintain the Lower Lakes above sea level 6. Adequate flushing to export an average 2 million tonnes of salt from the River Murray system into the Southern Ocean each year
Native vegetation: Maintain the extent and improve the condition of native vegetation in the Murray-Darling Basin.	7. Maintain the current extent of about 360,000 hectares of river red gum, 409,000 ha of black box, 310,000 ha of coolibah forest and woodlands, existing large communities of lignum, and non-woody communities near or in wetlands, streams and on low-lying floodplains 8. Maintain the current condition of lowland floodplain forests and woodlands of river red gum, black box and coolabah 9. Improve the condition of southern river red gum
Waterbirds: Maintain current species diversity, improve breeding success and numbers.	10. Maintain current species diversity of all current Basin waterbirds and current migratory shorebirds at the Coorong 11. Increased abundance of waterbirds by 20–25% by 2024 12. Improved breeding with up to 50% more breeding events for colonial nesting species and a 30–40% increase in nests and broods for other waterbirds
Fish: Maintain current species diversity, extend distributions, improve breeding success and numbers.	13. Improved distribution of key short and long-lived fish species across the Basin 14. Improved breeding success for short-lived species (1–2 years), long-lived species in at least 8/10 years at 80% of sites, mulloway in at least 5/10 years 15. Improved populations of short-lived species (numbers at pre-2007 levels), long-lived species (with a spread of age classes represented), Murray cod and golden perch (10–15% more mature fish at key sites) 16. Improved movement with more native fish using fish passages

Aim of the review

It is now ten years since the Water Act was passed, and five years since the Basin Plan was adopted by the Australian Parliament. The aim of this review is to assess progress in implementing the Basin Plan to date and identify the actions necessary to deliver the Basin Plan as approved by Parliament in 2012.

The Australian Parliament has committed to spending $13 billion of taxpayers money to deliver the Basin Plan objectives including the 16 outcomes specified in Table 2. So far, $7.9 billion has been spent to recover 2,107 GL, leaving $5.1 billion to deliver the remaining 1,093 GL or equivalent.

Given the scale of investment and the impacts of these reforms, there is significant public interest in and scrutiny of the outcomes. Governments are ultimately responsible for ensuring the highest net returns to the community and demonstrating the tangible benefits of these reforms to the public.[28-30]

This review by the Wentworth Group documents progress towards the Basin Plan objectives and outcomes, using evidence of the environmental, economic and social changes that have occurred in past decades following recent water reforms and broader drivers. The review has two main components:

1) Measuring progress towards Basin Plan objectives and outcomes; and
2) Actions necessary to deliver the Basin Plan 'on time and in full'.

Progress towards Basin Plan outcomes

Progress towards 3,200 GL water recovery or 'equivalent'

As at September 2017, 2,107 GL of surface water entitlements have been recovered for the environment, representing 66% of the 3,200 GL target. Water recovery targets consist of local targets which specify the volume of water to be recovered within a valley, and shared targets which specify the volume of water to be recovered across multiple valleys. Nearly all local targets have been achieved (99%; Figure 6) and less than half of the shared targets have been achieved (44%; Figure 7). See Appendix 1 for more information on progress towards water recovery targets.

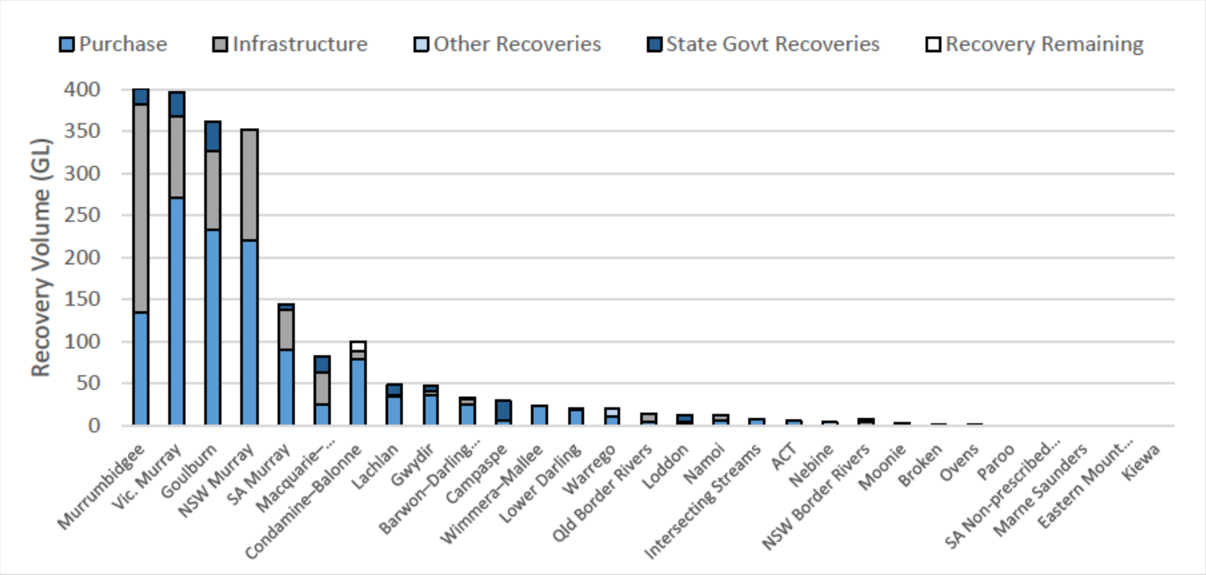

Figure 6. Surface water recovered towards local reduction targets within valleys of the Murray-Darling Basin as of 30 September 2017. White bars show recovery still required to reach target.[31]

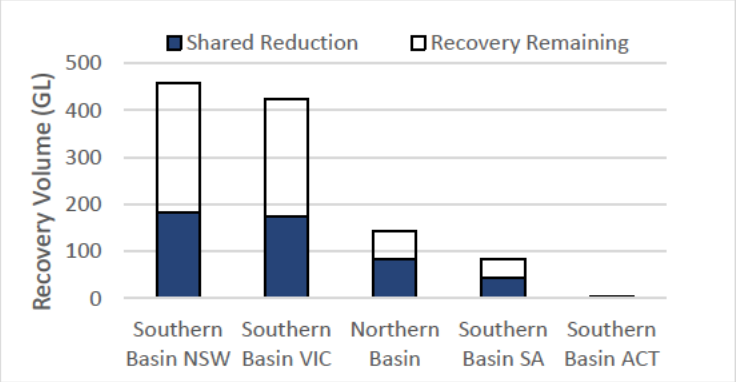

Figure 7. Surface water recovery towards shared reduction targets within zones of the Murray-Darling Basin as of 30 September 2017.[31] White bars show recovery still required to reach target.

Most of the surface water recovery has occurred in the Murrumbidgee, Murray and Goulburn rivers in the southern Murray-Darling Basin. A total of 1,093 GL of water recovery or equivalent outcomes is still required to achieve the 3,200 GL target in the Condamine-Balonne, Border Rivers in New South Wales and the Lower Darling. Nearly two thirds (63%) of all water acquired to date was recovered through direct purchase of entitlements. The remainder was recovered through infrastructure upgrades (Figure 6).

Three quarters of all surface water recovered to date occurred before the Basin Plan was enacted in 2012 (1,577 GL).[32] Progress slowed considerably after the Basin Plan was adopted, and has subsequently reduced to a trickle (Figure 8).

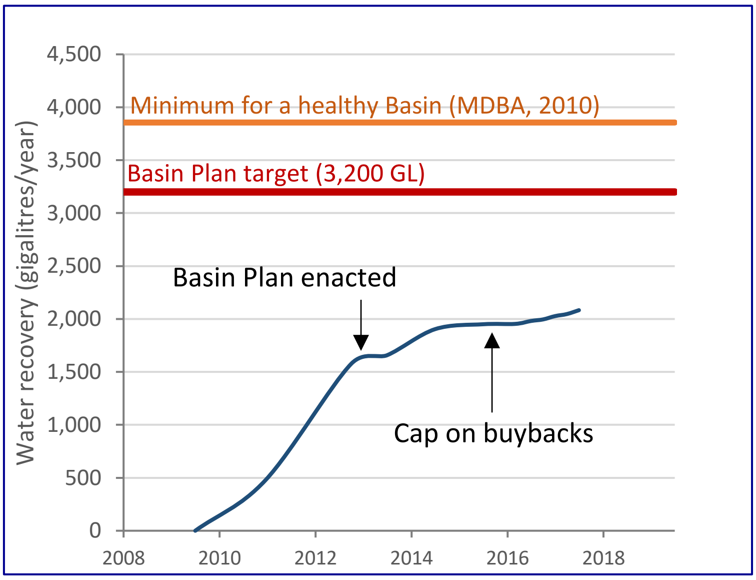

Figure 8. Progress on water recovery (blue line) towards the Basin Plan target (red line). The orange line shows the minimum amount of water required for a healthy Basin.[21] *(Source: SEWPAC, MDBA and DAWR records, 2012 – 2017)*[33-38]

Only 530 GL has been acquired in the past five years. None of the 450 GL of 'up-water' for outcomes in the Lower Murray, Lower Lakes and Coorong has been recovered under a $1.77 billion Commonwealth program funded through the Water for the Environment Special Account. South Australia is conducting a pilot test of projects that meet the objectives, but progress made by other states is unknown. Slowing of progress on water recovery coincided with a major policy shift by the Commonwealth Government in 2014 which prioritised infrastructure upgrades over water purchase.[39]

In addition to surface water limits, the Basin Plan sets long-term limits on groundwater extractions. Groundwater extractions are within these limits in 20 of the 21 groundwater resource units. The Central Condamine Alluvium is the only groundwater resource unit which requires a reduction in the long-term diversions under the Basin Plan. So far, only 6.7% of the groundwater target has been recovered from this unit (2.7 GL of the 40.4 GL; Figure 9).[38]

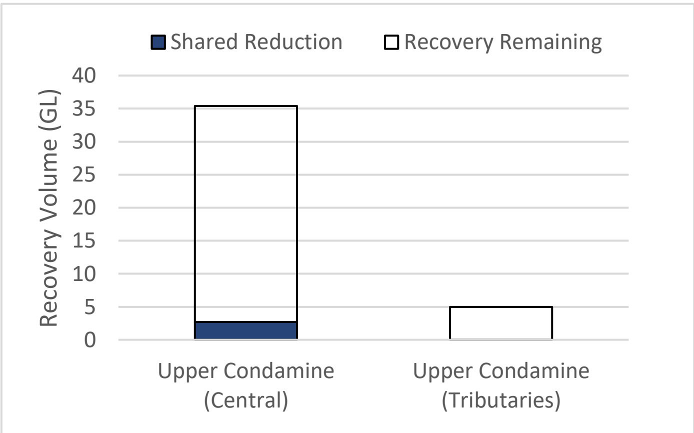

Figure 9. Groundwater recovery towards reduction targets within areas of the Murray-Darling Basin as of 30 September 2017.[31] *White bars show recovery remaining to reach groundwater target.*

Expenditure on water reform

The Australian Government is providing around $13 billion for implementation of the Murray-Darling Basin Plan and associated activities. Of this, $4.9 billion is for on- and off-farm irrigation efficiency projects, $3.1 billion is committed to water purchase, $1.6 billion is for efficiency measure projects to deliver enhanced environmental outcomes, $1.3 billion is committed to supply measures, $200 million is for constraints and the remainder is to fund a range of state and Commonwealth projects (Table 3).

More than half of this funding has already been spent ($7.9 billion; Table 3). Of this, nearly half has been spent on infrastructure projects ($3.6 billion), one third has been spent on water purchase ($2.7 billion) and the remainder has been spent on other activities.

Table 3.Commonwealth expenditure on water reform (as at 30 September 2017). Data provided by the Department of Agriculture and Water Resources.

Program	Component	Commitment ($b)	Expenditure ($b)
Sustainable Rural Water Use and Infrastructure Program (SRWUIP)	Infrastructure (MDB)	4.9	3.6
	Water purchase	3.1	2.7
	Supply measures	1.3	0.03
Enhanced Environmental Outcomes *(Water for the Environment Special Account)*	Efficiency Measures	1.6	0.01
	Constraints	0.2	
South Australian River Murray Sustainability Program		0.3	0.2
South Australian Riverland Floodplains Integrated infrastructure Program [1]		0.2	0.06
Murray-Darling Basin Regional Economic Diversification Program [1]		0.1	0.1
The Living Murray Initiative [1]		0.2	0.2
Other Basin-related activities [2]	Various	1.1	1.0
Total		**13.0**	**7.9**

[1]Where programs are delivered by other agencies, expenditure is reported as per the original funding profile when funding was transferred to the relevant agency. Refer to Portfolio Budget Statement or website of relevant agency for information on the status of the program.
[2]Other Basin related activities include, but is not limited to a part of the funding within Water Smart Australia, Murray Environmental Flows (Water for Rivers), South Australia Bioremediation and revegetation, Basin Plan activities and Hume Dam remedial works.

In 2014, expenditure priorities shifted from water entitlement purchase to investment in infrastructure projects (Figure 10). The average cost of water recovery using infrastructure upgrades ($5,100 per megalitre) was double that of water recovery through purchase of entitlements ($2,200 per megalitre) between 2007-08 and 2015-16.[40] Individual projects cost between 2 and 7 times more than direct purchase of equivalent quantities of water.[39]

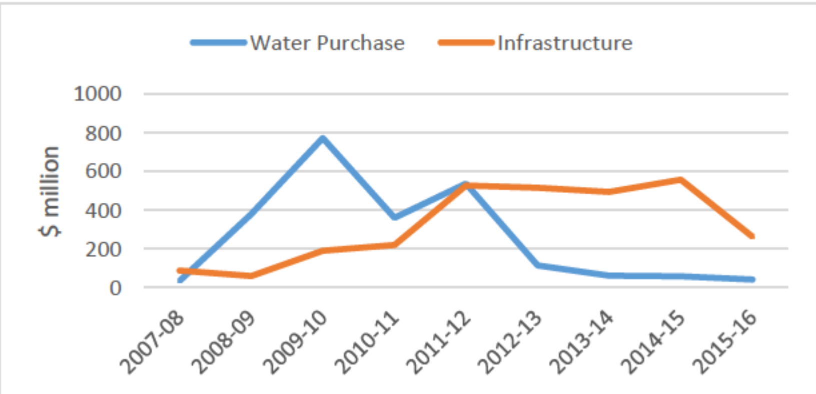

Figure 10. Commonwealth expenditure in the Murray-Darling Basin, 2007-08 to 2015-16.[41]

Progress towards Basin Plan objectives

We evaluated progress towards the management objectives to be achieved by the Basin Plan (Table 4). These include objectives and outcomes for the Basin Plan as a whole (s5.02 in Table 1), in relation to environmental outcomes (s5.03) including enhanced environmental outcomes (Sch 5), in relation to water quality and salinity (s5.04), and in relation to long-term average sustainable diversion limits (s5.05) and in relation to the operation of the sustainable diversion limit adjustment mechanism (s5.06). We did not report on progress towards objectives related to trading in the water market.

Table 4. Summary of progress towards Basin Plan objectives.

Objective	Progress
(s5.02) Objectives for the Basin Plan as a whole	
5.02 (1) (a) Give effect to international agreements	At the most recent 2015 Ramsar Convention, the Australian Government reported that ecological character had improved for 3 Ramsar wetlands, remained unchanged for 12 wetlands, and declined for one site, the Riverland, since the last triennium report in 2012.[42] While localised improvements have been made in some wetlands, e.g. in the Gwydir wetlands, Ramsar sites remain in a state that is more degraded than the ecological character for which they were listed under the treaty. Vegetation condition assessments by the Murray-Darling Basin Authority in 2015 show that less than a third of the area of red gum and black box forests across surveyed sites was in good condition, and the area of forests in degraded or severely degraded has increased (Figure 26).[43] The Coorong and Lower Lakes had improved in condition following the adverse changes to the ecosystem reported to the Ramsar Convention in 2010,[44-46] however "the Basin Plan is unlikely in the longer-term to maintain the ecological character of the [… Coorong, Lower Lakes and Murray mouth] Ramsar site".[47] The Wentworth Group did not assess the condition of other wetlands nor assets protected under other international agreements.
5.02 (1) (b) Establish adaptive management framework	Many of the key elements for an adaptive management framework and its implementation are already well established in the Basin Plan and related documentation, including measurable outcomes[27], a conceptual river model,[48] and a legislated requirement to review the Basin Plan on a recurring basis. Further work is needed in a number of areas including reaching consensus on shared management objectives, monitoring outcomes of reforms, preparing climate change responses and integrating natural resource management measures with flow management.
5.02 (1) (c) Optimise social, economic and environmental outcomes	An optimal social, economic and environmental reform requires first securing the water resources in the national interest, then assisting those who are likely to be most impacted to adapt to these changes. The Murray-Darling Basin Authority's approach to optimising social, economic and environmental outcomes[49] is based on a flawed assumption that a healthy Basin comes at the cost of jobs. This is not the case when water recovery is undertaken in concert with a regional development package to assist impacted communities.
5.02 (1) (d) Improve water security	The Murray-Darling Basin Authority reported that annual diversions in all valleys where a cap was defined have complied with the surface water diversion targets from 2011-12 to 2015-16 water years, with exception of the Queensland Moonie valley which was exceeded in 2014–15 and 2015–16.[33-35] However, Water Audit Monitoring reports and Independent Audit Group reports on cap implementation have not been published since 2011-12, so the accuracy of the assessments is not known (see page 48). We identified risks to water resources that may affect the security of water allocations for users: protection of environmental flows, growth in consumptive use and climate change (see pages 56 and 68).
(s5.03) Environmental outcomes	
5.03 (1) (a) Protect and	Environmental water monitoring reports by the Commonwealth and state governments have reported measurable improvements for vegetation, fish, waterbirds and a number of

restore water-dependent ecosystems	other environmental attributes for surveyed valleys where environmental flows have been delivered (see Appendix 2). However the condition of water-dependent ecosystems has not improved across the Basin as a whole (see page 30 for more detail).
5.03 (1) (b) Protect and restore ecosystem functions	Nearly all environmental watering flows delivered between 2013 and 2015 reported positive outcomes for flow variability and connectivity. However at a Basin scale, the recent State of the Environment report rated ecological process as 'very poor' with a "widespread loss of ecosystem function" although little detail was provided.[50] Some environmental watering events in the period between 2013 and 2015 were limited by physical and policy constraints.
5.03 (1) (c) Resilience to climate change and other threats	Climate change was not incorporated into the assessment of sustainable diversion limits for the Basin Plan, nor has climate change been considered in subsequent reviews (e.g. Northern Basin review).[51] While improvements in water quantity and quality expected under the Basin Plan could enhance the capacity of some species to adapt, migrate or cope with climate change and other risks, these outcomes are not guaranteed to be sufficient to support the long-term resilience of the Basin's ecosystems.
5.03 (1) (d) Coordinate environmental watering	There was some evidence of coordination among environmental water holders, with 1 in every 5 events undertaken by two or more jurisdictions.[52] Nearly all watering events reported between 2013 and 2015 aligned with Basin annual environmental watering priorities.[52] Constraints to river flows, which are becoming worse in some areas, pose challenges for coordinating environmental watering. For example, operators are not able to coordinate environmental watering events into South Australia because of upstream constraints to flow delivery between Yarrawonga and Wakool junction.
(Sch 5) Enhanced environmental outcomes[53]	
Sch 5 (2) (a) Reducing salinity levels in Coorong and Lower Lakes	Salinity levels in Lake Alexandrina at Milang have remained below 1,000EC since 2012 (Figure 23), although they came close to this threshold in the dry winter of 2016. Salinity targets were achieved for the 2015-16 reporting year,[54] but not for the years 2013 to 2015 due to the influence of the millennium drought on 5-year average calculations. Historically, salinity levels in the Coorong South and North Lagoons have exceeded the target figures.[55] Scenario modelling by Lester *et al.* 2013[56] showed salinity was up to 8 times that of seawater in the South Lagoon.[56] The South Coorong was in an unhealthy hypersaline state up to 10 times more frequently under the dry scenario compared to historical climate.[56]
Sch 5 (2) (b) Water levels in Lake Alexandrina	Water levels in Lake Alexandrina have remained within the target range since the Basin Plan was implemented in 2012, with the exception of a few short periods where water level fell below 0.4 metres AHD (Figure 23).
Sch 5 (2) (c) Open Murray mouth	After the 2010 floods, barrage flows increased and dredging was not required to maintain an open Murray mouth for 4 years. However, during this period, sand continued to accumulate at the mouth, requiring the reintroduction of dredging in late 2014. A flood event in spring 2016 saw the removal of dredging operations, only to be reinstated in January 2017. Even when the Basin Plan is fully implemented, the objective that the "mouth of the River Murray is open without the need for dredging in at least 95% of years"[57] will not be possible to achieve without significantly more river flow, permanent dredging and/or other major interventions (see page 63).
Sch 5 (2) (d) Export of 2 million tonnes of salt	This outcome has been met in 1 of the 3 reporting periods (2012-2014 and 2013-2015, not 2011-2013), based on a 3-year rolling average estimated by the Murray-Darling Basin Authority.
Sch 5 (2) (e) Increasing barrage flows	There is no coherent plan or action documented in the Basin Plan for the management of water levels in Lake Alexandrina for periodic flushing of lake water into the North Coorong and then the South Coorong. Any advances in this regard are further threatened by

	jurisdictional efforts to increase the permitted level of take by increasing sustainable diversion limits.
Sch 5 (2) (f) Watering of floodplains	Watering events remained largely in-channel, particularly in the southern Basin, or were diverted onto floodplains using engineering works. Stronger effort will be needed to address physical and policy constraints that have limited overbank environmental watering in the Basin.
Sch 5 (2) (g) Outcomes in Sth Basin	The condition of the Riverland / Chowilla wetlands is a key indicator for judging progress. The Australian Government's 2015 national report on the implementation of the Ramsar Convention reported that the ecological character had declined for the Riverland since the last triennium report.[42] Deterioration in the ecological character status of the Riverland region was attributed to changed hydrologic regime and changing climate.[58] We note that 'upper' floodplains, particularly those in South Australia, are excluded from this outcome and are at risk of becoming terrestrial ecosystems.
(s5.04) Water quality and salinity	
5.04 (1) Maintain appropriate water quality, including salinity	Salinity targets were met in four out of five locations in the southern Basin for the 2011 to 2016 reporting period.[10] Targets were not met at the end of the Darling River in Burtundy due to low flows. Around 525,000 tonnes of salt were diverted from the River Murray in 2015–16 through salt interception schemes.[59]
(s5.05) Long-term average sustainable diversion limits	
5.05 (1) Establish SDLs for surface and groundwater	Surface water recovery has progressed with 2,107 GL of the 3,200 GL Basin-wide recovery target acquired as of September 2017. Nearly all local recovery has been achieved (97%), however progress towards shared targets is poor (35%).[60] Only 6.7% of the groundwater target has been recovered (2.7 GL of the 40.4 GL),[38] from one groundwater zone, the Central Condamine Alluvium.
(s5.06) Operation of the SDL adjustment mechanism	
5.06 (1) Adjust SDLs	In 2017, states agreed on a package of 37 supply measure projects to be considered for SDL adjustment and 2 efficiency measure projects. We found that only one supply measure proposal satisfied the Basin Plan requirements, 25 did not satisfy the Basin Plan requirements and 11 projects required further information for assessment (see page 51 for results). Efficiency measure projects were listed by Basin states, however no water has been recovered towards the 450 GL through efficiency measures to date.

Progress towards social, economic and environmental outcomes

The outcome for the Basin Plan as a whole is to deliver a "healthy and working Murray-Darling Basin" (Basin Plan s5.02) that includes:

a) "Communities with sufficient and reliable water supplies that are fit for a range of intended purposes, including domestic, recreational and cultural use;
b) Productive and resilient water-dependent industries, and communities with confidence in their long-term future; and
c) Healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean."

Evidence of progress towards these outcomes has been documented and summarised in the following sections. The extent to which the Basin Plan will contribute to overall long-term outcomes will become apparent over coming years as the Basin Plan is implemented fully, monitoring and reporting on Basin Plan targets is completed, and lag effects play out across the Basin. It will also depend on how we address challenges and risks that could affect the achievement of Basin Plan outcomes, such as protection of environmental water and management of climate change impacts (see pages 56 and 68).

Outcome 1: Communities with sufficient and reliable water supplies

An outcome of the Basin Plan as a whole is "communities with sufficient and reliable water supplies that are fit for a range of intended purposes, including domestic, recreational and cultural use".[61] Central to this outcome is that water is of sufficient quality, quantity and reliability for water users.

QUALITY

Most water quality reporting focuses on salinity, but sedimentation, excess nutrient loads, hypoxic blackwater and algal blooms also affect the quality of water supply for communities. Average salinity targets were met in four out of five locations in the southern Basin for the reporting period from 2011 to 2016.[10] The target was not met at the end of the Darling River for this period due to low flows. Nearly 1 million tonnes of salt was exported out of the Basin each year from 2012 to 2015 on average, more than would have been exported without the Basin Plan but less than the Basin Plan objective of 2 million tonnes per year. This objective has been met in only 1 of the 3 reporting periods, based on a 3-year rolling average (Table 5),[62] due to low inflows into the River Murray system over the reporting period.

Table 5. Achievement of salt export objective for three reporting periods.[62]

Reporting period	Basin Plan outcome (tonnes)	Observation (tonnes)	Outcome met
Jul 10 – Jun 13	2 million	~2.9 million	Yes
Jul 11 – Jun 14	2 million	1.5 million	No
Jul 12 – Jun 15	2 million	0.9 million	No

Salt interception schemes have been used in conjunction with flows to manage water quality, by concentrating saline water for discharge into groundwater or for harvest as crystals. Around 525,000 tonnes of salt were diverted from the River Murray in 2015–16 through salt interception schemes.[59] The Commonwealth government expects the schemes will be viable over the next 15 years.[63] However, interception schemes may not be configured to mitigate future salt loads, given the potentially large projected increases in the century ahead.[64] Sufficient freshwater flow and an open Murray mouth are therefore essential to meeting the Basin Plan's long-term objective for the export of 2 million tonnes of salt each year.

QUANTITY

The volume of water allocations and diversions for water users is highly variable (Figure 11).[65] There was a steady decline in diversions from 1997-98 to 2008-09. The volume of water allocation had halved by the end of this period. Drought-breaking floods of 2010-11 resulted in surface water allocations across the Basin reaching a record high, then subsequently decreasing as rainfall decreased in the Basin. Surface water diversions followed a similar pattern to allocations. Diversions increased after the millennium drought to pre-drought levels, before falling again by about a third to 2014-15. Since 2012, water users have diverted more than three quarters of their allocation each year.

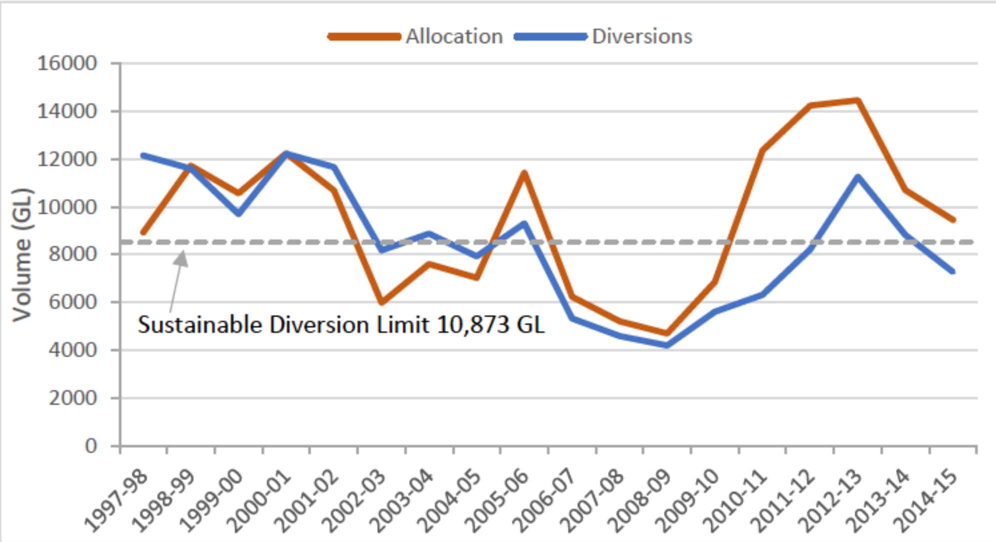

Figure 11. Total water allocations and diversions of surface water for water users in the Murray-Darling Basin (MDBA, 2016).[66]

Groundwater use appeared to be inverse that of surface water, with water users drawing greater volumes of groundwater during dry periods when surface water availability was low, while in wetter periods groundwater extraction decreased with increasing surface water availability. Groundwater use in the Basin reached levels of more than 1,500 GL during the millennium drought before decreasing by more than half during the wet period of 2010-11. Groundwater use returned to millennium drought levels by 2014-15 (Figure 12). These Basin-wide trends mask wider variations in water availability between valleys and entitlement types.

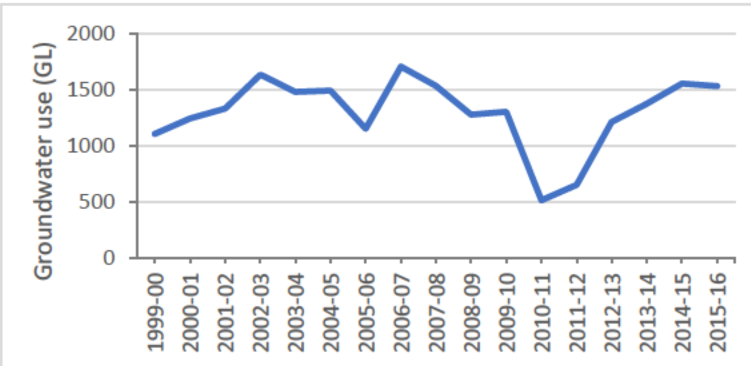

Figure 12. Total groundwater extracted in the Murray-Darling Basin from 1999-00 to 2015-16. The sustainable diversion limit for groundwater is 3,334 GL. Note: Groundwater data needs to be interpreted with caution. Source: MDBA Water Audit Monitoring Reports (1999-00 to 2011-12) and BOM National Water Accounts (2012-13 to 2015-16).[67]

RELIABILITY

The reliability of water entitlements in the Murray-Darling Basin is variable, driven by the high variability of river flows. The average annual inflow in the Murray-Darling Basin's rivers is 32,500 GL, but this amount has varied historically from less than 7,000 GL (in 2006) to almost 118,000 GL (in 1956).[11] This variability in water availability is reflected in the volume of water allocations and diversions for water users from 1997-98 to 2014-15 (Figure 11).[68]

Large dams have helped farmers to manage the reliability of water supply in highly variable river systems. For example, the Snowy Mountains scheme helps to manage the massive variation in water availability. There are now 93 major public storages in the Murray-Darling Basin with a combined capacity of 25,344 GL, or two thirds of the total annual inflow.[69] These storages allow water users to manage reliability by storing water over multiple years and calling on the desired volume of water at a required time.

Water trade and improved clarity of water entitlements since the National Water Initiative have also helped farmers to secure the appropriate level of reliability of water supply. Water entitlements with clearly defined characteristics (i.e. high security, general security and low security) allow water users to manage their water portfolio according to the supply reliability.

A key risk to reliability of water entitlements is the long-term changes in climate which could affect the volume of water available under water entitlements. The National Water Initiative seeks to assign risks arising from future changes in the availability of water. Under this framework, water access holders are to bear the risks of any reduction or less reliable water allocation as a result of changes in climate and natural events such as bushfires and drought (NWI Clause 48).

Outcome 2: Productive industries and communities with confidence in their future

To evaluate this outcome, the Wentworth Group commissioned an economist from the Australian National University to report on the status and trends of key socio-economic indicators in the Basin, and provide advice on the economic and social effects of water reform.[17] The report examined the changing nature of communities and industries in the Murray-Darling Basin and the possible drivers of these changes (Appendix 3). It documented changes in a number of key variables including the value of agricultural production, water use, water efficiency, employment and number of businesses for the Basin as a whole and for selected communities in the Basin. Statistical models were used to describe the likely causes of social and economic changes across the Basin.

ECONOMIC CHANGES IN THE BASIN

The Basin's economy has grown during the millennium drought and has been maintained in the period of water recovery under the Basin Plan (2009 – present). In 2014-15, the gross value of agricultural production in the Murray-Darling Basin reached a record high of $20,588 million, while in 2013-14 the gross value of irrigated agricultural production reached a record high of $7,135 million (Figure 13; nominal values). Long-term growth was interrupted by several years of decline in production during the millennium drought when water availability was half of pre-drought levels. Water recovery had a negative effect on irrigated agricultural production in the statistical model, however it did not have a significant influence on overall agricultural production.[17]

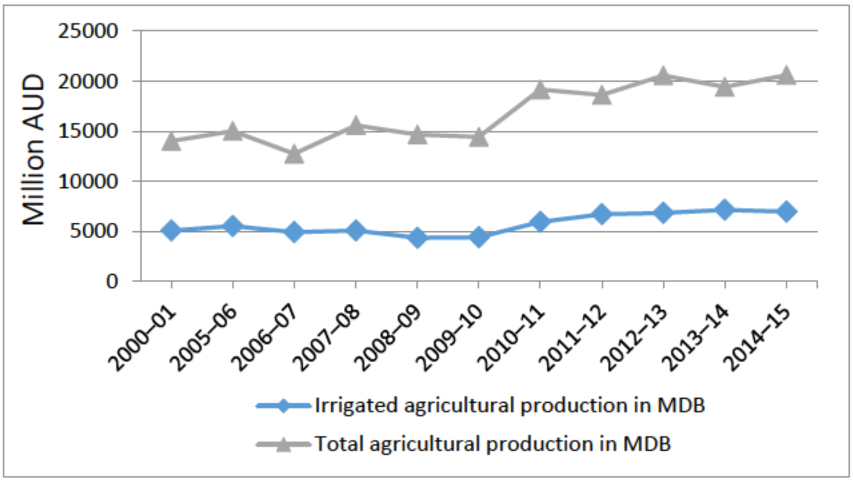

Figure 13. Gross value of irrigated and total agricultural production in the Murray-Darling Basin and Australia, in nominal values. Source: ABS, cat. No. 4610.0.55.008

Overall trends in economic indicators masked changes affecting some industries in the Basin. Since 2000, the cropping and dairy industries have experienced declines in total production while the horticulture and grazing industries have maintained production. Horticulture was sustained during dry periods using water from multiple sources including rainfall, allocations from reliable entitlements, and temporary trade from rice growers, mixed farmers and dairy.[70]

The 2004 National Water Initiative to return over-allocated systems to environmentally sustainable levels of extraction was part of a national imperative to increase the productivity and efficiency of Australia's water use.[7] To achieve these objectives, the National Water Initiative promoted the removal of barriers to trade to facilitate the transfer of water to higher value uses. Evidence since the National Water Initiative suggests that proportionally greater economic value is being derived with less water in drier periods. For example, despite more than a 70% decline in irrigated surface water applied during the drought from 2000-01 to 2007–08, the value of irrigated agricultural production fell by just 15% (Figure 14). As the Basin became drier again between 2012-13 and 2015-16, the value of irrigated agricultural production within the Basin was maintained despite a 40% decrease in water used for irrigation. Conversely, in wetter periods there was a tendency for water use to increase relative to production value: water use doubled from 2008-09 to 2011-12 but the gross value of irrigated production rose by only 30%.

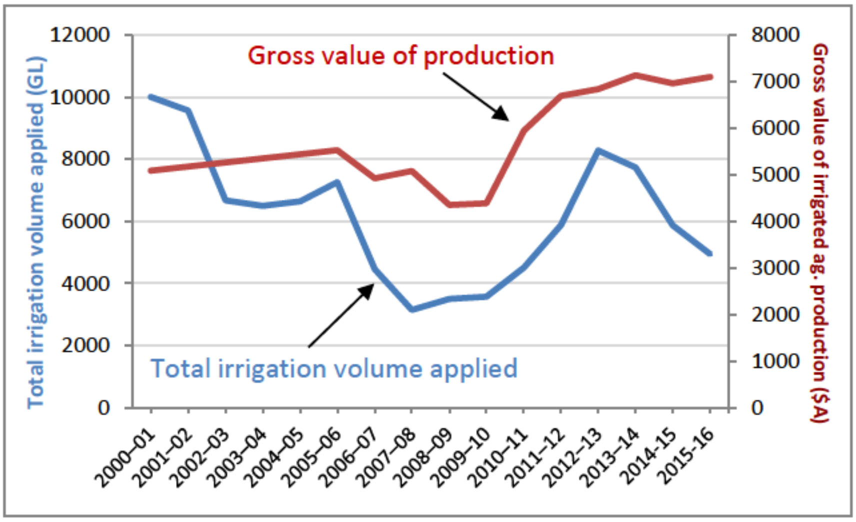

Figure 14. Total irrigation volume applied and gross value of production in the Murray-Darling Basin. Source: ABS, Water use on Australian farms, cat. No. 4618.0; ABS, Gross Value of Irrigated Agricultural Production, cat. No. 4610.0.55.008; MDBA Annual Report 2015-16.

The decoupling of water use from the value of agricultural production after 2012 was a result of multiple adjustments within the irrigation sector: a shift from higher to lower irrigation requirement crops, more efficient use of water in response to water scarcity, investment in on-farm productivity and water trade that allowed the highest value horticulture to stay in production while crops with lower marginal value and higher demand for water were fallowed.[71] These mechanisms, a central feature of the National Water Initiative, operated to greatly cushion the effects of reduced water availability during the drought and water recovery.

While some communities benefited from these reforms, others were adversely affected, partly because water was traded out of some districts and into regions where water use was more profitable. Overall, in the 11 years from 2004-05 to 2015-16, there was a 51% decline in the number of irrigation businesses in the Murray-Darling Basin. However, this decline was similar to the decline in the agricultural businesses outside the Basin (Figure 15), implying water prices or water recovery were not the driving factors of this decline. Communities such as Shepparton in Victoria and Griffith in New South Wales have experienced both population and economic growth, while others such as Deniliquin, Moree and Renmark have experienced declines in population and economic activity (see page 27).

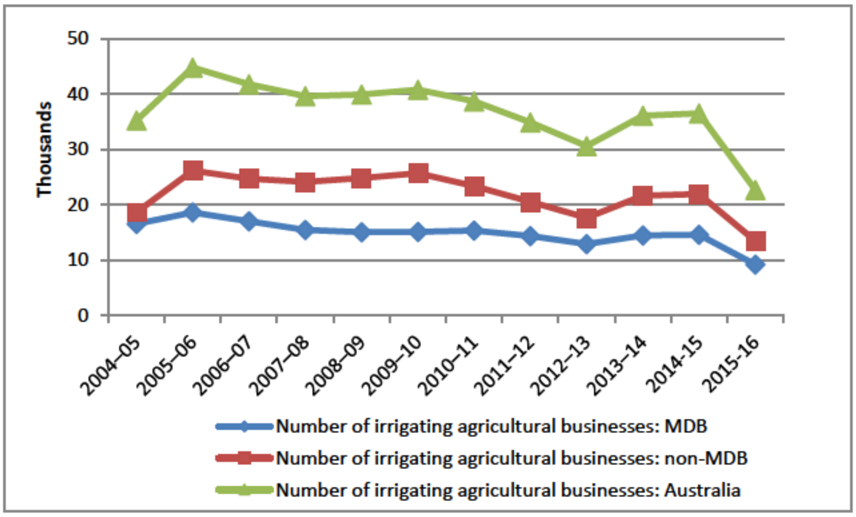

Figure 15. Number of irrigating agricultural businesses in the Murray-Darling Basin. Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

OUTCOMES OF WATER REFORM FOR IRRIGATED AGRICULTURE

Irrigated agriculture has been a major beneficiary of water reforms in Australia. Windfall gains were made from the large transfer of water entitlements from public to private ownership during the reform process. A further $2.7 billion investment in acquiring water entitlements from willing sellers and a $3.6 billion investment in irrigation infrastructure modernisation has already provided irrigators in the Basin with a capital injection worth more than an average of $400,000 per irrigation business.[72] Of the $13 billion available for water reform, a total of $3.1 billion is to be spent on purchasing water entitlements, $4.9 billion of public funds allocated to on- and off-farm infrastructure modernisation and a further $1.6 billion is for projects to increase on-farm water efficiency. The total investment could reach more than $700,000 per irrigation business on average when the Basin Plan is delivered in full.[73] This is arguably the largest single structural adjustment program in Australian history.[74]

National water reforms since 2004 have brought a significant range of direct and indirect benefits to the irrigation industry. Economic benefits of public funds to purchase water from willing sellers included a pathway for exiting the industry, an opportunity to pay down debt and/or invest in more efficient infrastructure, as well as access to cash flow which helped farmers persist through the drought.[75, 76] A 2012 survey of 589 irrigators found that 60% of respondents had sold some water and kept farming, 30% sold all water and left farming, and 10% sold all water and continued farming.[77] Overall, half of the respondents who continued farming said selling water had no farm production consequences.[78]

Improvements in water markets as part of the reforms have also benefitted irrigators.[79,80] A survey of more than 4,000 farmers in New South Wales, Victoria and Queensland found that water trade has enabled better and more flexible responses to past and future droughts.[81] Water entitlement holders have also benefited from capital growth of water entitlements. Five years of growth in Aither's water price index for the southern Basin to a record high in June 2017 was attributed to dry conditions and strong demand from the irrigation sector.[82]

Economic benefits of infrastructure modernisation, subsidised by public funding, have included greater flexibility to manage drought risk and avoided costs for maintenance and renewal of infrastructure. Up to 50% of water savings returned to irrigators as part of the scheme has provided opportunities to expand production or sell surplus water on the temporary or permanent market.[71] Evidence is emerging of the potential for adverse short and long-term impacts of on- and off-farm irrigation upgrades and infrastructure modernisation.[83]

The innovations in water markets resulting from the National Water Initiative have promoted private sector innovation in not only managing water for irrigation but also for the environment. For example, the Balanced Water Fund is a $25 million water investment fund established in 2015 to provide water security for farmers while supporting the health of wetlands along the Murray River. Annual allocations are optimised by the fund managers, by trading water allocations on a 'counter-cyclical' basis. This means in dry years when water is scarce and irrigation demand is high, more water is made available to irrigators, while in wet years when water is more abundant and agricultural demand is lower, water is made available to floodplains and wetlands.[84]

While water markets have resulted in mainly positive economic outcomes, water trade can result in adverse consequences for downstream communities and the environment. In the Barwon-Darling River for example, water trade allows water entitlements to be traded among landholders regardless of the capacity of their on-farm storage. Current water management rules allow irrigators with larger storages to take advantage of elevated river levels as a result of environmental water as it passes downstream. Environmental water in these rivers are risk of being extracted for consumptive use.

One third (37%) of the gross value of agricultural production in the Basin is irrigated, the remaining 63% is from dryland crops including wheat and rainfed cotton and floodplain grazing.[17] Few other studies exist on the effects of water reform on these industries, as well as non-agricultural industries including tourism and fishing which are generally accepted as beneficiaries of water reforms.

Of the few studies of floodplain grazing available, one study showed that water recovery is expected to compensate for some impacts of upstream irrigation on floodplain graziers. Environmental flows under the Basin Plan can help to restore lost stocking rates by an estimated 25% and lost earnings by 28% depending on the location and type of water entitlements recovered.[85] Data also show that floodplain pastures rely on flooding, rather than rainfall, to stimulate the growth of pasture for livestock.[86] Cattle growth rates can triple for a short period following good winter flood events compared to average growth rates, while weight can be lost over the heat of summer or when cattle remain in the floodplains during extended dry periods, such as the 2001-02 drought.[86] Flooding in 1995 provided about $36.1 million in income from cattle, sheep and dry land farming for the 236 properties on the Lower Balonne floodplain in New South Wales.[87]

REGIONAL COMMUNITIES IN TRANSITION

Over the past few decades, the population and social structure of the Murray-Darling Basin has experienced significant shifts, with many communities facing an "undercurrent of steady decline".[88] Agriculture is one of the few industries in Australia experiencing long-term decline in employment (Figure 16). Nationally, employment in agriculture has declined by a third since 1960 (Figure 17). Today, agriculture employs 8% of all workers in the Basin.[17]

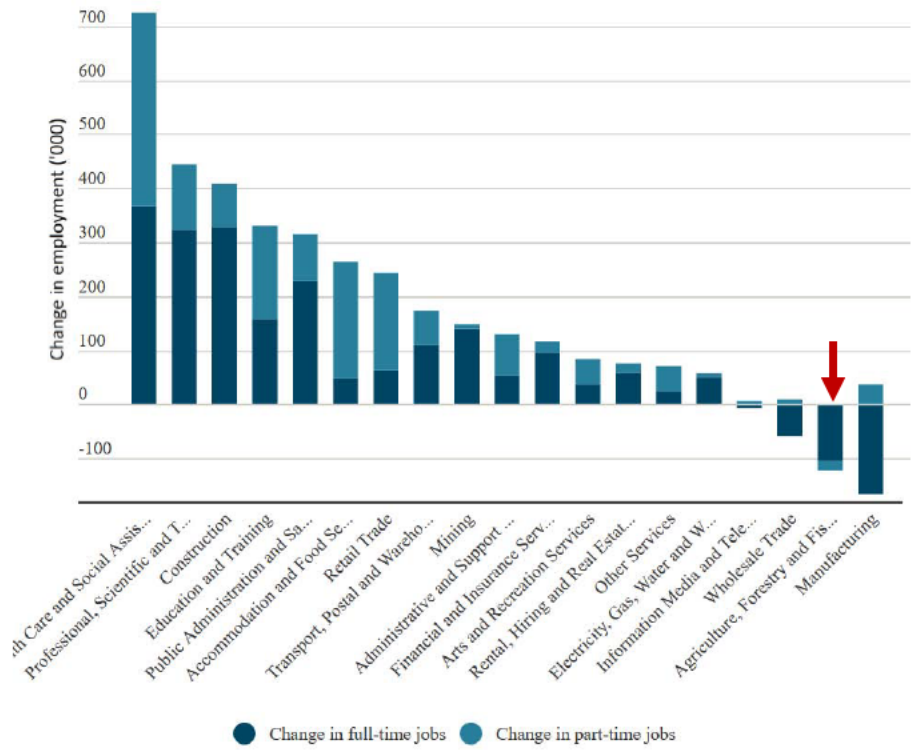

Figure 16. Australian job growth in the 21st century by industry of employment. Change (in '000) from Feb 2000 to Feb 2017. Source: ABS (catalogue 6291), published in The Australian 18 May 2017.

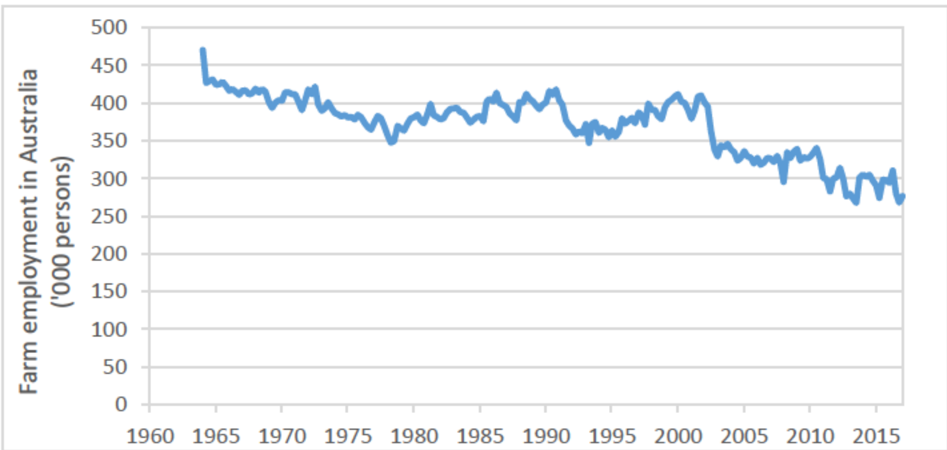

Figure 17. Farm employment (thousands of persons) in Australia since 1964. Source: ABS 2017.[89]

Between 2001 and 2016, employment in agriculture in the Basin has declined by 26% due to agricultural modernisation, commodity prices, drought, water policy and many other factors.[17] This decline slowed between 2011 and 2016 to -4%, while the nation-wide trend in agricultural employment grew by +4% over the same period. While total employment in agriculture has decreased, some sectors e.g. horticulture (plant/flower/seed growing) and beef cattle farming, have experienced an increase in employment in the past five years (Figure 18).

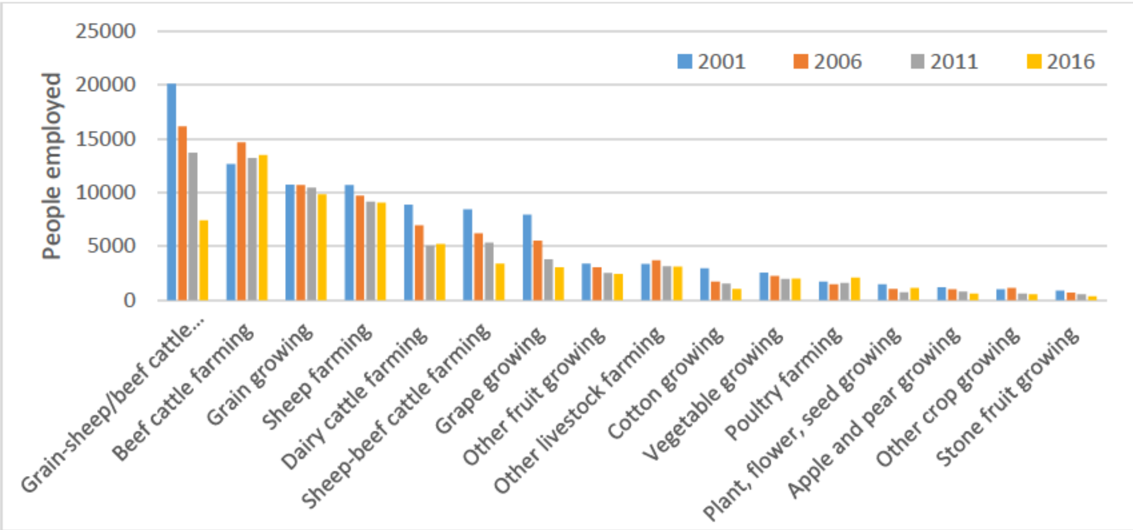

Figure 18. Trend in employment in agriculture in the Murray-Darling Basin. Source: ABS, Australian Census of Population and Housing 2001, 2006, 2011 and 2016.

The distinct shift away from employment in agriculture in the Basin has been balanced by growth in other sectors of the workforce. The number of people employed in Murray-Darling Basin has increased by 2% between 2011 and 2016, and by almost 8% over the period 2006 to 2016, largely due to increases in employment in other sectors such as education and training, health care and social assistance (Figure 19).

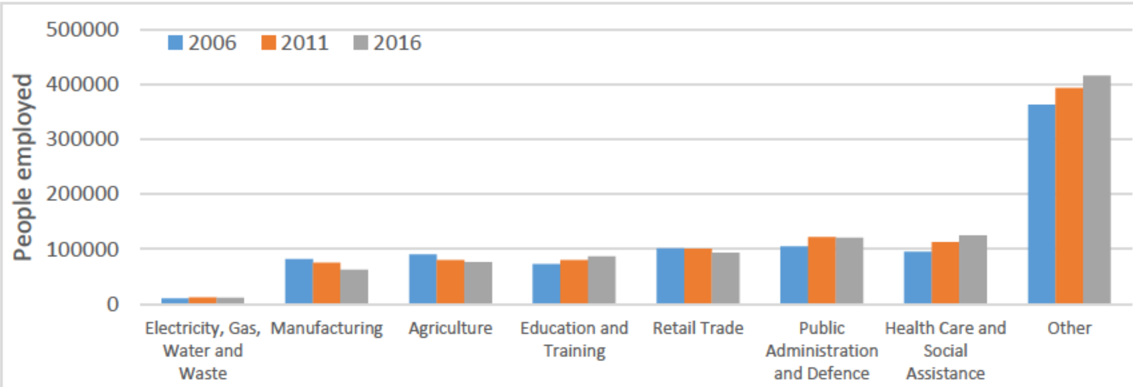

Figure 19. Trend in employment for sectors in the Murray-Darling Basin. Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016.

These Basin-wide changes have played out in rural and regional communities in diverse ways: some communities such as Shepparton in Victoria and Griffith in New South Wales have experienced both population, employment and economic growth, while others such as Deniliquin, Moree and Renmark have experienced declines in population and economic activity.[17]

In Griffith, for example, there was an increase of 17% in employment in agriculture between 2012 and 2015 following a 7-year decline as a result of the millennium drought. By 2015, Griffith's agriculture sector had fully recovered to pre-drought levels and agriculture employed the highest number of people of all reported sectors. Employment in the agriculture sector in Griffith increased by 42% between 2001 and 2015.

Strong growth in total employment in Shepparton from 2002 to 2007 reflected different structural changes in the local economy. Most growth occurred in services sectors including health care, construction and education. This growth outweighed a decline in employment in agriculture in Shepparton of 20% between 2001 and 2015.

Other regional centres have experienced significant declines in population and employment in agriculture. Deniliquin in southern New South Wales for example has experienced a drop in agricultural employment of 75% over the decade between 2003 and 2013. This is far greater than the national average. Over that period, the number of businesses almost halved, with agriculture/forestry/fishing businesses experiencing the most decline.

There are a number of reasons for the different trajectories of these Murray-Darling Basin towns and their associated districts. The 2007-08 drought seriously affected Deniliquin's rice industry, and this downturn exacerbated other pressures on the district including increased mechanisation of agriculture, and the closing of government agency offices in 2005. On the other hand, Griffith's population and employment increased over the same period, partly driven by the increase in local investment in the town. A younger population is attracted to Griffith due to large employment bases, particularly the Bajada Group which is the Riverina's largest employer, the Riverina Institute of TAFE campuses, and the Regional University Study Centre which was established in 2004. Griffith has also experienced strong commercial growth with new shopping centre developments in recent years.[90]

Shepparton, like Griffith, showed an increase in population and employment during the last 15 years. While the size of the agricultural workforce has decreased by 20% since 2001, it has fluctuated at about 2,600 for the last 8 years. However, employment in health care and social assistance has increased significantly (over 30%) during the same period so that it is now notably larger than agricultural employment. There has also been a growth in government investment in public administration and services, and new regional employment opportunities outside of the agricultural sector, such as the Shepparton Bypass project, the road-rail interchange at Mooroopna and additional production jobs at Unilever in Tatura.

The Renmark district has been severely affected by drop in grape prices and this impact has been exacerbated by prolonged drought and the operation of the Small Block Irrigators Exit Grant. Unlike Griffith and Shepparton, Renmark has not experienced a compensating increase in activity in non-agricultural sectors. Instead there has been a contraction in manufacturing and retail trade sectors. This example serves to illustrate the impacts of water reform on highly irrigation-dependent towns that are not yet economically diversified. It is consistent with other research showing that impacts of water recovery are more acute for those communities with greater dependence on irrigated agriculture and less diversified economies.[91]

Adverse effects of water recovery in some smaller communities occurred from water entitlements leaving production, resulting in downsizing or closure of businesses, fewer employment opportunities and reduced revenue streams for supply chain and other supporting services. Adverse effects of water reform may have also occurred as a consequence of the policy to invest in high efficiency, high value enterprises, leading to the rationalisation of farms (e.g. automation, out-sourcing and consolidation) and reduced labour costs.

Nevertheless, impacts of water reforms on employment are relatively small compared to other influences at work. Advances in technology (e.g. round cotton balers, 'Roundup Ready' crops that require less spraying) in the irrigation industry reduced the total demand for seasonal workers reduced by 75% or about 5,000 jobs from 1999 to 2013.[92] Community-level impacts of water recovery were likely to have compounded long-term changes in social and economic structure of some regional communities.

In summary, the Murray-Darling Basin has undergone a significant social and economic transformation in the past decades as a result of a range of economic, social, technological and policy reforms. At a macro level, the gross value of irrigated agricultural production and agricultural production have grown from 2001 to 2011 and have been maintained in the past five years. Agricultural production in the Murray-Darling Basin now contributes around $20 billion to the national economy. Employment in the Basin is also growing, and many sectors are experiencing considerable expansion (e.g. education, health care and social assistance) while others are in decline (e.g. agriculture). However, assessment at sectoral levels reveal divergent trends across the Basin. The decline in agricultural employment in the Basin over the past 15 years is slowing, but is not yet in line with the national trends which show rising agricultural employment in the past 5 years. This is mainly due to declines in employment in dairy farming and growing cotton, grapes, fruit and livestock grain. Trends also varied geographically across the Basin. For example, economic and employment growth has occurred in some regions (e.g. Griffith, Shepparton) but not others (e.g. Renmark, Moree, Deniliquin) as a consequence of a range of drivers. With the right information about these changes and their drivers at different levels, policies can be carefully designed to support those most impacted by reforms to adapt to a future with less water.

Outcome 3: Improving the health of water-dependent ecosystems

The Basin Plan sets out to improve ecological outcomes throughout the Basin as reflected in the sixteen specific outcomes related to river flows and connectivity, native vegetation, waterbirds and fish (Table 2). These objectives are expected to be achieved after 2019 through the recovery and delivery of environmental water and other projects that result in similar ecological improvement. In evaluating the effectiveness of the Basin Plan in achieving these outcomes, there are several considerations:

- **Hydrological outcomes:** Have planned management actions resulted in a hydrological regime predicted to support expected ecological outcomes?
- **Ecological outcomes:** Does environmental watering produce the expected ecological responses?
- **Ecological outcomes at the Basin scale:** Is the overall condition of each of the river valleys and the overall Basin improving?

The Wentworth Group has evaluated publicly available reports to address these questions, focusing on the subset of valleys where environmental water acquired under the Basin Plan was delivered in the three year period from July 2012 to June 2015. We found that there is currently insufficient information in the public domain to enable a proper analysis of progress against the targets in Table 2. Some surveys of broader changes in Basin health are available, however this information is not comprehensive as the Murray-Darling Basin Authority is yet to release its evaluation of the use of environmental water and environmental outcomes (due late 2017/early 2018). The information in the public domain has, however, enabled us to examine whether water recovery has produced demonstrable benefits for river flows and connectivity, native vegetation, waterbirds and fish.

Overall, environmental water available under the Basin Plan has provided benefits for river flows and ecosystems as the Basin transitioned from a wet to dry phase (2011-2015). Many aspects of the Basin's ecosystems receiving additional environmental flows were in better ecological condition than they would have been without the Basin Plan. Environmental watering from 2012 to 2015 played an important role in extending and building on the ecological responses of the previous three wet years, while at the same time slowing the rate of drying and alleviating the associated ecological impacts. However recent surveys of fish, vegetation and waterbirds across large areas of the Basin have indicated no clear improvements yet at the Basin-scale towards the outcomes in Table 2 since the Basin Plan was passed. The 2016 State of the Environment Report reported "deteriorating trends" in ecological processes and key species populations across the Murray-Darling Basin,[50] though no detailed information is available.

The extent to which environmental water will contribute to overall long-term improvements in the Basin's environment will become apparent over coming years as the Basin Plan is implemented fully, monitoring and reporting on targets is completed and made public, and lag effects play out across the Basin. There are major risks to environmental watering which may affect the ability to achieve the Basin Plan objectives (see page 46). Addressing these risks is critical to give the best chance of maximising ecological outcomes, delivering the Basin Plan's ecological objectives and ensuring the highest returns on the public investment in water reform.

ENVIRONMENTAL WATER ALLOCATION AND DELIVERY

In the three years between July 2012 and June 2015, an estimated 8,977 GL of environmental water was delivered to valleys in the Basin over 407 environmental watering events from July 2012 to June 2015 (Table 6). This water is additional to planned environmental water, unregulated flows including dam spills, and environmental water delivered prior to the Basin Plan. Most of this water was delivered in five regions of the southern connected system: South Australian Murray, Goulburn, Victorian Murray, Murrumbidgee and New South Wales Murray (92% of all environmental water delivered in 2013-14 and 86% in 2014-15; Figure 20). The Commonwealth Environmental Water Holder delivered the largest volume of water (4,602 GL, 51%), followed by New South Wales (1,272 GL, 14%) and the Murray-Darling Basin Authority under The Living Murray program (1,059 GL, 12%). Not all environmental water delivered to valleys reached target wetlands for several reasons including constraints in the river system and rules which allow irrigators to legally extract some of this environmental water for private use (see page 56). Unregulated flows and planned environmental water contributed to outcomes in the Basin, however their volume and effects are not reported.

Table 6. Volume of environmental water (GL) delivered by Basin jurisdictions between July 2012 and June 2015.[52] These flows were additional to consumptive and unregulated flows in the river. The same volumes may have been used to water multiple sites.

Year	Volume delivered (GL)							
	CEWH	MDBA	NSW	QLD	VIC	SA	Other	Total
2012-13[1]	1,272	277	670	n/a	364[2]	n/a	n/a	2,583
2013-14[3]	1,663	295	300	15	210	801	232	3,516
2014-15[3]	1,667	488	302	97	198	43	83	2,878
Total	4,602	1,059	1,272	112	772	844	315	8,977

[1] Calculated based on reports by CEWO (2013); MDBA (2013); NSW DPC (2013); VEWH (2013).[33, 93-95] Queensland did not report water delivered. South Australia reported 1,076 GL but it was excluded from this table as the proportion held by South Australia was not known.

[2] Includes some water held by the Commonwealth Environmental Water Holder and under The Living Murray program.

[3] Environmental water use reporting requirement under Schedule 12 Matter 9.3 of the Basin Plan. Reports available at www.mdba.gov.au/publications/mdba-reports/basin-plan-annual-report-2013-2014 and www.mdba.gov.au/publications/mdba-reports/basin-plan-annual-report-2014-15

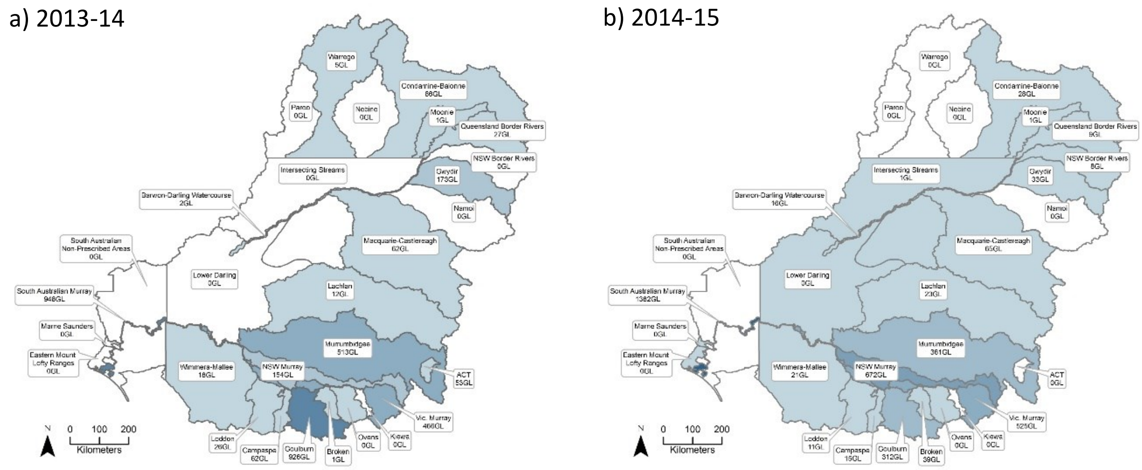

Figure 20. Environmental water delivered by Commonwealth and states in valleys of the Murray-Darling Basin in the (a) 2013-14 and (b) 2014-15 water years, compiled from Schedule 12 Matter 9 reports.[52] Valley-specific data were unavailable for 2012-13.

Dry conditions between 2012 and 2015 were not sufficient to support large scale watering events.[96] The median event size was 0.51GL for environmental flow releases between July 2013 and June 2015.[52] Under these circumstances, environmental watering in 2012-13 was used to build on the ecological responses of the previous three wet years, but as availability declined through 2013-14 and 2014-15, watering was focused on supporting in-channel outcomes and maintaining habitat for freshwater species during drought. Environmental watering actions between 2012 and 2015 were mostly focused on restoring in-channel flows and watering floodplains through infrastructure. Few watering events resulted in overbank flows and natural inundation of floodplains that would have delivered significant environmental benefits.[3]

There was evidence that environmental water holders used strategic approaches to maximise environmental outcomes. For example, for the last six years, environmental water holders have coordinated multi-site environmental watering trials to maximise its effectiveness by re-using return flows in the southern Basin. The trials have tested a range of actions including accounting methods, addition of environmental water to unregulated flows, use of loss factors and coordination of environmental releases with natural flow peaks.[97] Other examples of strategic use of environmental water include actions in which environmental water is used in conjunction with irrigation supply and planned environmental water to achieve a greater variety of water levels than would have been possible with environmental flows alone.

HYDROLOGICAL OUTCOMES

RIVER FLOWS AND CONNECTIVITY

Overall, flood extents were relatively small and localised in the period between 2012 and 2015 compared to the previous wet years, with some recovery in 2016 with the return of wetter conditions. As the Basin transitioned from a wet to dry phase from 2012 to 2015, the area of wetlands surveyed across the Basin declined by two thirds (Figure 21). By 2015, wetland area was similar to levels experienced during the millennium drought. The area of wetlands increased following flooding in 2016, however wetland area remained below the long-term mean.

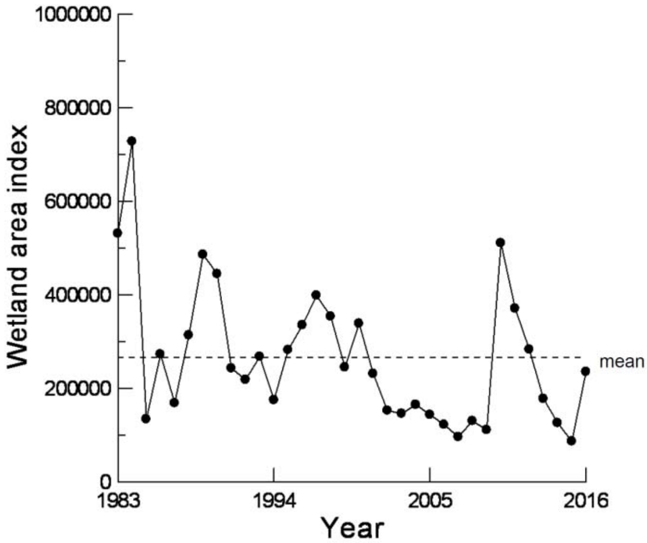

Figure 21. Changes in wetland area (hectares) between 1983 and 2016 across survey bands representing 13.5% of the Murray-Darling Basin (from Porter et al, 2016).[98]

In this period of relatively low flows, environmental water delivery focussed on extending the duration of small- to medium-sized flow events and taper the recession of flow events to better mimic naturally receding flows. For example, environmental flows provided by water managers in the summer of 2013-14 helped to extend the spring unregulated flow and contribute to flows over the South Australian border (Figure 22).

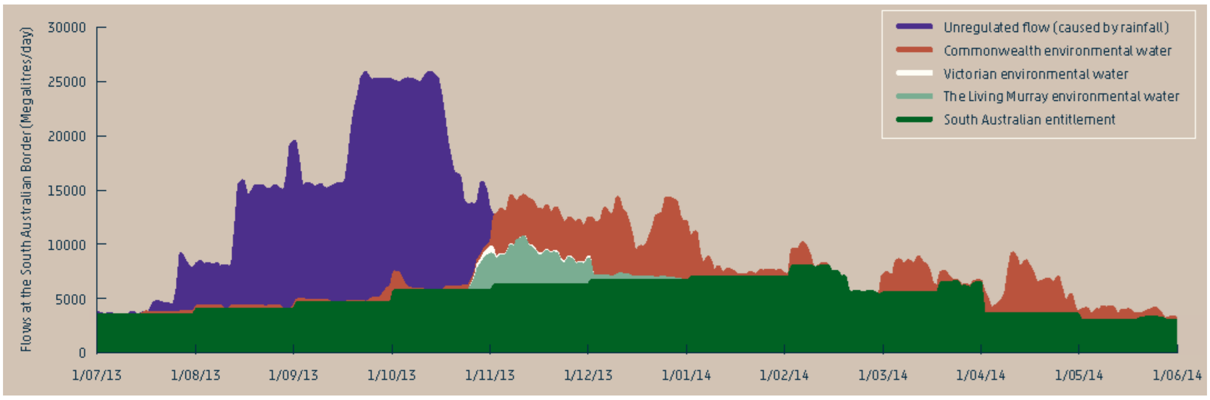

Figure 22. Hydrograph of flows at the South Australian border from July 2013 to June 2014 indicating the contribution of unregulated flow, environmental water held by Basin jurisdictions, and South Australian entitlement flow.[99]

In periods of low flow, environmental water helped to maintain permanent waterholes in channels of the lower Balonne in 2012-13,[94] provide baseflows along channels of the Gunbower forest in 2012-13,[100] break periods of low flow in the Warrego in 2014-15,[101] and extend periods of wetting of channels in the Namoi in 2012-13.[94] Small fresh flows were reinstated with environmental flows in the Barwon-Darling River in 2012-13,[94] the Edward Wakool in 2012-13 and 2013-14,[99, 102] and the Lower Balonne in 2014-15.[103] Freshes improved connectivity between rivers and creeks, mobilised sediment and nutrients, created slackwater habitat for juvenile fish and promoted movement of native fish.[104] The Great Cumbung Swamp in the Lachlan reached maximum capacity in 2012-13 and 2013-14 because of the contribution from environmental watering.[94, 105]

Environmental watering also resulted in overbank flows which naturally inundated floodplain wetlands, mainly in the northern Basin (Table 7). Environmental flows were pumped to isolated wetlands in the mid-Murrumbidgee in 2014-15, with secondary benefits for in-channel habitats.[106] Inundation of important habitat was observed in the Mallowa Creek in the Ramsar-listed Gwydir wetlands (2013-14), where environmental water inundated 1,545 ha of Coolibah-River Cooba-Lignum Association, 337 ha of Coolibah woodlands and around 1,288 ha of cultivated land. Environmental watering in the nationally important Great Cumbung Swamp on the Lachlan floodplain inundated core reed-beds, filled most open water bodies, and spread through river red gum and fringing black box communities.[105]

Table 7. Reported inundation events which benefitted from environmental water between 2012 and 2015.

Region	Area (ha)	Year	Duration & Frequency	Reference
Gingham and Lower Gwydir	6,342	2014-15	4-6 months	CEWO 2015; DOE 2015; EcoLogical and UNE 2015[101, 103, 107]
Mallowa Creek	1,600 2,011	2012-13 2013-14	n/a	CEWO 2013; Southwell et al. 2015[94, 108]
Macquarie Marshes	15,484 9,323	2013-14 2014-15	n/a	OEH 2014b; 2016[105, 109]
Lachlan floodplain	63,000	2013-14	n/a	OEH 2014b[105]
Edward Wakool	n/a	2014-15	n/a	Watts et al. 2015[110]
Lower Murray River, South Australia	~600	2012-13	n/a	CEWO 2013[94]

In a few valleys however, environmental flows were delivered but no significant effects on flow indicators were observed. In the Lower Balonne for example, 22GL of environmental water was delivered in 2013-14, but due to high evaporation losses only a small proportion reached the Narran Lakes.[100] In the Goulburn valley, delivery of environmental water in summer and autumn of 2015 had only a marginal effect on inundation and negligible impact on bank condition, because environmental watering events were small in size, and bank vegetation and other factors exerted a stronger influence over bank condition than flow.[111] The only reported negative flow response to environmental watering was observed in 2014-15 in Yallakool Creek of the Edward Wakool, where there was a reduction in the area of slackwater habitat during watering actions compared to area of available habitat during base flows.[110]

ECOLOGICAL OUTCOMES

Most regions of the Basin receiving environmental water were in better ecological condition than they would have been without environmental watering under the Basin Plan (see Appendix 2). Short-term improvements observed for a range of environmental attributes including vegetation, fish, waterbirds in surveyed valleys (see examples in Box 1). There was also evidence that environmental water alleviated the impacts of drying as the Basin transitioned from a wet period (2010-2012) to a dry period (2013-2015). Very few environmental watering activities reported negative outcomes, and most of these effects were short lived, or not harmful to aquatic biota in the long-term.[112]

Some environmental watering activities did not produce any measurable response, mainly due to insufficient overall flows, lack of flow protection, or factors aside from flow volumes such as water temperature which in some cases may be addressed through complementary measures. For example, there was no waterbird breeding response in the Lachlan River in 2014-15,[103] there was no evidence of anticipated frog spawning at surveyed sites following environmental flow delivery in the Edward-Wakool in 2013-14,[113] and macroinvertebrate biomass did not change in the Goulburn River following environmental flows in 2014-15.[111]

Box 1. Selected outcomes of environmental watering under the Basin Plan between 2012 and 2015.

- **Salt**: Salinity targets were met in three out of five locations in the southern Basin for the 2009 to 2014 reporting period.[62] Nearly 1 million tonnes of salt was exported out of the Basin each year from 2012 to 2015 on average, more than would have been exported without the Basin Plan but less than the Basin Plan outcome of 2 million tonnes.
- **Water quality:** Environmental water prevented dangerously low levels of dissolved oxygen in the lower Broken Creek weirpools in 2012-13.
- **Hydrological connectivity**: Environmental water helped maintain permanent waterholes in the lower Balonne and provided connectivity through to the Narran Lakes and Darling in 2012-13. Environmental water also helped to extend the unregulated flow peak over the South Australian border in late 2013, and contributed to 100% of the flows over the barrages into the Coorong from November 2014 to June 2015.
- **Vegetation**: Aquatic and semi-aquatic plant species abundance and diversity was significantly greater at sites receiving environmental water in the Edward Wakool in 2014-15.
- **Native fish**: Spring freshes in 2014 resulted in the largest golden perch spawning in four years in the Goulburn River, and spawning of the critically endangered silver perch.
- **Waterbirds**: There was a boom in native colonial waterbird breeding following environmental water delivery to Yanga National Park in early 2015, with the breeding of four species including the first breeding of the internationally recognised Eastern great egrets in the Park since 2011. In 2016, there was widespread colonial waterbird breeding in the Lower Lakes, Lachlan River, Kerang wetlands and the Macquarie Marshes.

NATIVE VEGETATION

Native vegetation responded positively to environmental watering, with the establishment of aquatic species and improved condition of flow-tolerant vegetation in those sites that received flooding (see Appendix 2). In areas receiving environmental water, monitoring showed improved condition of floodplain trees, with the canopy showing less dead material and canopy foliage cover generally increasing (e.g. Darling anabranch in 2013-14, Lachlan in 2014-15, Murrumbidgee floodplain in 2012-14, NSW Murray in 2013-14, Gunbower forest in 2014-15, and Koondrook-Perricoota in 2014-15).[101, 105, 109, 114-116] Environmental watering stimulated growth of a number of wetland species in the Lower Gwydir and Gingham wetlands (2012-13), Lachlan (2013-14, 2014-15), Lower Darling (2013-14), Murrumbidgee (2012-13) and Chowilla floodplain (2014-15), as indicated by fresh foliage, mass flowering, seeding, and recruitment.[105, 117] Wetland plant and community diversity increased in response to environmental flows at some sites. For example, increased species diversity was recorded on the Lowbidgee floodplain).[101, 103, 106] and the Loddon where the number of local indigenous plant species at Lake Yando increased from 60 to 97 after environmental watering in 2014-15, including twelve species of rare or threatened plants.[116] Monitoring results were consistent with scientific understanding of the role of environmental water in reducing or suppressing the growth of terrestrial and exotic species in wetlands.

The extent of wetland species increased in valleys in sites where environmental watering occurred in two or more consecutive years. For example, in the Goulburn valley, environmental watering in 2012-13 followed by spring freshes in 2013-14 saw the return of vegetation on the lower Goulburn River to flow-adapted species, with terrestrial species becoming less prevalent.[99, 104] Subsequent delivery of environmental water in 2015 maintained vegetation abundance and diversity in the regions inundated in the previous year.[101, 111] Similarly, vegetation in the Lower Gwydir and Gingham wetlands responded positively to environment watering in 2012-13 and 2013-14 with an increase in area of vegetation communities and increased biomass production, with up to 25 times more biomass in flooded areas compared to non-flooded areas.[117] Similar observations were made in the Edward-Wakool where there was gradual improvement in vegetation at sites that have received environmental water over three years, with greater persistence of submerged aquatic habitat where there was slow recession of flows.[99, 110, 113]

In areas that did not receive environmental watering, monitoring showed aquatic species in decline and transitioning to terrestrial or exotic communities. In the absence of environmental flows in the Lower Lachlan river system, few flow-tolerant species were observed by the end of the 2014-15 water year, and vegetation communities within the floodplains, wetlands and billabongs were dominated by terrestrial species.[115] Significant declines in the cover of aquatic species were observed in the mid-Murrumbidgee wetlands in the absence of environmental water.[118] River red gums in the mid-Murrumbidgee have encroached into previously wetted areas and risk forming dense stands. Successive watering events were not available to promote ecological thinning.[106] Monitoring in the Broken Creek weir pools showed very strong zonation in vegetation from aquatic plants to terrestrial species due to attenuated flow variability which was atypical of a natural flow regime.[104] Sites on the Goulburn River exhibited a more natural, gradual zonation from aquatic plants to terrestrial species where environmental flows have reinstated a more natural flow regime.[99, 104]

WATERBIRDS

Environmental watering has supported outcomes for colonial waterbirds with evidence of localised improvements in abundance and diversity at sites receiving environmental water.[106, 116, 119] Most improvements were related to increases in wetland area and floodplain inundation, providing food and habitat opportunities. Environmental flows were critical for the completion of some colonial waterbird nesting, breeding and fledging events, in conjunction with natural and unregulated flows.[94, 100, 117, 120]

The overall magnitude of site-specific responses was difficult to ascertain as most monitoring reports showed presence/absence of species rather than quantitative measures in relation to a target or expected outcomes. Threatened species were recorded at many sites where environmental watering occurred, but there was no indication of their overall status in relation to obligations under international migratory bird agreements (e.g. JAMBA, CAMBA and ROKAMBA).

NATIVE FISH

Native fish responded positively to environmental flows delivered between 2012 and 2015, with outcomes reported for spawning and fish movement. There was evidence to suggest that environmental flows have enhanced juvenile recruitment success of some species including Australian smelt and Murray cod in the Murrumbidgee[94, 117, 120] and golden perch in the South Australian Murray.[121] Spawning of adult golden perch in the Goulburn River[99, 104] and bony bream and spangled perch in the Gwydir valley were directly attributed to environmental flows in 2013-14.[99, 105, 108] However there is insufficient evidence to date suggesting that spawning events resulting from environmental flows have translated into recruitment of juveniles into the local population. There was no conclusive evidence that environmental water stimulated carp breeding or movement in the Basin. Between 2012 and 2015, the Macquarie Marshes was the only site where carp recruitment was reported as prolific following environmental watering.[103, 109, 122]

CONDITION OF THE LOWER LAKES, COORONG AND MURRAY MOUTH

An overall objective for the Basin Plan is to provide a “healthy and working Murray-Darling Basin that includes…healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean” (s5.02 (2) (a)). The Basin Plan also contains a series of objectives and outcomes related to the Lower Lakes, Coorong and Murray mouth:

1. *Objectives for water levels of the Lower Lakes (s8.06 (3) (e))*: The levels of the Lower Lakes are managed to ensure sufficient discharge to the Coorong and Murray mouth and help prevent river bank collapse and acidification of wetlands below Lock 1, and to avoid acidification and allow connection between Lakes Alexandrina and Albert, by (i) maintaining levels above 0.4 metres Australian Height Datum for 95% of the time, as far as practicable; and (ii) maintaining levels above 0.0 metres Australian Height Datum all of the time.

2. *Objectives for salinity levels and salt export (s9.09 (3))*: Average discharge of 2 million tonnes of salt from the River Murray System into the Southern Ocean likely for each water accounting period; Requirements of salinity levels to be achieved 95% of the time: Lower Lakes at Milang 1000 EC (uS/cm).

3. *Objectives for barrage flows (s6.07 (c) and BWS[27])*: Barrage flows are greater than 2000 GL per year on a three year rolling average basis with a minimum of 650 GL in any year, to be achieved for 95% of years; and barrage flows are greater than 600 GL over any two year period, to be achieved for 100% of the time.

4. *Objectives for openness of the Murray Mouth* (s8.06 (3) (c-d)): The Murray mouth remains open at frequencies, for durations, and with passing flows, sufficient to enable the conveyance of salt, nutrients and sediment from the Murray-Darling Basin to the ocean; and the Murray mouth remains open at frequencies, and for durations, sufficient to ensure that the tidal exchanges maintain the Coorong's water quality (in particular salinity levels) within the tolerance of the Coorong ecosystem's resilience.

5. *Ramsar objectives* (s8.05 (2) (a)): The Basin Plan also contains an objective to ensure that declared Ramsar wetlands (including the Lower Lakes and the Coorong, that depend on Basin water resources maintain their ecological character.

1. Lake levels

The condition of the Lower Lakes has improved as a result of river flows following the millennium drought, at which time lake levels dropped below sea level. Water levels in the Lower Lakes have returned to levels prior to the millennium drought (Figure 23). Since 2010, Lake Alexandrina water levels have oscillated annually between 0.4m and 0.9m AHD, reflecting inflows, outflows and evaporation losses. Water level targets in Lake Alexandrina have also been achieved since the Basin Plan has been in place (s8.06 (e) of the Basin Plan). Environmental water contributed to achieving lake level targets, particularly in the 12 month period from June 2014 to July 2015 when environmental water was the main source of inflow into Lake Alexandrina.[3]

2. Salinity and water quality

Water quality in the Lower Lakes has also improved since the millennium drought with the increase in freshwater inflows including environmental water. Salinity levels in Lake Alexandrina at Milang have remained below 1,000EC (Figure 23), although they came close to this threshold in the dry winter of 2016. Salinity targets for Milang,[123] measured as long-term averages, have not been achieved because of the influence of the millennium drought on average calculations. Modelling suggests that the Commonwealth environmental water delivered between 2014 and 2015 had no effect on in-channel salinity levels upstream but these additional flows increased salt exports from the Murray River Channel, Lower Lakes and Coorong, contributing 21% and 64% of the total modelled export from the Lower Murray River Channel and Lower Lakes, respectively.[124] Modelling suggests that Commonwealth environmental water greatly reduced the net import of salt to the Coorong during 2014–15 due to increased outflows (from 3.2 × 106 tonnes down to 1.6 × 105 tonnes).[125] Salt export targets are reported on page 22.

However, additional environmental flows were not sufficient to enable surface and groundwater quality in large parts of the region to fully recover from the drought, and in some areas water quality remains poor. In Lake Albert, salinity levels had not returned to pre-drought levels by February 2016.[126] Monitoring by the South Australian Environmental Protection Agency across the region from 2011 to 2016 found ongoing low levels of acidity at some previously acidified locations, and acidic shallow groundwater at multiple sites.[126] The Environmental Protection Agency concluded that water quality, soil, ecosystems and infrastructure may not fully recover from the impacts of poor water quality that followed the severe drought.

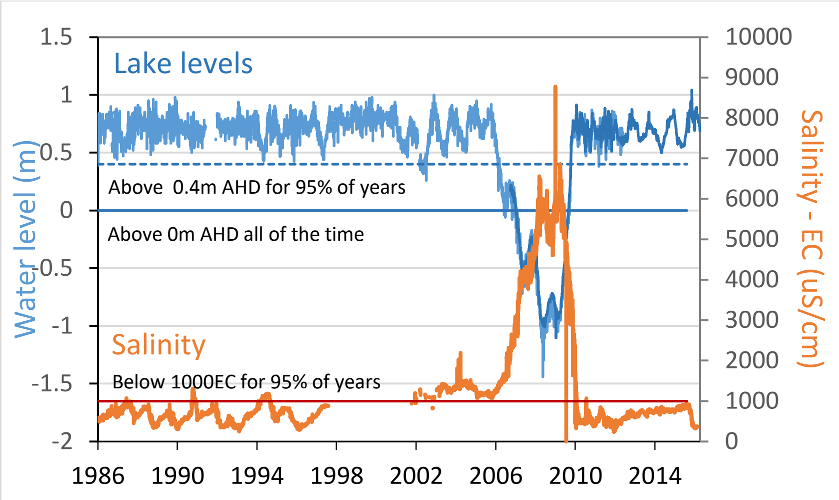

Figure 23. Daily water levels (blue) and salinity levels (red) for Lake Alexandrina from 1986 to 2015 measured at Milang.[127] Basin Plan targets are shown for water levels (s8.06 (e)) and salinity (s9.14 (5) (c)).

3. Barrage flows

Barrage flows for the 2012–15 reporting period (2,680 GL/yr) were within the 2,000 GL/yr minimum target in the Basin-wide environmental watering strategy.[128,3] However there was considerable variation between years. Barrage flows over spring 2016 were low even though lake levels were above full supply level (0.75m AHD; Figure 24). A report commissioned by the Commonwealth Environmental Water Holder concerning the current management of lake levels stated that South Australia "appears to prioritise high lake water levels over maintenance of flows to the Coorong and Murray mouth".[3] With the limited environmental water available, retaining high water levels in the Lower Lakes at the expense of barrage flows compromises the connection of the river to the sea, and may put at risk the Australian Government's international obligations to protect the Coorong under the Ramsar Convention. This is discussed on page 63 in more detail.

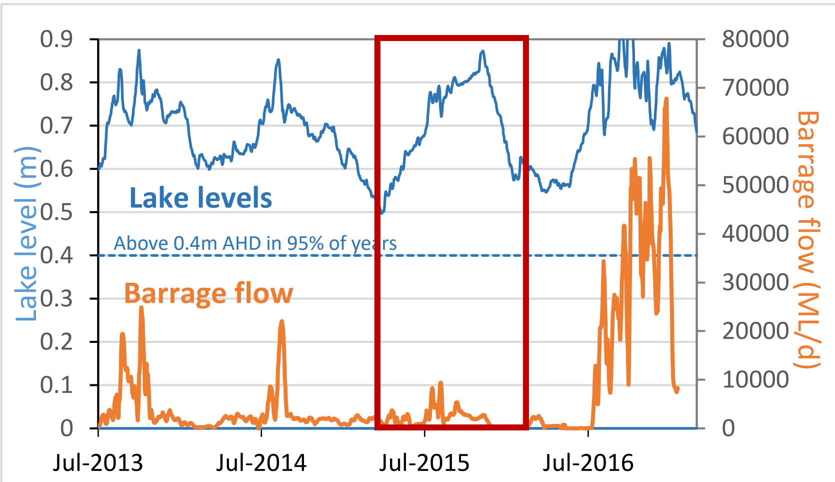

Figure 24. Water levels at Milang in Lake Alexandrina and barrage flow for the period 2013 to 2016. Red rectangle indicates the period where high water levels were prioritised over barrage flows to the Coorong and Murray mouth. Water level data was from MDBA's River Murray Data portal and barrage flow supplied by South Australian Department of Environment and Natural Resources.

4. An open Murray mouth

A Basin Plan objective is for the Murray mouth to "remain open at frequencies, for durations, and with passing flows, sufficient to enable the conveyance of salt, excess nutrients and sediment from the Murray-Darling Basin to the ocean" (s8.06 (c)). A further outcome to be pursued with a Commonwealth program to deliver 450 GL is the "mouth of the River Murray is open without the need for dredging in at least 95% of years" (Sch 5 (2) (c)). This target for the Murray mouth is far from being met. To date, it is only during periods of unregulated flow (i.e. floods) that the Murray mouth has been scoured open by river flows (e.g. 2010, 2016; Figure 25). At other times, dredges were required to maintain an open Murray mouth, given the power of the sea in bringing sand into the mouth (e.g. 2003 to 2006 and 2014 to 2015) at a cost of about $6 - 7 million per year.[129] Even with one dredge in operation, there was a net sand accumulation into the mouth due to very low barrage flows (e.g. 2006 to 2010). Since the construction of the barrages in the 1930s, large quantities of sand have accumulated between the mouth and the barrages, further restricting egress of river water through the mouth when being released over the barrages. This sand accumulation has formed a continually growing flood tidal delta that includes Bird Island.[130] A report commissioned by the South Australian Government in 2017 showed the rate of sediment inflow from the sea is around 2,250m^3 per day based on surveys between June 2015 and July 2016.[131] During winter 2016, a larger than usual number of severe storms contributed to higher ocean levels, Murray mouth sedimentation and shoal development.[131] Data provided on volumes dredged for 2015-16 indicate the necessity for two dredges to sustain an open mouth. Given continued onshore sand transport to the mouth, it is unlikely that targets for an open Murray mouth can be met in the future without dredging.

Freshwater flow through the barrages as well as an open Murray mouth is necessary to sustain the ecological health of the tidally-flushed north Coorong and the more saline south Coorong. A Basin Plan objective for water-dependent ecosystems is "the Murray Mouth remains open at frequencies, and for durations, sufficient to ensure that the tidal exchanges maintain the Coorong's water quality (in particular salinity levels) within the tolerance of the Coorong ecosystem's resilience" (s8.06 (d)). Higher River Murray flows and water releases through the barrages and into the Coorong in late 2010 resulted in decreasing salinity, decreasing total nitrogen (mg/L) and decreasing total phosphorus, while chlorophyll *a* and turbidity increased from 2011 to 2016.[126]

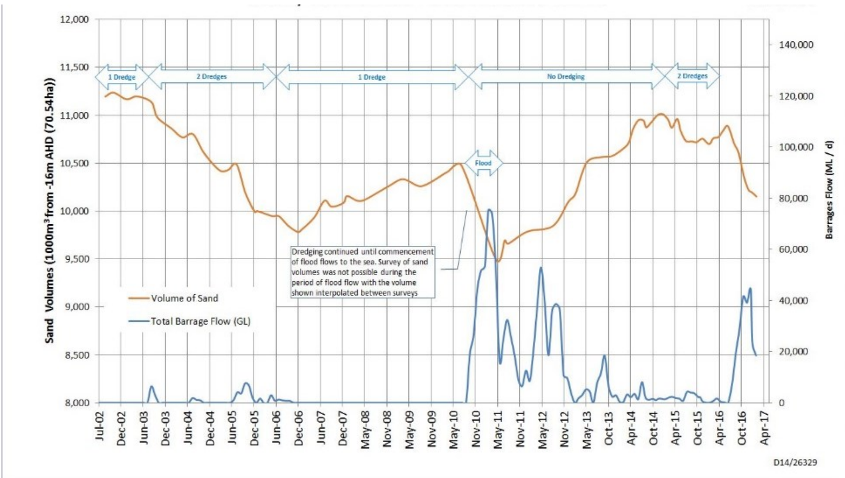

Figure 25. Barrage flow, sand volumes and dredging of the Murray mouth between 2002 and 2017. Supplied by South Australian Department of Environment and Natural Resources.

5. The Coorong Ramsar site

Recent work by Paton and colleagues have highlighted complex relationships between Coorong water levels, salinity, aquatic vegetation and waterbirds.[132, 133] Since the return of freshwater flows to the Coorong, the recovery of the seagrass *Ruppia tuberosa* in the South Lagoon has been slow. *R. tuberosa* is a source of food and habitat for macroinvertebrates and fish, and provides food for migratory waterbirds. Extensive beds of *R. tuberosa* that had gradually established in the North Lagoon between 2006 and 2010 were quickly lost following the return of freshwater flows, probably due to interference from filamentous green algae. There has been limited improvement since. Although flows returned to the region in spring 2010, flows diminished dramatically during each spring of the next five years (2011-2015) resulting in water levels once again falling at critical times for *R. tuberosa* production. It is clear from trends in *R. tuberosa* and other condition indicators, that the availability and management of water is not yet sufficient to meet the objectives of the Basin Plan for the Coorong, Lower Lakes and Murray mouth, nor is it adequate to maintain the ecological character of the Ramsar wetlands. The South Australian and Commonwealth Governments need to undertake a medium-term process of scientific assessment and stakeholder consultation to identify more realistic long-term management options for the Coorong.

ECOLOGICAL OUTCOMES AT THE BASIN SCALE

Since 2012-13, many environmental outcomes have been observed at the specific sites where environmental water was directed, however there are many more sites across the Basin which have not received sufficient environmental flow and remain in a poor and degrading condition (e.g. see Appendix 2). Improvements in the condition of the Basin across large scales have not yet been assessed and reported. We are also yet to observe longer lasting improvements in the Basin's environment because, like watering a garden after a drought, it will take consecutive watering events for degraded ecosystems to respond given the lag effects and the trajectory of declining health in past decades. Even when the Basin Plan is implemented in full with constraints relaxed, only 66% of the 112 target environmental water requirements set by the Murray-Darling Basin Authority in 2012 are expected to be achieved.[156]

We do not have Basin-wide monitoring in place that measures condition of river systems and enables detection of ecological changes even when they become apparent. No measures of Basin-wide health have been produced since the Sustainable Rivers Audit was discontinued. The Sustainable River Audit was a Basin-wide assessment of river health for the 23 valleys of the Basin for key indicators — vegetation, physical form, macroinvertebrates, fish and hydrology. It was an initiative of Basin governments, coordinated by the Murray–Darling Basin Authority, and overseen by a panel of independent ecologists. Two audits were undertaken for the periods 2004 to 2007 and 2008 to 2010. In 2012, states cut funding for the joint management of the Murray-Darling Basin system and as a consequence, Basin governments decided to cease the audit.[134] Without the ability to track the condition of the Basin it is not possible to understand the ecological changes at a valley and Basin scale.

NATIVE VEGETATION

The stand condition of woody vegetation (river red gum and black box) was monitored at seven icon sites in the Southern Basin totalling 134,000 ha in area.[43] This analysis included areas that have not received environmental water or natural flooding since at least 2009. Between 2009 and 2015, there was an 11% decline in the area of red gum and black box stands classified as good condition, and a 26% increase in the area that was classified as severely degraded (Figure 26).[135] Black box stands were generally classified in poorer condition than red gum stands, because black box stands are situated in the upper floodplains which are less frequently flooded.[135] Due to the dry conditions there was very little environmental water available in The Living Murray portfolio until 2010-11. The Living Murray works only started to become operational at different icon sites between 2013 and 2016. Data on recruitment, understorey and other aspects of vegetation condition were not included in the assessment of stand condition.

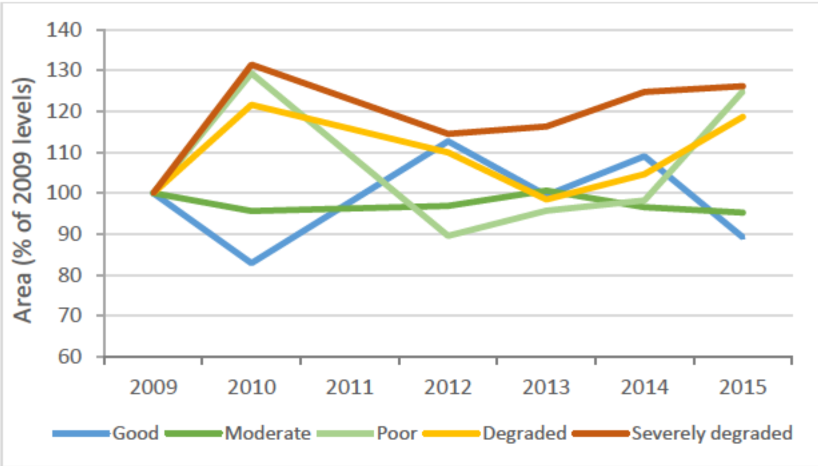

Figure 26. Change in area of floodplain forests and woodlands of different condition across seven Living Murray sites (total of 134,200 ha) relative to 2009 areas. (Source: Compiled from MDBA's stand condition reports; error not quantified).[43]

WATERBIRDS

Colonial waterbird abundance measured using the Eastern Australian Waterbird Survey for the sample area (13.5% of the Basin) peaked at the beginning of the 33 monitoring period at about 700,000 individuals (1984), then declined through the Millennium drought to a record low of less than 50,000 individuals (2009; Figure 27).[98] Drought-breaking rains in 2010 and 2011 led to a small recovery in waterbird abundance, reaching about 350,000 individuals (2012). Further, aerial waterbird surveys across the major wetlands of the Murray-Darling Basin showed low populations of waterbirds after 2012, following a small peak in population during the wet period from 2010 to 2012 (Figure 27).[98]

Between 2012 and 2015, declines were observed in total waterbird abundance, wetland area, breeding abundance and breeding species richness,[98] interrupted by a peak related to the wet period from 2010 to 2012. Colonial waterbird abundance has not exceeded 100,000 individuals in any year since the Basin Plan was implemented.[98] Declines were related to reduced frequency and magnitude of flows and inundation extent due to changes in climate and impacts of river regulation, given large-scale colonial waterbird breeding generally requires large areas of wetland (>20,000 ha) to be inundated.[118]

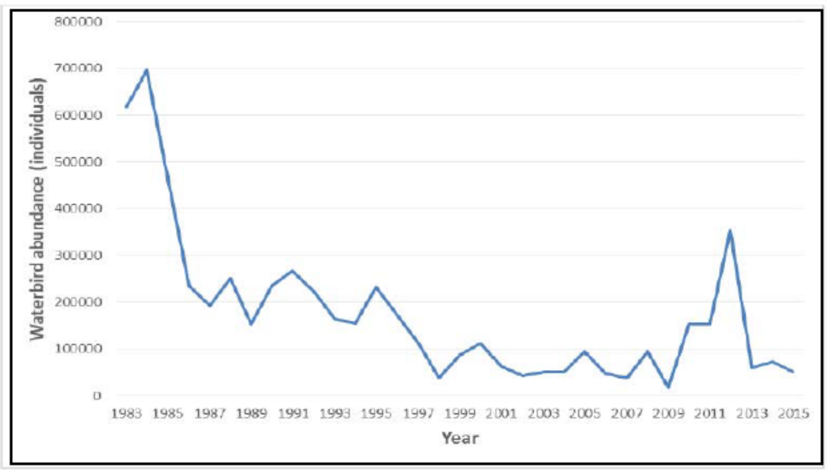

Figure 27. Waterbird abundance across the Murray–Darling Basin 1983–2015 (as estimated during aerial waterbird surveys).[98]

The ten most important wetlands for waterbird breeding in the past 33 years have been Lowbidgee, Cuttaburra Channels, Menindee Lakes, Macquarie Marshes, Paroo overflow, Darling River, Corop Wetlands and the Coorong, Lower Lakes and Murray mouth, Fivebough Swamp and Coolmunda Dam. These wetlands, together with seven additional sites, represented 80% of total abundances of all 52 waterbird species over the 33 year period.[136] Different wetlands were important for waterbirds in dry years compared to wet years. In dry years, waterbirds preferred 12 river and lake habitats for refugia, while in wet years waterbirds preferred 8 lake and wetland habitats as breeding grounds.

NATIVE FISH

The abundance and distribution of native fish has declined in the past 50 years (Figure 28).[137] In the southern Basin, native fish populations in the Murray River have declined to about 10% of the pre-European level over the last 100 years.[121] In the northern Basin, fish communities in most valleys are in extremely poor to poor condition, with the exception of the Border Rivers (moderate), Condamine (moderate) and Paroo (good; Figure 29).[138] Low condition scores for the Lower Lachlan were attributed to a number of native species predicted to have historically occurred within the area that were absent (50% of species absent) and because recruitment within the population was observed to be very low.[115]

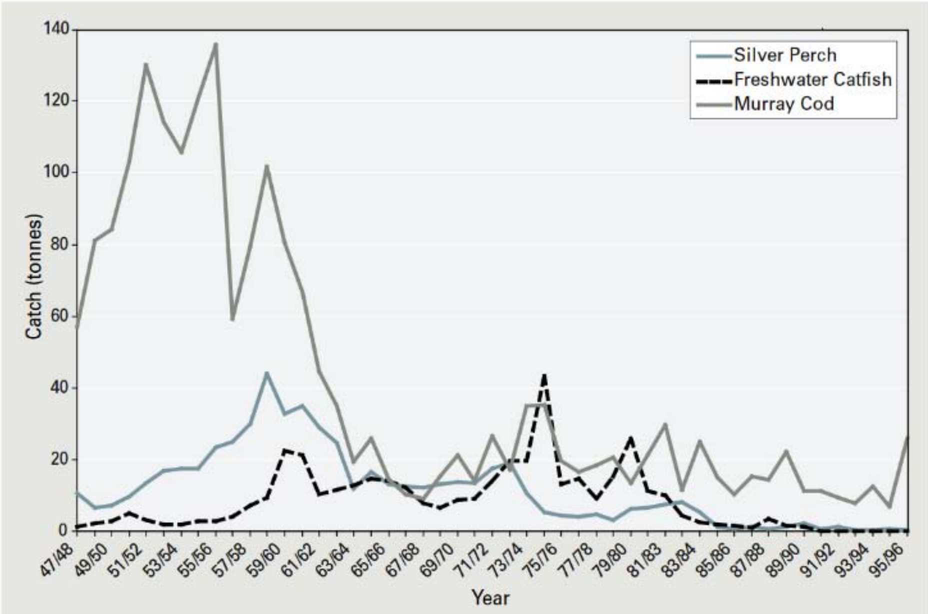

Figure 28. Decline in commercial catches of Murray cod, Freshwater catfish and Silver perch in NSW between 1947 and 1996 (Source: Reid et al. (1997) in Lintermans (2009)).[139]

Despite the localised benefits of environmental water, fish communities in most valleys in the Murray-Darling Basin of New South Wales, particularly in the southern Basin, remained in poor to extremely poor condition in 2015 (Figure 29).[138] Results also showed the condition of fish communities changed within valleys, for example in the Macquarie River, where fish condition declined along a downstream gradient from 'poor' below Burrendong Dam to 'extremely poor' downstream of the Macquarie Marshes .[122] There was a small improvement in trend of the native fish communities in some valleys (e.g. from 'very poor' to 'poor' in the Edward-Wakool).[113]

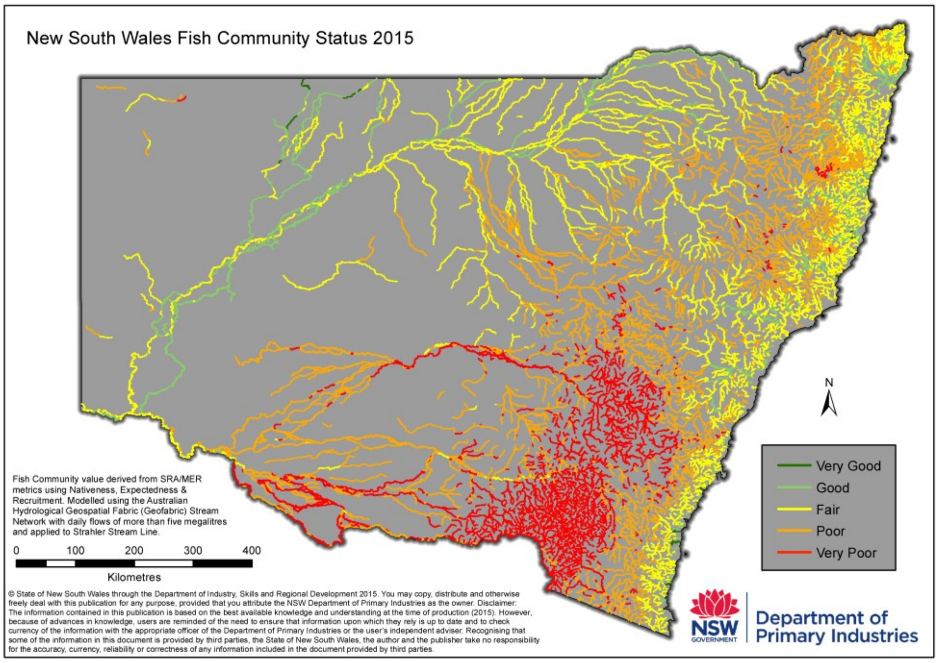

Figure 29. Fish community status in New South Wales.[138]

RAMSAR OBLIGATIONS

The mandate for the Water Act 2007 and the Basin Plan is based on Australia's international environmental obligations. Under the Ramsar Convention on Wetlands, Australia has committed to protecting the ecological character of sixteen internationally recognised wetlands in the Murray-Darling Basin. Table 8 shows the expected improvement in flow indicators at Ramsar sites as a result of the Basin Plan. For example in the Barmah-Millewa forest Ramsar site, the proportion of years with a successful event of 12,500 ML/d for 70 days from June to November will be restored from 57% to 95% of its natural state.

The Australian Government's 2015 national report on the implementation of the Ramsar Convention reported that the ecological character had improved for three wetlands (Gwydir wetlands, Coorong and Lower Lakes and Banrock Station), stayed the same for ten wetlands, and declined for one site (Riverland) since the last triennium report (Table 9).[42] Deterioration in the ecological character status of the Riverland region was attributed to changed hydrologic regime and changing climate.[58]

While many of these wetlands may have marginally improved since the last report, e.g. Gwydir wetlands, they remain in a degraded condition that does not meet the ecological character description for which they were listed under the treaty. Vegetation condition assessments by the Murray-Darling Basin Authority in 2015 show that less than a third of the area of red gum and black box forests across all surveyed sites was in good condition, and the area of forests in degraded or severely degraded has increased since 2009 (Figure 26).[43] Red gum or black box forests were identified as critical components of ecological character, or support critical components of ecological character, of the Ramsar sites surveyed.[140-144] This decline in line with predictions that eight of the ten Ramsar sites assessed in the modelling underpinning the Basin Plan (2,800 GL water recovery scenario) are likely to decline beyond the "limits of acceptable change" mandated under the Ramsar Convention in the long-term.[145]

Under a median climate scenario, the period between flood events at the Riverland Ramsar site is expected to double and volumes are expected to be reduced to 23% of natural conditions, with adverse consequences for floodplain vegetation.[146] Similarly, there is evidence that NSW Central Murray State Forest "is on a trajectory of decline and it is thought that hydrological conditions at the time of listing were insufficient to maintain the ecological character of the site".[141] Additional pressures including drought and hypersalinisation have resulted in adverse changes to the ecological character of Ramsar wetlands as reported in past assessments, including the Coorong and Lower Lakes.[44-46].

Table 8. Achievement of flow indicators for Ramsar sites in the Murray-Darling Basin, showing the proportion of years with a successful event relative to the natural (without development, WOD) scenario.[147]

Ramsar site	Proportion of years with successful event (as a % of WOD)		
	Without dev.	Pre-Basin Plan	Basin Plan (3,200 GL)
Fivebough and Tuckerbil Swamps	100%	N/A	
Gwydir Wetlands			
150 ML/Day for 45 days from Oct - Jan	100%	213%	232%
1000 ML/Day for 2 days from Oct - Jan	100%	96%	96%
45 GL during October & March	100%	104%	118%
60 GL during October & March	100%	111%	116%
80 GL during October & March	100%	92%	100%
150 GL during October & March	100%	69%	72%
250 GL during October & March	100%	79%	86%
Narran Lakes	100%	N/A	N/A
NSW Central Murray State Forests	100%	N/A	N/A
Paroo River Wetlands	100%	N/A	N/A
Macquarie Marshes			
1.5 year ARI at Marebone Break	100%	85%	86%
2.5 year ARI at Marebone Break	100%	93%	93%
5 year ARI at Marebone Break	100%	97%	97%
Barmah-Millewa Forest			
12,500 ML/d for 70 days from Jun - Nov	100%	57%	95%
16,000 ML/d for 98 days from Jun - Nov	100%	45%	92%
25,000 ML/d for 42 days from Jun - Nov	100%	45%	71%
35,000 ML/d for 30 days from Jun - May	100%	45%	58%
50,000 ML/d for 21 days from Jun - May	100%	46%	46%
60,000 ML/d for 14 days from Jun - May	100%	42%	33%
15,000 ML/d for 150 days from Jun - Dec	100%	25%	82%
Gunbower-Koondrook-Perricoota Forest			
16,000 ML/d for 90 days from Jun - Nov	100%	36%	83%
20,000 ML/d for 60 days from Jun - Nov	100%	39%	70%
30,000 ML/d for 60 days from Jun - May	100%	42%	65%
40,000 ML/d for 60 days from Jun - May	100%	28%	62%
20,000 ML/d for 150 days from Jun - Dec	100%	16%	67%
Hattah Lakes			
40,000 ML/d for 60 days from Jun - Dec	100%	45%	75%
50,000 ML/d for 60 days from Jun - Dec	100%	40%	70%
70,000 ML/d for 42 days from Jun - Dec	100%	29%	55%
85,000 ML/d for 30 days anytime	100%	30%	42%
120,000 ML/d for 14 days anytime	100%	35%	35%
150,000 ML/Day for 7 consecutive days anytime	100%	29%	35%
Kerang Wetlands	100%	N/A	N/A
Lake Albacutya	100%	N/A	N/A
Currawinya Lakes	100%	N/A	N/A
Coorong and Lakes Alexandrina and Albert	100%	N/A	N/A
Banrock Station Wetland Complex	100%	N/A	N/A
Riverland-Chowilla Floodplain	100%		
20,000 ML/d for 60 days from Aug - Dec	100%	48%	84%
40,000 ML/d for 30 days from Jun - Dec	100%	46%	76%
40,000 ML/d for 90 days from Jun - Dec	100%	38%	67%
60,000 ML/d for 60 days from Jun - Dec	100%	29%	66%
80,000 ML/d for 30 days anytime	100%	29%	41%
100,000 ML/d for 21 days anytime	100%	32%	37%
125,000 ML/d for 7 days anytime	100%	24%	24%

*Based on 150GL water recovery scenario in the Condamine-Balonne valley.

Table 9. Sixteen Ramsar wetlands in the Murray-Darling Basin, their change in ecological character as reported by the Australian Government to the Ramsar Convention's 12th Conference of Parties in 2015 and the Murray-Darling Basin Authority's 2015 assessment of condition of red gums and black box forests.[42, 148]

Wetland	Australian Government assessment 2015[42]	MDBA vegetation condition assessment 2015[148]
Fivebough and Tuckerbil Swamps (NSW)	No change	n/a
Gwydir Wetlands (NSW)	Status improved	n/a
Narran Lakes (NSW)	No change	n/a
NSW Central Murray State Forests (NSW)	No change	Millewa: Good (18%), Moderate (71%), Poor (9%), Degraded (1%), Severely degraded (1%) Koondrook: Good (5%), Moderate (66%), Poor (27%), Degraded (2%), Severely degraded (<1%)
Paroo River Wetlands (NSW)	No change	n/a
Macquarie Marshes (NSW)	No change	n/a
Barmah Forest (Vic)	No change*	Good (32%), Moderate (64%), Poor (4%), Degraded (<1%), Severely degraded (<1%)
Gunbower Forest (Vic)	No change*	Good (19%), Moderate (63%), Poor (18%), Degraded (<1%), Severely degraded (<1%)
Hattah-Kulkyne Lakes (Vic)	No change*	Hattah: Good (2%), Moderate (29%), Poor (23%), Degraded (42%), Severely degraded (4%)
Kerang Wetlands (Vic)	No change**	n/a
Lake Albacutya (Vic)	No change	n/a
Currawinya Lakes (Qld)	No change	n/a
Coorong and Lakes Alexandrina and Albert (SA)	Status improved	n/a
Banrock Station Wetland Complex (SA)	Status improved	n/a
Riverland (SA)	Status deteriorated***	Chowilla: Good (6%), Moderate (24%), Poor (8%), Degraded (44%), Severely degraded (18%)
Ginni Flats Wetland Complex (ACT)	No change	n/a

*A preliminary assessment of potential change in ecological character is underway, due to one or more Limits of Acceptable Change (LACs) being exceeded as of June 2011. There is no evidence that the site as a whole has undergone further adverse change in ecological character since then. In fact, in the last triennium conditions at the site have improved due to the ending of a long period of drought in 1997- 2009.

** Some LACs have been exceeded for this site, however a preliminary assessment is not proposed at this time. There is no evidence that the site as a whole (comprised of 23 separate wetlands) has undergone a change in ecological character since the last triennium. In fact, in the last triennium conditions at the site have improved due to the ending of a long period of drought in 1997-2009.

***A formal assessment of change of ecological character is in development.

Actions needed to deliver the Basin Plan 'on time and in full'

The National Water Initiative, the Water Act 2007 and the Basin Plan are nationally significant reforms aimed at bringing Australia's most productive river basin back into a more sustainable balance. Our review of water reform in the Murray-Darling Basin shows that progress has been made in some aspects of water reform, however there remain many major risks to the delivery of the Basin Plan.

We have identified five key risks to delivering a Basin Plan 'on time and in full':

1. Erosion of public trust;
2. Failure to reach the target of 3,200 GL or equivalent outcomes;
3. Risk that environmental flows are being undermined and fail to reach their target location;
4. Inadequate support for communities most affected by water reform; and
5. Managing water in a changing climate.

To address these risks, we have identified five actions needed to deliver the Basin Plan:

1. Rebuild trust with greater transparency; and
2. Guarantee recovery of the full 3,200 GL or genuinely equivalent outcomes;
3. Ensure that water recovered achieves measurable improvements to the river system;
4. A regional development package that puts communities at the centre of reform;
5. Prepare for the prospect of a future with less water.

In this section, we describe the nature of these risks and the actions needed to deliver the Basin Plan in full.

1. Rebuild trust with greater transparency

The 2004 National Water Initiative was almost universally supported, and the Basin Plan was a bipartisan agreement, yet how governments have gone about these reforms has resulted in conflicts among communities and this has contributed to an overwhelming erosion of public trust in government.

The first sign that trust had been lost was in the development of the Basin Plan itself, which put bureaucrats in charge rather than allowing communities to be at the front and centre of the solution. We saw a centralist, top down program driven by government agencies, where one arm of government produced a plan, while another arm spent billions of dollars without any genuine consultation with the communities affected. Release of 'The Guide to the proposed Basin Plan' in October 2010 and the disaffection from communities that followed, reflected the breakdown of public trust.

The second sign of the erosion of trust was when the Murray-Darling Basin Authority ignored the best available science for delivering a healthy, working Murray-Darling Basin and instead "manipulate[d] science in an attempt to engineer a pre-determined political outcome".[24] In Senate hearings in November 2012, the Wentworth Group stated "there has been no scientific evidence produced by the Authority to suggest that 2,750 or 3,200 would achieve the objectives of the Water Act,"[149] and "the Australian community in that scenario would have been misled by the parliament".[150]

Institutional changes since the Basin Plan was enacted have reduced national oversight over water reforms with little accountability of governments to their commitments. The Murray-Darling Basin Ministerial Council abandoned the Sustainable Rivers Audit in 2012 (a program to measure the condition of the 23 valleys in the Basin) when states withdrew funding. In 2013, the Council of Australian Governments Standing Committee on Environment and Water was discontinued, and in 2014, the independent water reform review body (the National Water Commission) was abolished.

In 2017, revelations of possible water theft and meter tampering by ABC Four Corners have exposed the inadequacy of New South Wales Government's monitoring and compliance regimes. An investigation by the

New South Wales Ombudsman in November 2017 stated that "these failures potentially affected the integrity and reputation … and undermined public confidence in the water regulation system".[151]

Water reform is essential to restore over-allocated systems, and successful water reform must be built on cooperation and transparency so the public can trust the reforms are both fair and effective. To rebuild trust, four actions are required to create greater transparency and restore community confidence in governments to progress water reform:

1. Improve metering and compliance;
2. Improve accountability;
3. Reinstate a basin-wide river health monitoring program; and
4. Strengthen regulatory capacity.

1.1 Improving metering and compliance

Metering of all water extractions is fundamental for equitable and sustainable management of water in the Murray-Darling Basin. It is also a goal of the 2004 National Water Initiative. Across the Basin, 30% of the total surface water extraction and 10% of extractions from watercourses are unmetered (Figure 30). In 2017, with all the technology, the significant value of water, and the $500 million investment in water accounting, it is inconceivable that we do not know how much water is being extracted from surface and groundwater systems for consumptive use.

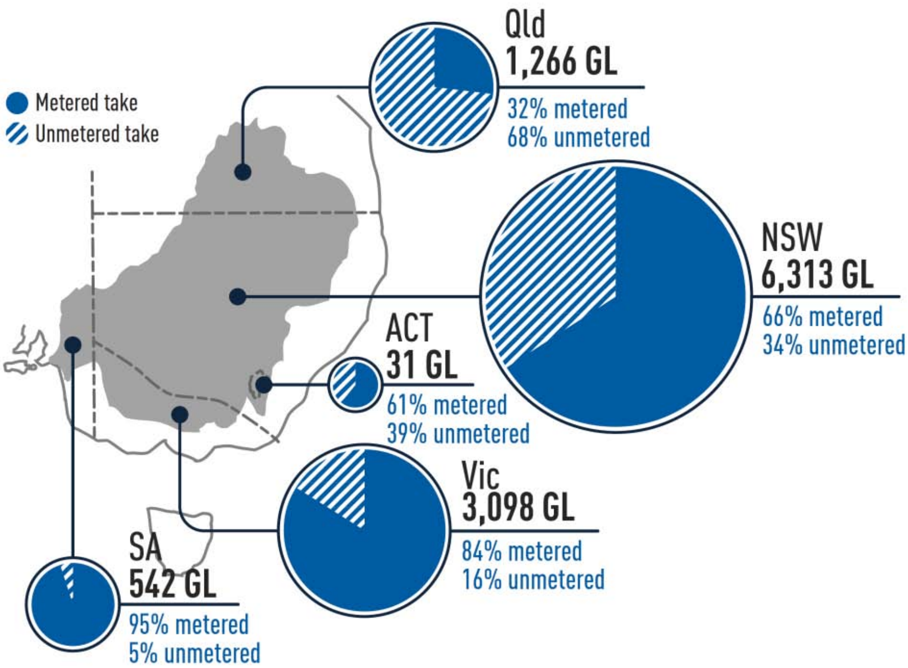

Figure 30. Average annual take (all forms) in the Northern and Southern Basins from 2012-13 to 2015-16. Source: MDBA 2017.[152]

Inadequate metering, enforcement and compliance regimes have been reported at least since the National Water Commission's 2009 biennial assessment. While some improvements have been made since 2009, the Commission's 2014 report identified progress was lacking in key areas: "the generation of groundwater data is still significantly underfunded and poorly appreciated and environmental water accounting remains incomplete. In addition, metering and measuring provides the basis for water use accountability and allows water markets to function, but the National Framework for Non-Urban Metering has not been implemented."[153]

In October 2016, the statutory Northern Basin Advisory Committee of community representatives warned the Murray-Darling Basin Authority of the ineffective compliance regimes in the northern Basin, where "current compliance regimes are poorly resourced and ineffective […] the potential to derail the Basin Plan is glaringly obvious."[154]

Following allegations of water theft raised on the ABC's Four Corners program in July 2017, an independent investigation into New South Wales water management and compliance by Mr Ken Matthews (2017) found that "water-related compliance and enforcement arrangements in NSW have been ineffectual and require significant and urgent improvement".[155] Specifically:

- "The overall standard of NSW compliance and enforcement work has been poor.
- Arrangements for metering, monitoring and measurement of water extractions, especially in the Barwon–Darling river system, are not at the standard required for sound water management and expected by the community.
- Certain individual cases of alleged non-compliance have remained unresolved for far too long.
- There is little transparency to members of the public of water regulation arrangements in NSW, including the compliance and enforcement arrangements which should underpin public confidence."[155]

The interim Matthews report to the New South Wales government proposed a range of Basin-wide initiatives to ensure all states are engaged alongside New South Wales in improving compliance and enforcement efforts.[155] The report recommended implementing a new NSW Natural Resources Access Regulator created by legislation responsible for water and other natural resources. Such measures would go a long way in restoring public confidence in water reform process. Comprehensive water metering of consumptive water use and water interception across the Basin is required as per the National Framework for Non-urban Water Metering.[156] Metering should be mandatory condition of any licence to extract water for consumptive use, and the 'no metering, no pumping' rule should apply.[155] Opportunities for progressing metering reforms that could be implemented widely in the Basin include technological advancements to improve real time data collection and online access to public data.[157]

A subsequent 2017 compliance review by the Murray-Darling Basin Authority identified failures in the regulatory framework at the Commonwealth level. The review found "the MDBA has not given sufficient attention to compliance, has not provided a clear statement of its compliance role, and has not dealt adequately with allegations of compliance breaches."[152] Water audit monitoring reports and reports by the independent audit group for assessing compliance with extraction limits have not been published by the Murray-Darling Basin Authority since 2010-11 after states withdrew funding for joint programs, and groundwater assessments are not publically available. There are also issues with the models that are used for assessing compliance: (1) use of three non-accredited models and four temporarily-accredited models,[35] (2) lack of up-to-date demand data in model calibration, and (3) possible overestimation of baseline and sustainable diversion limits.[158] As a result, it is not possible for anyone to have confidence that diversion limits are being complied with.

Estimates of consumptive use should be based on metered use against an accredited sustainable diversion limit model for that year, rather than only modelled use for that year. Standard auditing practices should also be in place to validate data on water use, by applying financial reporting, auditing and insurance standards to a water context, and using multiple lines of evidence, such as hydrographs, metering records, aerial imagery and production data. Risk assessments can help focus initial auditing efforts on valleys where risks of non-compliance are high, such as valleys which are poorly metered or remote.

To rebuild public trust with transparency, Commonwealth, state and territory governments should agree to comprehensive measurement of consumptive water use and water interception, including groundwater, across the whole Basin to a standard suitable for compliance action.

2.2 Improve accountability

The Commonwealth Government does not currently have sufficient measures in place to prevent Basin states from gaming the Basin Plan and ensuring recalcitrant states deliver necessary actions. Already, $7.9 billion has been spent with inadequate governance, poor transparency and for unknown returns. Further funding is earmarked for Basin states to implement projects which are not consistent with the requirements of the Basin Plan.[5]

From 2006 onwards, the New South Wales Ombudsman's office has received complaints and public interest disclosures alleging that the water management principles and rules were not being properly complied with and enforced. A formal investigation by the Ombudsman in November 2017 found "underlying structural and systemic problems… including chronic under-resourcing of the compliance and enforcement roles, the constant stream of restructures and transfers of water regulation responsibilities (seven times since 2007) that resulted in significant staff turnover, loss of corporate memory and poor staff morale, and a clash of cultures between a customer service focus and enforcement obligations."[151]

The Commonwealth Government needs stronger measures to ensure states are held accountable for delivering the activities and outcomes required by the Basin Plan. The Murray-Darling Basin Authority's audit program was significantly reduced in 2013 after Basin states withdrew funding from the joint program arrangements.[134] Audit program functions included ensuring monitoring compliance with the 'cap' which limits surface water diversions in the Basin, ensuring water is correctly accounted for when it is traded and conducting a range of independent audits. Water audit monitoring reports and Independent Audit Group reports on cap implementation have not been published since 2011-12.

Annual, public reporting to COAG on a range of aspects of Basin Plan implementation is required, including reporting on progress of water resource plan development, status of pre-requisite policy measures, achievement of Basin Plan targets, addressing risks to water resources, and independent audits of Basin Plan implementation. Reporting on expenditure is also needed, as there is almost no information in the public domain about how the $7.9 billion has been spent, nor assessment of the cost effectiveness or return on investment in terms of the entitlements acquired.

COAG should agree to introduce professional water accounting standards and independent auditing against standards, accompanied by annual audits of expenditure of public funds and annual independent reviews of the Basin Plan's progress.

3.3 Reinstate a basin-wide river health monitoring program

The Australian Government is investing $13 billion to restore "healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean."[159] Governments owe it to the community to demonstrate that these investments are resulting in demonstrable improvements in the condition of the river systems across the Murray-Darling Basin. In 2012, the year parliament adopted the Murray-Darling Basin Plan, the Government abolished the Sustainable Rivers Audit program that was established to measure the condition of the river systems. Governments no longer have evidence of environmental condition to make informed management decisions. It is vital, therefore, that an annual Basin-wide program of condition monitoring is reinstated, based on lessons from the Sustainable Rivers Audit, to monitor the condition of the Basin's environmental assets as a whole, in addition to regular, targeted monitoring of the health of the system to ensure Basin Plan objectives are being met. There is also a need for counter-factual monitoring to assess what would have happened without environmental water for a particular year.

COAG should reinstate a basin-wide river monitoring program to measure and report regularly on the overall condition of the 23 river systems across the Basin as well as targeted programs reporting on progress towards specific Basin Plan objectives against what would have occurred without the Basin Plan.

4.4 Strengthen regulatory capacity

The Water Act 2007 established the Murray-Darling Basin Authority to prepare, implement, enforce and review an integrated plan for the Murray-Darling Basin. The Authority's key regulatory roles are in relation to advising the Minister on the accreditation of Basin State water resource plans that are consistent with the Basin Plan, ensuring accredited plans are complied with, and ensuring there is compliance with trading rules (chapter 12 of the Basin Plan). The Authority is yet to fully exercise their regulatory powers and is currently working with states to implement the Basin Plan including completing the development of water resource plans. However there is a clear need for strengthened capacity as a regulator, not only in compliance but across all aspects of Basin Plan implementation.

An independent review of compliance in the Murray-Darling Basin Authority published in November 2017 found that the "MDBA has the central leadership and coordinating role but has been unable to assert its authority during the development of water resource plans and transition to SDLs; the Australian Government Department of Agriculture and Water Resources (DAWR) and the Basin Officials Committee (BOC) also have important roles which are not being effectively discharged. The Panel notes an underlying lack of acceptance that the Water Act has fundamentally changed roles and responsibilities for management of Basin water resources: it is not business as usual."[152] A 2017 internal review of compliance conducted at the same time by the Murray-Darling Basin Authority recognised that "the MDBA should strongly assert its right to take enforcement action in cases of non-compliance in the face of inaction by states."[152]

As implementation continues, sustainable diversion limits come into effect and water resource plans proceed through accreditation, the Murray-Darling Basin Authority will need to exercise its statutory responsibility as a regulator as required in the Water Act 2007 to ensure states fulfil all obligations to implement the Basin Plan.[160] This will require building the capacity of the Authority as a regulator by, for example, through adequate resourcing and by introducing experienced regulators on the board and within the agency.

We recommend that COAG agrees to strengthen the capacity of the Murray-Darling Basin Authority to fulfil its duties as a regulator.

2. Guarantee recovery of the full 3,200 GL or genuinely equivalent outcomes

The best publicly available estimate suggests that achieving environmentally sustainable level of extractions would require the recovery of between 3,856 GL (high uncertainty) and 6,983 GL (low uncertainty) of surface water from consumptive use.[21] In 2012, the Authority's Board rejected this advice and instead put to the Australian Parliament a Basin Plan for a water recovery target of 2,750 GL by 2019, with a program to recover an additional 450 GL of water by 2024, bringing the total to 3,200 GL. The Basin Plan also allowed for a reduction in water recovery if equivalent outcomes can be achieved, and provided for an increase in groundwater extractions across the Basin by 949 GL.[23]

Proposed changes to surface and groundwater would result in increased long-term extraction volumes and reduced environmental water for river health:

- In October 2017, the Murray-Darling Basin Authority released a draft determination to increase water extraction limits by 605 GL through projects which propose to deliver equivalent environmental outcomes. Our assessment showed only one project should be approved. Eleven projects (representing in the order of 150 to 270 GL water savings) require additional information before a proper assessment can be undertaken. Twenty five projects (in the order of 316 to 436 GL) do not satisfy Basin Plan requirements.[5] See page 51 for more detail.
- Amendments to the Basin Plan tabled in the Senate on November 2017 would increase surface water extraction limits for irrigation by 70 GL in the Northern Basin and increase groundwater extraction limits by 160 GL. This would result in less water available for the environment and reduced likelihood of achieving environmental outcomes in the Basin.[161]
- Some Basin states are attempting to adjust river management rules and change computer model settings in a way that will allow larger volumes of water to be legally pumped for private use (including water that has been recovered for the environment). See page 56 for more detail.

Failure to reach the target of 3,200 GL of water or equivalent outcomes, in addition to the water available prior to the Basin Plan, carries significant risks to the river system. Modelling by the Murray-Darling Basin Authority in 2011 showed recovery of 2,400 GL "was insufficient to achieve a number of key environmental objectives for the River Murray" depriving many ecosystems including the Ramsar-listed Riverland and the Coorong, Lower Lakes and Murray Mouth from sufficient flows.[48] Under this scenario, there will be insufficient end of system flows that are important for exporting salt out of the Basin. There will also be reduced likelihood of inundation across the large majority of floodplains and wetlands that are not served by environmental works and measures.[22] Running the river system on tighter water volumes leaves less room for error and increases vulnerability to climatic and other changes. For these reasons, environmental water remains a vital and superior option to achieve Basin Plan objectives.

Three actions are necessary to ensure the 3,200 GL target is reached: (1) secure the remaining 1,093 GL or equivalent; (2) ensure environmental outcomes are equivalent; and (3) ensure water is being protected in the river and not being undermined by changes to rules, assumptions and models.

2.1 Secure the remaining 1,093 GL or equivalent

It is possible to recover the remaining water in a way that results in measurable additional flows to the river, while supporting communities likely to be adversely impacted by reforms. However, water recovered using infrastructure efficiency upgrades (e.g. lining of channels, conversion of flood irrigation to drip irrigation) may not achieve the anticipated water savings because of the reduction in return flows and groundwater recharge from existing arrangements that would have otherwise benefitted the environment.[162, 163] Impacts on return flows are not currently accounted for by the Commonwealth when investing in on-farm infrastructure upgrades. Accounting for return flows is necessary to guarantee that water savings are genuine and result in additional flows in the river system. Water recovery through purchase may also result in less water savings than expected because of the potential reduction in return flows and groundwater recharge associated with changing patterns of on-farm water use or ceasing of irrigation on a property altogether.

Recovering water through infrastructure upgrades is between two and seven times more expensive than water purchase.[39] Recovering the remaining 1,093 GL of water or equivalent through infrastructure efficiency investment may therefore exceed the available budget. A report commissioned by the New South Wales Government in 2017 estimated that the total cost of recovering 450 GL through on- and off-farm infrastructure could reach $2.4 billion, $600 million more than is available in the Special Account.[129]

A better approach is to offer irrigators capital for on-farm investment to improve farm productivity in exchange for an agreed volume of water entitlements. Projects could include activities such as netting of orchards, new or improved soil moisture monitoring networks, paddock renovation including laser grading and upgraded feedlots, provided they do not result in increased consumption of water. This approach provides farmers with greater flexibility to invest in a wide range of activities that will improve farm productivity, not just irrigation infrastructure upgrades which lock farmers into irrigation and may not deliver the anticipated water savings.

Another approach is to use strategic purchase to recover water for the environment while releasing funds for regional development. Water recovery through voluntary purchase provides farmers with several benefits: flexibility in managing impacts of drought, a pathway to retire from their land, cash flow during drought and improved on-farm water efficiencies.[77, 81] Recovering remaining water through strategic purchase requires lifting the recent 1,500 GL cap on buybacks, and reassigning 450 GL of the water already recovered through existing infrastructure programs towards the program to achieve enhanced environmental outcomes (s7.09 (e) of the Basin Plan).

COAG needs to commit to securing the remaining 1,093 GL or equivalent through a combination of strategic water purchase, water efficiency programs and on-farm productivity investment, but only where such recovery results in measurable additional water to the river system. Water recovered must also account for the reduction in runoff and groundwater recharge that would have otherwise benefitted the environment.

2.2 Ensure environmental outcomes are equivalent in any adjustment to the sustainable diversion limit

The Basin Plan includes an agreement between the Commonwealth and states to allow environmental works and measures to offset the water recovery target through projects which achieve equivalent environmental outcomes (see Chapter 7 of the Basin Plan). New South Wales, Victoria and South Australia have brought forward a package of 37 projects to be considered for a reduction under the sustainable diversion limit adjustment process. This package includes engineering works, changes in river operations, evaporative savings, and enhancements to ease or remove constraints to the delivery of environmental water. The Murray-Darling

Basin Authority has estimated the outcomes that could be achieved by this package is equivalent of up to 605 GL of environmental water.

We have compiled a set of twelve conditions that we believe any proposal submitted for sustainable diversion limit adjustment would need to comply with to meet the Basin Plan and associated requirements (Table 10). Eleven of these conditions were taken from the Basin Plan itself, as well as policies that have been adopted by the Authority. The Wentworth Group has added one further condition which is that any water savings from rules-based projects will be converted into a water entitlement (Condition 8). We believe that all twelve conditions are necessary to ensure projects are designed and operated in a way that is likely to deliver equivalent environmental outcomes.

Table 10. Recommended conditions of approval of supply measure projects proposed by state governments to ensure all projects are operated in line with the requirements of the Basin Plan and related documents.

Condition of Approval	Policy	Source
1. Works-based projects must align with Basin Plan targets.	All works-based project proposals must specify quantitative targets that contribute to outcomes set out in the Basin Plan or Basin-wide Environmental Watering Strategy.[27] The required operating practices and procedures to meet these targets must be clearly specified and consistent with modelling assumptions.	Basin-wide environmental watering strategy [27]
2. All works-based projects must be assessed using a scientifically robust method.	All works-based projects assessed using the agreed Ecological Elements scoring system developed by CSIRO[164] and independently reviewed in 2014. This is the default method specified in Schedule 6 of the Basin Plan that measures whether a project is able to produce equivalent environmental outcomes. Any adjustment must be once-off with no further push to use alternative methods or proposals that do not fall under the default method (e.g. carp herpes, fish ladders and other complementary projects) to justify future reduction in environmental water.	Basin Plan s6.05
3. Any adjustment of the sustainable diversion limit must ensure that there is no change in flow indicators.	There is no change to river flow indicators within the main channel and no more than a 10% change in flow indicators for overbank flows.	Basin Plan s6.07
4. Sustainable diversion limit must not change by more than ±5% overall.	When combined with irrigation efficiency measures, the overall net change in sustainable diversion limit is no more than ±5% across the whole Basin.	Basin Plan s7.19
5. Environmental risks must be mitigated to acceptable levels.	Risks are mitigated to acceptable levels and funded as part of the proposed project, rather than as separate supply measures justifying less environmental water. This includes risks to achieving objectives in the Basin Plan, risks to third parties, adverse water quality and salinity impacts, threats to water-dependent species and ecosystems, risk of invasive species, cumulative risks, and likely effects of climate change over the lifetime of the project.	Phase 1 Assessment Guidelines for Constraint and Supply Proposals, Overarching Evaluation Criteria #4.
6. Long-term governance arrangements must be secured.	The following conditions must be met: 1. Ownership and management responsibilities must be clearly defined and operations and maintenance must be borne by the owner; 2. Projects must be independently audited and periodically re-licenced; 3. Funding must be committed in advance for ongoing operation, risk mitigation measures, long-term monitoring and auditing; and Agreement must be secured from landholders affected by the project (e.g. by acquiring easements, upgrading roads or building bridges to enable delivery of flows), and if necessary, the existing state and Commonwealth legislation should be used to achieve constraints targets specified in the Constraints Management Strategy.[165]	Phase 1 Assessment Guidelines for Constraint and Supply Proposals, Overarching Evaluation Criteria #3.

7. Environmental water must be able to reach works projects and the broader floodplain in the future.	Proposed projects must be able to operate (1) in a natural way with all structures open during regulated and unregulated river flows, and (2) under a range of future water availability scenarios, based on an assessment of climate change impacts. The use of environmental works should not substitute for the aim of watering the broader floodplains and wetlands to achieve the outcomes in the Basin-wide Environmental Watering Strategy.	Basin-wide environmental watering strategy [27]
8. Any water savings from rules-based projects will be converted into a water entitlement	Any water savings from rules-based projects should be converted into a water entitlement. The entitlement should be issued to the environment by the proponent of the proposal that is environmentally equivalent to the claimed water savings to ensure the savings will be realised in the real world.	Recommended in a report commissioned by MDBA "Converting savings to licence entitlements is required to achieve a supply contribution" [166]
9. Projects must deliver value for money.	Projects estimated to cost more than $1,900 per megalitre should not be approved as per the *Intergovernmental Agreement on Implementing Water Reform in the Murray-Darling Basin*.	*Intergovernmental Agreement on Implementing Water Reform in the Murray-Darling Basin*, and Phase 1 Assessment Guidelines for Constraint & Supply Proposals, Overarching Evaluation Criteria #2
10. Projects must be monitored to ensure outcomes are delivered.	Careful monitoring of projects is needed to ensure the outcomes match what was expected, starting with a review of existing The Living Murray projects against their expected outcomes. If there are discrepancies that cannot be addressed by management actions, a review of sustainable diversion limits will be required.	Basin-wide environmental watering strategy [27]
11. Projects are consistent with the Constraints Management Strategy. Constraint levels as at 2012 must be used as a benchmark to compare changes.	Constraint levels at 2012 in Table 13, as described by the Murray-Darling Basin Authority,[147, 167] should be used as the benchmark as they represent flow rates that could be delivered at the commencement of the Basin Plan according to state water sharing plans and state and Commonwealth river operators. Any illegal constraints (e.g. unlicenced levees) should be removed.	Constraints Management Strategy, Phase 2 Assessment Guidelines for Supply & Constraint Measure Business Cases #3.2.2
12. Pre-requisite policies proposed by states for managing environmental water must be configured in the model used to calculate an adjustment.	Prerequisite policy measures for crediting return flows and calling environmental water from storage (s7.15 (b) (ii), including shepherding arrangements) proposed by states should be configured into the model when calculating the adjustment to the sustainable diversion limit, to avoid the risk that policies presented by Basin governments do not enable the same outcome as the benchmark model for sustainable diversion limit adjustment.	Basin Plan s7.15 (1) (ii)

The Wentworth Group has undertaken an analysis of the 37 projects against these twelve conditions.[5] For this analysis, we used information available on government websites and business cases provided by the Victorian and South Australian Governments. The New South Wales Government declined our request for business cases.

For each project, we determined whether the conditions were met, conditions were not met, further information was required, or the conditions were not applicable. On the basis of this assessment, we have identified those projects that meet all conditions and should be approved; those projects where further information is required; and those projects that should not be approved in their current form.

The results for each project are summarised in Table 11. Our assessment shows that:

1. Only one project, the *South Australian Murray Key Focus Area* meets the necessary conditions for approval. Approval of this project for adjusting the sustainable diversion limit is however, contingent on upstream constraints proposals meeting targets in the Constraints Management Strategy.

2. Eleven of the projects (representing in the order of 150-270 GL water savings) require additional information before a proper assessment can be undertaken. With such information it might be possible for some or all of the projects to satisfy the 12 conditions for approval. However, all projects would need to ensure there is no significant change in environmental flows reaching the Lower Lakes and Coorong (Condition 3).
3. Twenty five projects (representing in the order of 316-436 GL) do not satisfy these conditions and should not be approved in their current form. This includes The Living Murray works which, although they are able to be considered for a sustainable diversion limit adjustment, they are not likely to result in equivalent environmental outcomes because of the environmental risks identified.

In addition, of the six nominated constraints proposals, three were not consistent with the Constraints Management Strategy and should not be considered in the sustainable diversion limit adjustment determination (Table 11 and Table 13). Constraints measures are, however, essential to the successful implementation of the Murray-Darling Basin Plan. Constraints proposals need to be modified in line with the Constraints Management Strategy and funding should be reallocated to support the amended projects.

Table 11. Assessment of projects based on twelve conditions necessary for delivering the Basin Plan outcomes.

Project	Estimated Adjustment (GL)
1. Projects that should be approved	0
• South Australian Murray key focus area	
2. Projects requiring further information	195-340
• 2011 Snowy Water Licence Schedule 4 Amendments to River Murray Increased Flows Call Out Provisions • Computer Aided River Management (CARM) Murrumbidgee • Flexible Rates of Fall in River Levels Downstream of Hume Dam • Hume Dam airspace management and pre-release rules • Structural and operational changes at Menindee Lakes and Lower Darling key focus area • South East Flows Restoration Project • Flows for the Future • Hume to Yarrawonga key focus area • Murrumbidgee key focus area • Murray and Murrumbidgee Valley National Parks SDL Adjustment Supply Measure • Nimmie Caira Infrastructure Modifications Proposal	
3. Projects that should not be approved	271-366
• Barmah-Millewa Forest Environmental Water Allocation • Enhanced environmental water delivery (Hydro Cues) • Improved Regulation of the River Murray • SDL offsets in the Lower Murray NSW • Yarrawonga to Wakool junction key focus area • New Goulburn key focus area • Lindsay Island (Stage 2) Floodplain Management Project • Wallpolla Island Floodplain Management Project • Belsar-Yungera Floodplain Management Project • Guttrum and Benwell State Forests Floodplain Environmental Works Project • Hattah Lakes North Floodplain Management Project • Gunbower National Park Floodplain Management Project • Burra Creek Floodplain Management Proposal • Nyah Floodplain Management Project • Vinifera Floodplain Management Project • Gunbower Forest TLM Project • TLM environmental works and measures – Koondrook-Perricoota Forest Flood Enhancement proposal	

- Mulcra Island Environmental Flows TLM Project
- Lindsay Island (Stage 1) Upper Lindsay watercourse Enhancement TLM Project
- Hattah Lakes Environmental Flows TLM Project
- Chowilla Floodplain TLM Project
- Improved Flow Management Works at Murrumbidgee River – Yanco Creek Offtake
- Modernising Supply Systems for Effluent Creeks – Murrumbidgee River
- Riverine Recovery Project
- South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP)

Broadly, environmental works projects were a simplistic engineering response designed to divert water from river channels into a prescribed landscape to produce a limited suite of hydrological outcomes mainly for eucalypts. Works projects had little regard for the wide range of water requirements for river health, with inevitable risks on third parties and the environment that could reduce or cancel out their benefits. There was a lack of scientific precedent for achieving their stated benefits. The following risks were common to works projects we assessed:[168]

1. Adverse water quality impacts when water ponded on floodplains eventually returns to the channel (salt migration; anoxic blackwater; eutrophication);
2. Poorly defined project governance arrangements considering the complex planning, operational and management procedures that will involve the collaboration and cooperation of Federal and State government agencies, e.g. who will own and pay for operations and maintenance of infrastructure;
3. Private land impacts from flooding are known for five of the Victorian projects, with no comprehensive assessment of third party impacts for another two projects;
4. Increases in carp and other pest fish species are a risk for all of the projects assessed;
5. Stranding of native fish during/after watering or lack of flow cues for exit. General adverse impacts on ecological function and connectivity for aquatic species;
6. Limited protection of outer floodplain communities, like black box floodplain forests, failing a key conservation principle for representative conservation of different ecosystems;
7. Demands on water infrastructure design to operate effectively through a wide range of hydrological regimes including under climate change (even though climate change projections have not been used in their design). Associated episodic reduction in hydrodynamic diversity (e.g. lentic habitat creation, prolonged inundation of vegetation);
8. Finalisation of infrastructure design (see above point), construction and ongoing operation and maintenance cost and ownership have not been addressed in business cases. Smaller projects are likely to yield a low supply volume benefit at very high cost. Plausible supply contribution for nine Victorian environmental works and measures projects was estimated at 40-50 GL with a moderate certainty;[166]
9. Works projects may compete for available environmental water with other works projects. It is also possible that some non-works proposals could compete for water;[166] and
10. Questionable value for money in terms of the volume of water saved for many individual projects.
11. 'Complementary measures' such as carp herpes virus, fish ladders, water quality management and thermal pollution control devices are important for river restoration, however these measures should not be substituted for the recovery of environmental water.

We recommend the Murray-Darling Basin Authority adopt the conditions of approval set out in Table 10 to ensure environmental outcomes are equivalent or better, and consistent with the Basin Plan. On the basis of our assessment of projects against these conditions, we recommend that the Murray-Darling Basin Authority should:

1. **Approve the *South Australian Murray Key Focus Area* project;**
2. **For those projects that don't satisfy the necessary conditions, the proponent should be invited to demonstrate that conditions can be met prior to approval for funding and SDL adjustment; and**
3. **Projects that fail to meet the conditions should be removed from the SDL adjustment determination and should not proceed to implementation.**

In addition, of the six nominated constraints proposals, three were not consistent with the Constraints Management Strategy and should not be considered in the SDL adjustment determination. Constraints measures are, however, essential to the successful implementation of the Murray-Darling Basin Plan. Constraints proposals need to be modified in line with the Constraints Management Strategy and funding should be reallocated to support the amended projects.

2.3 Ensure water recovery is not being undermined by changes to rules, models and assumptions

The Basin Plan can only be effective if it delivers an additional 3,200 GL of water or equivalent outcomes which provide real, long-term benefits to the river system. We identified four potential risks water recovery that may undermine the Basin Plan's effectiveness:

1) Inadequate protection of environmental water;
2) Growth in water extractions, including increases in groundwater, floodplain harvesting and unregulated flows;
3) One-sided reviews of hydrological models; and
4) Rules in water resource plans that would reduce availability of water in the river system.

2.3.1 INADEQUATE PROTECTION OF ENVIRONMENTAL WATER

Environmental water is not well protected by existing water management rules and even when the Basin Plan is in place, environmental water in the river may be vulnerable to illegal extraction, reducing the overall volume of water that is available to achieve environmental outcomes in the Basin.[29] While illegal extraction of environmental water is an obvious threat, there are also many different ways in which environmental water can be taken legally with adverse consequences for the river system (Box 2).

Box 2. Types of legal take of environmental water.

- **Unregulated rivers:** Environmental water in unregulated rivers are left instream and can elevate river levels. Raised levels can trigger pumping thresholds, placing environmental flows at risk of extraction.
- **Regulated rivers:** Environmental water in regulated rivers is ordered from dams or actively delivered to achieve specific outcomes. River operators determine how much water to release by taking into account irrigation demand, environmental needs, tributary flows and predicted losses (i.e. evaporation and seepage). If operators underestimate requirements and the full amount of consumptive water is taken, the volume of unregulated flows and any environmental water in channels will be reduced.
- **Interconnected valleys and across borders:** Once environmental water leaves a valley and flows downstream (e.g. in tributaries to the Barwon-Darling), it may contribute to the unregulated pool of flows and without shepherding rules, lose its status as environmental water. These flows may be extracted by irrigators subject to entitlement conditions, or reach a dam or state/territory border where they may be allocated for other purposes (e.g. Menindee Lakes).
- **Groundwater:** Groundwater flows cannot be ordered or actively delivered, they remain in the aquifers after consumptive take and thus at risk of being extracted.
- **All systems:** Water ministers may have discretion to reverse embargos to extraction, or declare flow events available for consumption. Environmental flows are also vulnerable during critically dry periods when water plans are switched off.

It is not known how much environmental water is legally extracted, but all the examples in this Box have already taken place and, without any intervention, could happen again. Currently, both held (entitlement-based) and planned (rules-based) environmental water may be legally extracted. Planned environmental water is particularly vulnerable because volumes are difficult to account for.[169] This is despite the National Water Initiative, the Water Act 2007 and the Basin Plan all including specific provisions to protect planned environmental water.

The Barwon-Darling river system is one region where environmental water is known to be vulnerable to legal extraction. The 2012 Barwon-Darling Water Sharing Plan contains no event-by-event based protection of environmental flows. That is, environmental water from tributaries is be able to be legally taken by irrigators if they comply with specified pumping thresholds. Nine weeks before the Basin Plan was passed in 2012, the New

South Wales Government made several changes to the Barwon-Darling Water Sharing Plan to increase the volume water that can be pumped for irrigation. These include tripling the volume of water that can be extracted under some entitlements, and allowing for unlimited carryover. The Murray-Darling Basin Authority acknowledged these changes may have reduced the protection of low flows,[170] by allowing irrigators to pump larger volumes of water and take advantage of elevated water levels as a result of environmental water arriving from Queensland and rivers of northern New South Wales. It is only over the long-term where this additional diversion results in a breach of the sustainable diversion limits. These long-term diversion controls will be ineffective at protecting many flow events containing environmental water purchased, particularly low flow events.

Safeguards and permanent rules need to be in place to protect environmental watering events (both held and planned environmental water) from extraction, and ensure that increased river flows resulting from environmental water do not trigger increased diversions. Sustainable diversion limits alone do not protect environmental watering events because they are long-term average extraction limits. Permanent arrangements must also be in place to protect environmental water on an event-by-event basis, in water resource plans or via agreement between states. Options include applying conditions on water entitlements, embargoes on extractions during environmental watering events, 'shepherding' flows through valleys and over borders (where an equivalent volume of environmental water available upstream is re-allocated at a downstream location), adjusting pumping thresholds, and short-term extraction limits that restrict the volume of take over a short period of time.

When the Basin Plan was negotiated, states agreed in principle to revise their water management rules to include rules to protect environmental water in line with the Basin Plan, on the proviso that there will be no changes to the reliability of water available under entitlements.[171] This proviso provided water users with assurance that the reliability of water entitlements would not be eroded under the Basin Plan, giving certainty to investors. However, it also meant that states could be exempt from including rule changes which affect reliability (both increase and decrease). Under a narrow interpretation, the reliability clause has the potential to release states from their water resource plan obligations, including those for the protection of environmental water. For effective protection of environmental water, the Murray-Darling Basin Authority should clarify their interpretation of the reliability clause[172] when reviewing water resource plans and the onus of proof should be on states to prove there will be an impact on reliability.

COAG should ensure that:

1. **There is no net reduction in 'planned' environmental water, including spills, as required by the Water Act 2007 and Basin Plan (see Table 12 Safeguard 1 for details).**
2. **All environmental water ('planned' and 'held' under entitlement) is protected within and between valleys, including over state borders (see Table 12 Safeguard 2 for details).**

2.3.2 GROWTH IN SURFACE AND GROUNDWATER EXTRACTIONS

Plantations, runoff dams, commercial forestry, mining, coal seam gas and other activities pose significant risks to surface and groundwater reserves in the Basin. The Bureau of Meteorology estimated that the volume of runoff harvested by farm dams alone was 2,037 GL in New South Wales, South Australia and Queensland in 2015-16, or 12% of the total annual water use.[69] A 2010 report for the National Water Commission estimated that interception activities could amount to a quarter of all entitled water on issue.[173]

Basin states are required to report on the quantity of water taken from a water resource unit each water year (s71 of the *Water Act 2007*), including water taken from interception activities. However, there is little progress on estimating the water taken through interceptions.[174] Improved and up to date estimates of interception activities are required to ensure compliance with sustainable diversion limits for surface water and groundwater.

The Murray-Darling Basin Authority should also have procedures in place for identifying and managing increases in water interceptions including floodplain harvesting, growth in water use, and risks from shifting of diversions to other water sources (e.g. groundwater). These should also recognise links between groundwater and surface water, because managing surface and groundwater resources conjunctively in the future is critical. There is evidence that some water users with access to suitable quality groundwater have used it as a drought reserve, substituting groundwater for surface water in periods of reduced surface water availability.[71, 175] Rules in water resource plans are needed to manage risks to groundwater during dry periods given the increased demand and the need to preserve the productive base of groundwater (s10.20 of the Basin Plan).

Future impacts of groundwater use on surface and groundwater quality and quantity are likely to increase with growth in mining activities. For example, the New South Wales Government estimated that future demand for water in the Western Porous Rock unit will triple with the development of four proposed mines.[176,177] The Authority is now proposing to increase the sustainable diversion limits for three groundwater areas within the Murray-Darling Basin by a total of 160 GL, and make a number of changes to the way groundwater is managed under the Basin Plan. Sufficient evidence must be in place to demonstrate the capability of states to manage uncertainty and current and future risks to water resources prior to changing sustainable diversion limits.

COAG should ensure that water recovery is not being undermined by growth in extractions (see Table 12 Safeguard 3 for details).

2.3.3. POTENTIAL FOR ONE-SIDED REVIEWS

The Basin Plan enables the Murray-Darling Basin Authority to revise the sustainable diversion limits on the basis of new evidence or improved methods.[178] These reviews, however, are susceptible to bias that needs to be appropriately mitigated to ensure estimates are valid and fit for purpose. Selection bias can occur when evidence is cherry-picked rather than brought forward as part of a comprehensive assessment. As part of the Northern Basin Review in 2016, the Murray-Darling Basin identified two valleys - the Macquarie and Gwydir Rivers - as "over-recovered" because of planning assumptions which under-valued some entitlements.[179] The Murray-Darling Basin Authority stated that "revised planning assumptions in the northern Basin are likely to result in an increase of approximately 31 GL in the value of entitlements currently recovered".[179] Had similar review been conducted across all rivers of the Northern Basin, it may have found a different outcome. A submission by the Macquarie Marshes Environmental Landholder Association to the Murray-Darling Basin Authority in 2017 stated that the landholders "remain fearful that allocations can be manipulated to favour one group of water users over another."[180] The only way to overcome the risk of selection bias is by ensuring reviews are conducted in a systematic, robust and transparent way for all valleys against standards, and are subject to independent oversight.

All models used to inform decisions should be up to date and accredited against standards. There should be no change to the baselines, rules and assumptions without a systematic, independent and publicly available review (see Table 12 Safeguard 4 for details).

2.3.4 RULES IN WATER RESOURCE PLANS SHOULD NOT REDUCE AVAILABILITY OF WATER IN THE RIVER SYSTEM

The Basin Plan requires states to prepare water resource plans which comply with Basin Plan requirements in order for these plans to be adopted and accredited (Chapter 10). This may require states to make changes to existing rules in water resource plans. Some proposed changes may result in backsliding on the current level of protection of environmental water, unregulated flow and dam spills. For example, the New South Wales Environmental Defenders Office has identified the risk of backsliding on environmental water protections and compromising environmental outcomes as a result of potential rule changes being considered for the Gwydir Water Resource Plan: (1) reducing carryover from 200% to 150%, (2) changes to the '3T minimum flow rule',(3) increased flexibility for some entitlement holders, and (4) review of mandatory conditions on entitlements and approvals.[181] Potential risks have also been identified in the process of accrediting the Namoi Regulated River Water Sharing Plan where the New South Wales Government is proposing to allow for an increase in the share of supplementary water for extractive use. The current rules specify a 90:10 sharing of supplementary water access for the environment and extraction respectively, while the proposed rule is a 50:50 sharing provided there is no growth in use. Growth in use is a weak safeguard because it is difficult to quantify and can only be enforced retrospectively.

The Murray-Darling Basin Authority should produce standards for accreditation of water resource plans that are consistent with Basin Plan requirements and model assumptions. Water resource plan rules should be assessed against standards using hydrological modelling. Accreditation needs to be subject to independent and public review (see Table 12 Safeguard 5 for details).

This requires adopting the safeguards in Table 12 to ensure water recovery is not undermined by changes to state water resource plans, river management and operating rules, changes to baselines or model assumptions, and other land use changes that affect water availability in the catchments (e.g. farm dams, plantations, floodplain harvesting).

Table 12. Safeguards to ensure that any changes to state water resource plans, river management and operating rules, or changes to baselines or model assumptions do not undermine the water recovery effort.

Safeguard	Policy
1. No net reduction in 'planned' environmental water.[182]	There must be no net reduction in 'planned' environmental water as required by the Water Act 2007 and Basin Plan. COAG should agree to a definition of planned environmental water that includes dam spills and unregulated river flow. • The Authority must be satisfied the volume of planned environmental water in each valley under proposed water resource plans is equal to or greater than the volume of planned environmental water in each valley before the commencement of the Basin Plan. • The Authority should not interpret the reliability clause (section 6.14) in a way that would release states from their water resource plan obligations under the Basin Plan. Instead, the effects of any changes to plans, operating rules or baselines should be managed in a way that is consistent with the National Water Initiative Risk Assignment principles. The onus should be on states to prove there is an impact on reliability.
2. All environmental water ('planned' and 'held' under entitlement) must be protected within and between valleys, including over state borders.	Prior to accrediting a state water resource plan, the Murray-Darling Basin Authority must be satisfied that environmental water (both held and planned) can be delivered without risk of en-route extraction, and without triggering other extractions. This requires permanent arrangements in water resource plans or via agreement by Basin jurisdictions, including: 1. Embargoes on extractions during environmental flow events; 2. Flow 'shepherding' arrangements, allowing an equivalent volume of environmental water available upstream to be re-allocated at a downstream location (including within and between valleys and over borders); and 3. Short-term (e.g. daily) extraction limits, pumping thresholds and other rules that restrict the volume of take to protect environmental flow events.
3. Water recovery must not be undermined by growth in extractions.	To guarantee water recovery results in additional water in the Basin, the following must be ensured: 1. Any growth in water intercepted by farm dams, commercial plantations or water taken under a riparian right must be offset by a reduction in consumptive water use (s10.13 in the Basin Plan), requiring improved and up to date estimates of the scale and impacts of interception activities; 2. Risks to water interceptions resulting from mining activities including coal seam gas mining, and floodplain harvesting are managed to ensure they do not compromise environmental outcomes (s10.23 – 10.25); 3. Water resource plans must include rules to preserve the productive base of groundwater (s10.20); and 4. The activation of underused water entitlements (i.e. sleeper and dozer licences) is reviewed to ensure models accurately reflect expected utilisation over the life of the Plan.
4. All models used to inform decisions should be up to date	Without this policy, there is a risk of incremental changes to rules or assumptions in the flow models without appropriate scrutiny,

and accredited against standards. There should be no change to the baselines, rules and assumptions without a systematic, independent and publicly available review.	undermining the goal of recovering water for the environment. Any change to the accredited models for assessing the baseline diversion limit (MDBA Baseline Model Run 2012) and sustainable diversion limits (model not yet assessed) should therefore require independent review. This includes changes to assumptions which influence the reliability of water available under entitlements. Modelled sustainable diversion limits for that year should be compared with actual metered use to assess compliance.
5. Accreditation of water resource plans should be subject to independent and publicly available review.	This policy is aimed at reducing the risk of changes to state water resource plans that result in an increase in the quantity of unregulated flow or dam spills that can be taken for consumptive use.

3. Ensure that water recovered achieves measurable improvements to the river system

Once environmental water is allocated in a river system, it is essential that is then able to reach the target location to achieve the desired outcomes. This review has identified four risks that could prevent the delivery of flows to the target location: (1) physical constraints and policy actions which impede the delivery of water to floodplains and wetlands; (2) challenges of providing sufficient flows to the Coorong, Lower Lakes and Murray Mouth; (3) the risk that environmental water outcomes are omitted from regional watering plans and (4) risks of water theft and inadequate compliance. We discuss the first three risks in this section and the fourth risk in the section on page 47.

3.1 Constraints to the delivery of flows

Flow constraints are physical barriers or policy actions which impede the delivery of water to floodplains and wetlands. They are among the most frequently cited challenges affecting the delivery of environmental water under the Basin Plan to date. They included operational constraints,[94, 117, 118] channel capacity constraints,[183] access to irrigation pumps,[184] crop harvesting, [94, 185] maintenance work,[103, 117] even a water skiing event,[183] cod fishing,[184] and other third party impacts.[113] Key constraint areas identified by the Murray-Darling Basin Authority were on the upper Murray River from Hume to Yarrawonga, mid-Murray River from Yarrawonga to Wakool Junction, Goulburn River, Murrumbidgee River, Lower Darling River, Gwydir River and on the lower Murray in South Australia.[165] These constraints are preventing environmental water from passing across low-lying areas next to watercourses and in designated floodways below minor flood levels.

In 2012, the Commonwealth Government committed $200 million to address physical, institutional and operational constraints over ten years from 2014/15.[186] A key focus of the Murray-Darling Basin Authority's Constraints Management Strategy in 2013 was addressing the constraints to the delivery of overbank flows into South Australia, and allowing environmental watering of floodplain wetlands in the mid-Murrumbidgee and the lower Goulburn River at higher flow rates than were achievable in 2012.

Modelling by the Murray-Darling Basin Authority in 2012 showed that a flow of 80,000 ML/d into South Australia was needed to provide sufficient water to enable 75% of wetlands and flood dependent vegetation in South Australia to be inundated, compared to just 40% with the river system constraints possible in 2012 (Figure 31).[167] This target is necessary to allow environmental water to reach the floodplain forests, maintain connection between the river and the floodplain (Basin Plan s5.02) and achieve better outcomes with the water available. On the basis of the modelling, the Murray-Darling Basin Authority identified the flow targets for each key constraint area, which reflected the minimum flow rates required to achieve outcomes in the Basin-wide Environmental Watering Strategy[27] and in Schedule 5 of the Basin Plan.

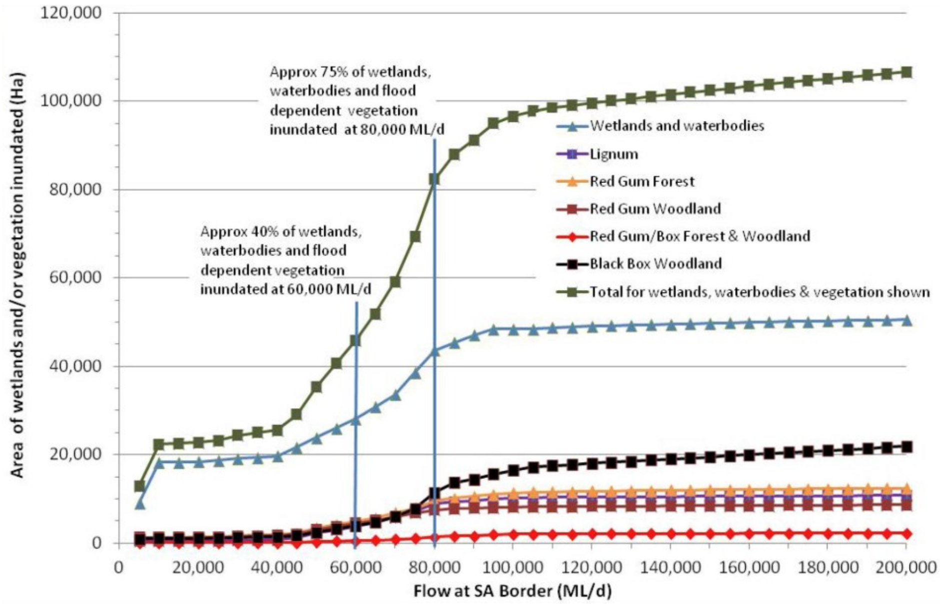

Figure 31. Relationship between inundation of wetlands and flood-dependent vegetation and flow at the South Australian border (Source: MDBA 2012)

In mid-2017, Basin states put forward projects which would alleviate constraints identified in the key constraint areas. Table 13 shows the major constraints existing in 2012, the level of constraint relaxation required by the Constraints Management Strategy, and the constraint levels achieved by the measures proposed by Basin states.

The level of constraint relaxation being proposed by Victoria and New South Wales (Table 13) is not sufficient to achieve the aims of the Constraint Management Strategy or the enhanced environmental outcomes in Schedule 5 of the Basin Plan. In some cases the proposed constraint levels represent a return to what could be delivered prior to the Basin Plan, reflecting the fact that constraints in these areas have worsened since the Basin Plan came into effect in 2012.

Of the six nominated constraints proposals submitted for assessment under the sustainable diversion limit adjustment mechanism, only three were found to be consistent with the Constraints Management Strategy. Constraints proposals that do meet the targets should not be considered in the adjustment determination. These measures are, however, essential to the successful implementation of the Murray-Darling Basin Plan. Constraints proposals need to be modified in line with the Constraints Management Strategy and funding should be reallocated to support the amended projects.

Without addressing the identified constraints, it will be difficult for environmental water holders to deliver water to key floodplains and wetlands in the southern connected system to achieve the Basin Plan objectives. If constraints are not relaxed to allow higher flow levels than could be delivered in 2012, there is a risk that environmental water holder will not be able to deliver overbank flows and will have to use their environmental water at low flow rates inside the river channel all year round. This will deprive, for example, 35,000 ha of floodplain wetlands in South Australia from receiving environmental water and compromise the Basin Plan outcome of “healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean.”[159, 165]

Table 13. Physical constraints that must be addressed to permit delivery of water to floodplains and wetlands in the southern Murray-Darling Basin. Constraints highlighted in red are those projects proposed by states that will fail to meet the Murray-Darling Basin Authority's target in the Constraints Management Strategy.

Region	**Location**	**PRE-BASIN PLAN: Constraint in 2012[165] (ML/d)**	**TARGET: Target in MDBA Constraints Management Strategy (ML/d)**	**PROPOSED BY STATES: Constraint in business case[187] (ML/d)**
Murray	Hume to Yarrawonga	25,000	40,000	40,000
	Downstream of Yarrawonga	40,000 (but effectively 22,000* due to upstream constraint of 25,000)	40,000 (50,000 for reaching disconnected wetlands and ephemeral creeks)[188]	30,000
Darling	Weir 32/Increase Menindee outlet capacity	9,300	18,000	14,000
	Darling anabranch	Water flows into anabranch over 9,300ML/d	Regulator added & closed above 9,300ML/d when env. water is supplied from Menindee	n/a
Murrumbidgee	Gundagai	30,000	50,000	40,000 at Wagga (~30,000 at Gundagai)
	Balranald	9,000	13,000	9,000
Goulburn	Seymour	12,000	15,000	n/a
	McCoys Bridge	20,000	40,000	20,000***
Total flow at SA border		66,000**(assuming 26,000 from Goulburn)	111,000** assuming Menindee allowed 18,000	78,000**

*10,600 ML/d in regulated periods in summer and in other periods Hume to Yarrawonga constraint of 25,000 ML/d was in place meaning that flows downstream of Yarrawonga were effectively restricted to 22,000 ML/d.
**This number assumes perfect co-ordination of flows between the Murray and tributary flows, something which is highly unlikely. The 111,000 ML/d target is most likely to achieve the outcomes in schedule 5 of the Basin Plan.
***Target was revised down from the 25,000 ML/d to 20,000 ML/d in 2017 by the Victorian Government.[189]

The current 'good neighbour policy'[190] (where environmental water holders seek landholder approval for the passage of environmental flows on private property) is desirable but it cannot guarantee the passage of critical flows for the environment. Permanent solutions are required, including acquiring rights to inundate floodplain land through covenants and easements to compensate landholders for any reduction in land value , while enabling landholders to use their lands for flood resilient activities, such as grazing and timber production.

Once all reasonable options are exhausted, existing state and Commonwealth legislation or new legislation should be used, either by compulsory acquisition of easements, or by upgrading roads and building bridges – as would occur with any other public infrastructure program.

Constraints (physical and policy) that restrict the use or passage of environmental water to target floodplains and wetlands need to be removed to achieve targets in the Constraint Management Strategy (Table 13). This requires re-configuring infrastructure, negotiating flood easements with landholders, enforcing planning restrictions in designated floodways, and where appropriate compensating for any third party impacts.

3.2 Providing sufficient flows to the Lower Lakes, Coorong and the Murray mouth

3.2.1. AN OPEN MURRAY MOUTH

Analysis by the Wentworth Group with the assistance of experts in the South Australian Department of Environment and Natural Resources showed that the commitment made by Parliament in 2012 that the Basin Plan would ensure "the mouth of the River Murray is open without the need for dredging in at least 95% of years, with flows every year through the Murray Mouth Barrages" is, beyond reasonable doubt, impossible. We estimate that the mouth will remain closed in 9 of every 10 years without intervention. This has implications for the ability to export salt into the ocean. It also means less tidal exchanges to support the health of the Coorong and comply with Australia's international obligations under the Ramsar Convention.

Since at least 2002, dredging has been needed to keep the Murray mouth open except during major flood events, as occurred in 2010/11 and 2016/17. The reason for the discrepancy between the Basin Plan objective and observations is that the modelling underpinning the Basin Plan did not incorporate information related to marine processes affecting the Murray Mouth. Consequently, the percentage of time the Murray Mouth will close was grossly underestimated. The only way to maintain an open Murray mouth is additional environmental flows, permanent dredging, and/or some other longer-term large scale physical re-structuring of the entrances to the Coorong and Lower Lakes.

3.2.2. LAKE LEVELS AND BARRAGE FLOWS

Water must be delivered to the Lower Lakes in sufficient volumes to continue to achieve the Basin Plan targets for water levels above 0m AHD and within the range of 0.4m to 0.75m AHD in 95% of years. These targets have been met over the last 7 years and need to be maintained during prolonged dry periods to minimise the risk of acidification of Lower Lakes.

If we accept the proposition that rivers die from the bottom up, then it is necessary for the River Murray at Wellington to convey sufficient water into Lake Alexandrina on a near-continuous basis. If less than 2 GL/day is discharged into the Lake over a protracted period of time, as was the case in the Millennium drought, then evaporation and other losses will lead to lake water levels falling below the MDBA targets, and deteriorating water quality in the Lower Lakes and Coorong estuary.

At least 2 GL/day (about 700 GL/yr long term average) is required to offset net losses to maintain water levels within the target range for the Lower Lakes, but this provides for no barrage or fishway releases to the Coorong and Southern Ocean. To achieve minimum desired outflows at the barrages into the Coorong a higher inflow is needed, in the order of 4 GL/day at Wellington. When higher barrage flows supported by unregulated flow or environmental water delivery are not possible, near-continuous barrage releases in the order of 2 GL/day assists in maintaining estuary conditions in the Coorong and with maintaining an open Murray mouth (Andrew Beal, *pers. comm*., Director, River Operations, DEWNR).

The Basin Plan does not specify minimum flow requirements for the Lower Lakes, so delivering minimum flow requirements to the Lower Lakes should be a key priority of water holders during drought periods to avoid lake levels dropping below 0m AHD and triggering a repeat of the environmental crisis of the millennium drought. It is also critical that constraints in the Lower Darling and River Murray are addressed in line with the Constraints Management Strategy, to allow water holders to take advantage of greater storage capacity in New South Wales and Victoria as a way to improve flow reliability to the Lower Lakes.

A further consideration is ecological requirements of the Ramsar wetlands. Stewardson and Guarino (2016) concluded that "the current management regime appears to prioritise high lake water levels over maintenance of flows to the Coorong and Murray mouth."[3] The operation of barrages needs to be adjusted so that flushing into Coorong occurs at times to best meet ecological requirements of the Ramsar wetlands.

3.2.3. LONG-TERM MANAGEMENT

The Basin Plan contains a number of other objectives for the end of the system, including water quality and salinity targets. Some of these are not yet met and require a review of management practices to ensure the end of the system can be maintained as a healthy, functioning (Ramsar listed) estuary and allow the export of salt accumulating in the river. There are other issues that need to be addressed in future reviews, particularly the long-term impacts of sea level rise affecting the import of sand into the Murray mouth and seepage of sea water through the barrages and into the lakes.

1. Sufficient water flows are required to export two million tonnes of salt over the barrages per year on average. The Murray-Darling Basin Authority's modelling showed that 3,200 GL of water recovery in the Basin will achieve this objective, while water recovery of 2,400 GL and 2,800 GL was likely to be insufficient to meet this objective.[147] It is unlikely that the salt export objective will be met under the current level of water recovery (2,107 GL) or the levels proposed by the Murray-Darling Basin Authority following the proposed adjustment of the sustainable diversion limits.
2. Current dredging operations involves the disposal of sand from the Murray mouth channel into discharge locations on either side of the mouth. This sand is available for redistribution back into the mouth during periods of relatively low barrage flow. Dredge spoils will need to be relocated to sites where coastal processes are unable to return the sand back to the mouth.
3. Adverse impacts of climate change on water availability in the Murray-Darling Basin along with potential impacts of sea level rise will have implications for management of the Lower Lakes, Murray mouth, Coorong and barrage operations.

Governments need to ensure sufficient water reaches the Lower Lakes, Coorong and Murray Mouth to export salt from the Basin, reduce water quality risks, and deliver freshwater to maintain the ecological character of the Ramsar wetlands. This requires:

1. **Sufficient inflows into the Lower Lakes during dry periods to meet water level targets and reduce the water quality risks.**
2. **Management of upstream constraints in line with the Constraints Management Strategy to allow for flows of sufficient volume and timing to reach the end of the system.**
3. **Agreement should be reached by responsible government agencies on priorities for the Lower Lakes, Coorong and Murray mouth, taking into consideration the need to protect the Coorong Ramsar site and export salt through the mouth.**
4. **Assurance from the Murray-Darling Basin Authority that the objective for salt export will be achieved following adjustment to the sustainable diversion limits.**
5. **An ongoing dredging program because of the power of the sea to bring sand into the mouth.**
6. **Review of the placement of dredge spoil to reduce the return of sand to the Murray mouth.**
7. **Adaptation strategies to cope with adverse impacts of long-term changes in climate including water availability and sea level rise on the Lower Lakes and Coorong.**

3.3 Ensuring environmental targets are implemented at the catchment scale to achieve objectives

When preparing long-term watering plans for each valley, section 8.20 (2) of the Basin Plan requires states to have regard to the Basin-wide environmental watering strategy that was prepared by the Murray-Darling Basin Authority in 2014 with quantified targets at the Basin scale. These targets need to be clearly integrated into long-term watering plans so they can be implemented and monitored at the catchment level. For example, the Basin-wide targets for forests and woodlands are to maintain the current extent of forest and woodland vegetation at 360,000 ha of river red gum, 409,000 ha of black box and 310,000 ha of coolibah. These are specified for regions in the Basin (Table 14).[27] Once aligned, achievement of targets at the catchment level should result in achievement of targets at the Basin scale. These targets need to be incorporated into regional plans as part of the water resource plan accreditation process.

The solution is to align the Basin Plan targets, the Basin-wide environmental watering strategy, and water resource plans, at the catchment level as part of the accreditation process. Environmental flows recovered under the Basin Plan should be used to achieve the ecological outcomes specified.

Table 14. The Murray-Darling Basin Authority's estimate of expected extent outcomes for communities of water-dependent vegetation as a result of the Basin Plan.[27]

Basin region	Outcomes for water-dependent vegetation	Area of river red gum (ha)*	Area of black box (ha)*	Area of coolibah (ha)*	Shrublands	Non–woody water-dependent vegetation
Paroo	Maintain extent and condition of water-dependent vegetation near river channels and on the floodplain	2,300	38,300	22,800		Closely fringing or occurring within the Paroo River
Warrego	Maintain extent and condition of water-dependent vegetation near river channels and on the floodplain	7,300	80,400	121,400		Closely fringing or occurring within the Warrego, Langlo, Ward & Nive rivers
Nebine	Maintain extent and condition of water-dependent vegetation near river channels and on the floodplain	200	28,800	15,400		Closely fringing or occurring within the Nebine Creek
Condamine–Balonne	Maintain extent and condition of water-dependent vegetation near river channels and on areas of the floodplain	11,500	36,100	62,900	Lignum in Narran Lakes	Closely fringing or occurring within the Condamine, Balonne, Birrie, Bokhara, Culgoa, Maranoa, Merivale & Narran rivers
Moonie	Maintain extent and condition of water-dependent vegetation near river channels and on the floodplain	2,200	2,500	7,900		Closely fringing or occurring within the Moonie River
Border Rivers	Maintain extent and condition of water-dependent vegetation near river channels and on areas of the floodplain	10,700	3,800	35,200	Lignum in the lower Border rivers region	Closely fringing or occurring within the Barwon, Dumaresq, Macintyre rivers & Macintyre Brook
Gwydir	Maintain extent and condition of water-dependent vegetation near river channels and on low-lying areas of the floodplain.	4,500**	600	6,500	Lignum in the Lower Gwydir	Closely fringing or occurring within the Gwydir River and marsh club-rush and water couch in the Gwydir Wetlands
Namoi	Maintain extent and condition of water-dependent vegetation near river channels.	6,100	800	4,200		Closely fringing or occurring within the Namoi River
Macquarie–Castlereagh	Maintain extent and condition of water-dependent vegetation near river channels and on low-lying areas of the floodplain	58,200	57,100	32,200	Lignum in the Macquarie Marshes	Closely fringing or occurring within the Bogan, Castlereagh, Macquarie and Talbragar rivers; and common reed, cumbungi and water couch in the Macquarie Marshes
Barwon–Darling	Maintain extent and condition of water-dependent vegetation near river channels and on low-lying areas of the floodplain	7,800**	11,700	14,900		Closely fringing or occurring within the Darling River

Lachlan	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition of black box and river red gum	41,300	58,000		Lignum in the Lower Lachlan	Closely fringing or occurring within the Lachlan River and Willandra Creek; and common reed and Cumbungi in the Great Cumbung Swamp
Murrum-bidgee	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition of black box and river red gum	68,300	38,900		Lignum in the Lower Murrumbidgee	Closely fringing or occurring within the Murrumbidgee River, Billabong and Yanco creeks
Lower Darling	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition of black box and river red gum	10,300	38,600	600	Lignum swamps in the Lower Darling region	Closely fringing or occurring within the Darling River, Great Darling Anabranch and Talyawalka Anabranch
Ovens	Maintain extent and condition water-dependent vegetation near river channels and on the floodplain	10,200	<100			Closely fringing or occurring within the Ovens River
Goulburn–Broken	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition of black box and river red gum	19,800	500			Closely fringing or occurring within the Broken Creek, Broken and Goulburn rivers
Campaspe	Maintain extent and condition of water-dependent vegetation near river channels	1,900	<100			Closely fringing or occurring within the Campaspe River
Loddon	Maintain extent and condition of water-dependent vegetation near river channels	2,200	700			Closely fringing or occurring within the Loddon River
Murray	Maintain extent of water-dependent vegetation near river channels and on low-lying areas of the floodplain. Improve condition of black box and river red gum.	90,600	41,700		Lignum along the Murray River the Wakool River to downstream of Lock 3	Closely fringing or occurring within the Murray, Edward, Kiewa, Mitta Mitta, Niemur and Wakool rivers and Tuppal Creek; *Ruppia tuberosa* in the Coorong and Moira grasslands in the Barmah– Millewa Forest
Wimmera–Avoca	Maintain extent of water-dependent vegetation near river channels. Improve condition of black box and river red gum.	6,500	3,100			Closely fringing or occurring within the Avoca, Avon, Richardson and Wimmera rivers
Eastern Mt Lofty Ranges	Maintain extent and condition of water-dependent vegetation near river channels	<100	<100			

4. A regional development package that puts communities at the centre of reform

National water reforms since 2004 have brought a range of direct and indirect benefits to the irrigation industry, however some communities have been adversely affected and there is inadequate support for regional communities most affected by water reform. Impacts of water reform have compounded long-term changes in social and economic structure of some regional communities as a result of influences such as drought and mechanisation of agriculture. Impacts of water recovery are more acute for those communities with greater dependence on irrigated agriculture and less diversified economies.[91]

Water reforms have failed to provide adequate support for communities most adversely impacted by the Basin Plan. Under the current reforms, only those with water to sell will receive financial compensation, and only irrigators will benefit from infrastructure improvements. Less than one per cent of the $13 billion has been made available to assist communities to adapt to a future with less water. Well-coordinated irrigation groups have used this failure to lobby governments to halt water recovery, at the expense of Basin communities and river health.

Different solutions will be required in different locations. Community representatives are best placed to advise governments on the support that is required. Commonwealth and state governments need to work directly with all relevant community leaders, local governments, regional development boards and natural resource management agencies in an equitable and transparent way to implement the Basin Plan in the best interest of the community as a whole. With just $500 million, or 10% of the remaining $5.1 billion, it is possible to implement the Basin Plan in full while delivering a regional development package to assist communities to manage the necessary transition.

Successful water reform requires supporting communities likely to be adversely affected by water reforms by investing in social and productive capital that assists these communities to adapt to a future with less water.[191] Solutions for regional development can include restructuring industries as a whole, providing specific assistance to individual businesses, assisting with the labour market, and investing in new economic opportunities.[192] A regional development package could also include investment in other non-water infrastructure (e.g. internet, education, transport) to support new economic opportunities, decentralisation of public services, and a regional development fund from which community groups can bid for projects. In addition to the direct economic benefits, these initiatives can also improve the resilience of communities to adapt to changing conditions such as market volatility, climate change and demographic change.

A regional development package could build upon work already underway in the Basin. For example, in 2015 the Regional Australia Institute and the Namoi Joint Organisation of Councils identified the drivers shaping the future of the region over the next 10 to 15 years.[193] Six factors were identified that were likely to have the greatest influence on the future of the Namoi region: national and global cycles in commodity markets; maximising innovation in agricultural production; seeking international investment, on the right terms; engaging the Namoi in major overseas markets; urbanisation; and leveraging regional/brand marketing to attract people to live and work in the Namoi.

In 2016, a statutory advisory committee to the Murray-Darling Basin Authority consisting of community representatives from the northern Basin put forward four priority areas for structural adjustment. They recommended:

- supporting individuals to reskill, relocate and find employment;
- assisting businesses to build capacity and diversify;
- providing low interest loans to assist restructuring and adaptation; and
- developing exit strategies and covering relocation costs.

Such models could be the basis for a regional development program and replicated more widely throughout the Murray-Darling Basin where reform is needed for triple bottom line outcomes.

The solution is for COAG to agree to a regional development package that puts communities at the centre of reform, by:

- **Assisting communities most affected by water recovery to restructure their economies to adapt to a future with less water. Assigning for example, 10% of the remaining $5.1 billion would release up to $500 million for regional development initiatives.**
- **Linking public funding directly to the Basin Plan, by the Commonwealth working directly with community leaders, local government, regional development boards and natural resource management agencies to recover water in a manner that optimises regional development opportunities for those communities.**

5. Prepare for the prospect of a future with less water.

Global demand for food, energy and resources is predicted to rise in the 21st century and the Murray-Darling Basin's industries can benefit significantly. The world will need to increase food production by 70 percent compared to 2007 levels if it is to feed the 9.1 billion people projected by 2050.[194] Almost half of this demand will come from China's rising middle class and their demand for high quality agriculture and food products.[195] As a global leader in water management, Australia is well placed to harness the demand and build global capacity for food, energy and water security. In a world of increasing resource constraints, the challenge for Australia is to produce more food with less land and less water. This requires (1) an improved understanding of potential future stresses on water resources such changes in rainfall and runoff induced by climate change, (2) integrated management of land and water resources, (3) investment in knowledge and capacity for sustainable agriculture, and (4) a reinvigorated national water reform agenda.

5.1 Improve scientific understanding of potential future stresses

Australia is the driest inhabited continent and flows in the Murray-Darling Basin are among the most variable in the world. Climate change will compound existing pressures on water resources, with significant shifts in temperature and precipitation predicted across the Basin by 2030. The Basin Plan does not directly address the risks of climate change on water availability and river health,[51, 196] and there is no information on the effectiveness of the Plan to cope with long dry periods such as that experienced throughout the Basin during 1997 to 2009. This leaves business and communities with no clear policy setting or process to manage the anticipated changes in water availability into the future. It also places ecosystems across the Basin at risk. As part of upcoming reviews of the Basin Plan there is an obligation for government to consider the "management of climate change risks and include an up-to-date assessment of those risks" (s6.06 (3)). There is much groundwork to do in improving scientific understanding of potential stresses, in preparation for incorporating climate change into the Basin Plan in the future.

5.1.1 LONG-TERM IMPACTS OF CLIMATE CHANGE

The Wentworth Group commissioned an assessment of the best available science into how climate change is affecting and likely to affect the health of the Murray-Darling Basin in the future (see Appendix 4). We reviewed the implications of climate change in the Basin using CSIRO's latest climate change projections, and assessed the continuing relevance of the detailed hydrological climate change projections for the Basin provided by Murray-Darling Basin Sustainable Yields project in 2008.[197] The wet and dry extreme climate scenarios used in the 2008 Sustainable Yields were assessed as still valid and representative given latest science, and thus the consequent hydrological scenarios are similarly still valid and representative. However, we note that latest climate modelling results suggest that the probability of the dry scenario may have declined slightly.

The Basin has warmed by nearly 1 degree on average since 1910 and temperatures are projected to increase by another 0.6 to 1.5 degrees Celsius by 2030 relative to 1995 and by between another one to two (0.9 to 1.9) degrees Celsius by 2050 without mitigation (Figure 32).[198] There is medium confidence that more time will be spent in drought across the Basin in the future, as defined in terms of rainfall deficits. The changes largely follow the projected changes to mean rainfall which could increase or decrease, but a decrease is more likely.

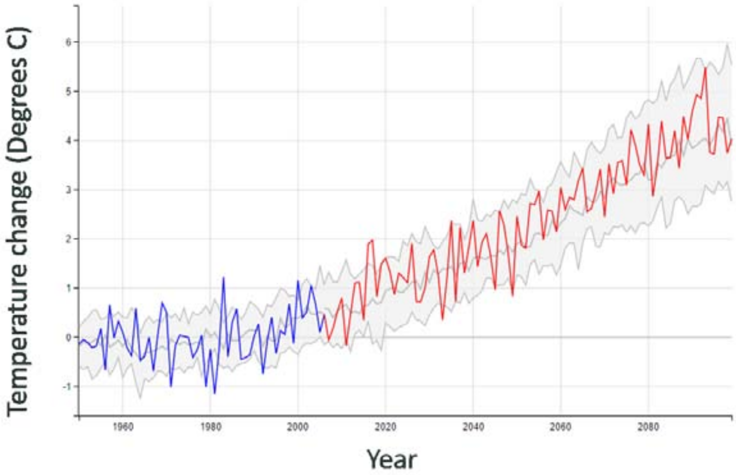

Figure 32. Example of model simulated historical (blue) and projected (red) annual temperature (in Celsius) for Murray Basin region from a single global climate model (ACCESS-3 model, RCP8.5). Grey envelope indicates results from multiple models. Projected warmings in the text are based on multiple climate models. Source: Time Series Explorer, Climate Change in Australia.[199]

Annual average rainfall in the southern Basin is expected to change by between -11% and +5% by 2030 from 1995 levels while rainfall in the northern Basin is projected to change by -13% to +8%.[199] By 2050, these ranges are around -17% to +8% and -16% to +11%. An example of how a rainfall decline could unfold in a drying model is illustrated in the results for one model in Figure 33.

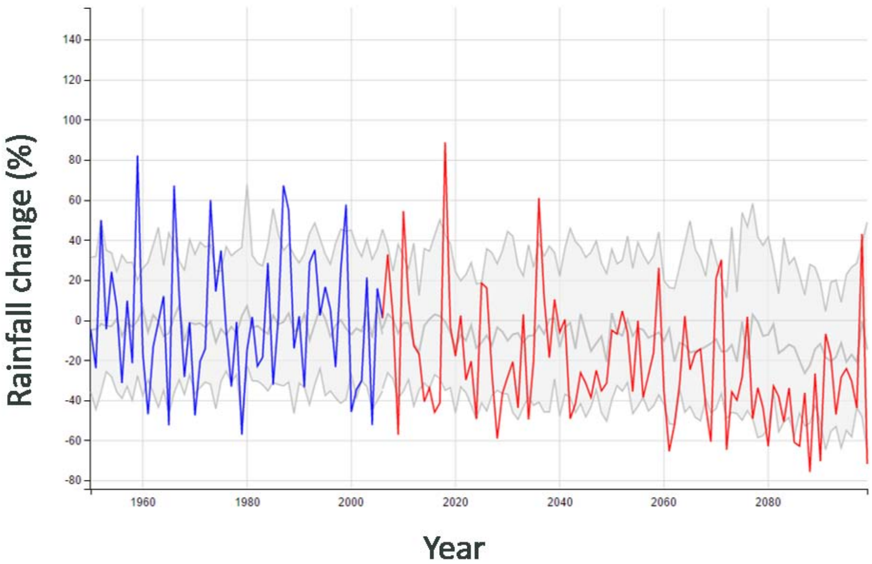

Figure 33. Example of modelled historical (blue) and projected (red) winter precipitation anomaly (in %) for the southern Basin region from a single global climate model (GFDL-ESM2M model, RCP8.5). Grey envelope indicates results from multiple models. Source: Time Series Explorer, Climate Change in Australia.[199]

Any reduction in precipitation is likely to have significant impacts on water flows in rivers (Figure 34), in some cases driving a threefold reduction in runoff.[200, 201] For example, a 10% decline in rainfall could result in a 30% reduction in streamflow. Averaged across the Basin, annual average runoff is predicted to decline by 33% in the dry scenario and increase by 16% in the wet scenario by 2030.[197] Changes to runoff in the southernmost catchments are around -40% to little change, and between -30% and +30% in the northern catchments. The dry scenario reduces flow more strongly in winter, and the wet scenario increases flows more strongly in summer. Modelled impact on water supply for Victoria, which used the latest climate models, show runoff reductions which are somewhat less weighted to decreased runoff,[202] whilst still broadly consistent with the reductions in runoff modelled in CSIRO's Sustainable Yields in 2008.

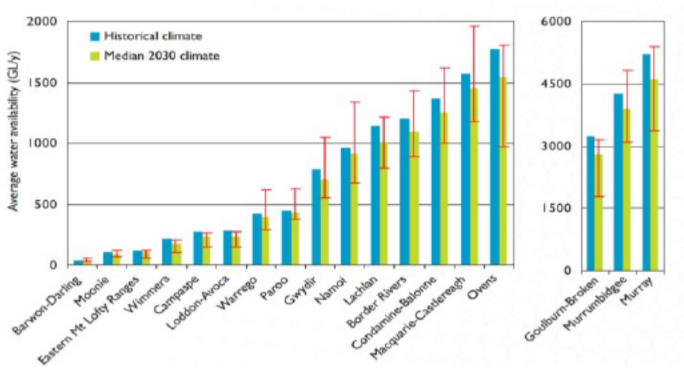

Figure 34. Average surface water availability in GL/yr for regions in the Murray-Darling Basin. Historical and median future climate for 2030 shown in bars, and the wet and dry scenarios by the red bar. Source: Reproduced from CSIRO.[197]

Extreme daily rainfall is very likely to increase in magnitude, and with it the risk of increased flooding and erosion. Projected warming is also associated with increased potential evapotranspiration, increased bushfires and reduced soil moisture across the Basin.[198] Higher temperatures lead to less precipitation likely to fall as snow, and faster snow melt,[203] resulting in changes to the seasonality of river flows. Water-dependent species with narrow ranges of environmental tolerances are most likely to be disadvantaged, and this would be exacerbated in wetland systems as connectivity between freshwater habitats is reduced.

Using a climate analogue approach to describe how these changes may affect the Murray-Darling Basin, generally speaking, sites 'move' inland/northwest under the hottest/driest scenario and north/northeast in the coolest/wettest scenario. The climate analogues for range of selected sites in the Murray-Darling Basin are listed in Table 15 and mapped in Figure 35. In 2050 under the highest emission scenario, climate analogues may be many hundreds of kilometres away in areas of differing agricultural production and sometimes outside the Basin.

In summary, the Murray–Darling Basin has already experienced changes in temperature and rainfall, and is vulnerable to future climate changes, especially in the southern catchments. A priority in future Basin planning should be preparing the Basin for future droughts and other climate change impacts.

Table 15. Climate analogue sites for nine locations in the Basin under the climate scenarios indicated. Temperature and precipitation changes indicated for each MB (Murray Basin) and CS (Central Slopes). Source: Climate Analogues Explorer, Climate Change in Australia website.[199]

	Hottest and driest 2030 RCP4.5* MB, +1.1 C, -7% CS +1.1 C, -9%	Coolest and wettest 2030 RCP4.5* MB, +0.9 C, 0% CS. +0.9 C, 10%	Hottest and driest 2050 RCP8.5* MB, +2.1 C, -21% CS, +2.5 C, – 20%	Coolest and wettest 2050 RCP8.5* MB, +1.3 C, 8% CS +2.0 C, 7%
Bendigo	Kyabram	Corowa	Griffith Leeton	Wagga Wagga, Cootamundra
Griffith	Hay, Balranald	Cobar	Ivanhoe	Condobolin
Wagga Wagga	West Wyalong, Condobolin	Parkes Forbes	Griffith, Cobar	Dubbo, Parkes
Forbes	Condobolin	Gilgandra	Nyngan, Cobar	Gunnedah, Scone
Renmark	Port Augusta	Menindee	Leigh Creek	Menindee
Dubbo	Coonamble	Gunnedah	Nyngan Lightning Ridge	Narrabri Moree

Goondiwindi	Roma	Gayndah	Tambo	Collinsville
St George	Charleville	Taroom	Barcaldine	Charters towers Emerald
Moree	Roma St George	Goondiwindi.	Tambo Charleville	Gayndah

**The RCPs comprise: RCP8.5 (high emissions and thus greatest impact on the climate), RCP4.5 and RCP6.0 (intermediate emissions and climate impact) and RCP2.6 (low emissions and least climate impact).[204] The RCP8.5 future involves little reduction to current emission patterns, whereas at the other extreme, RCP2.6 represents a very ambitious program where emissions peak by 2020 and decline rapidly after that to eventually less than zero. See further discussion in CSIRO & BoM.[198] Results presented here are primarily for RCP4.5 and RCP8.5.*

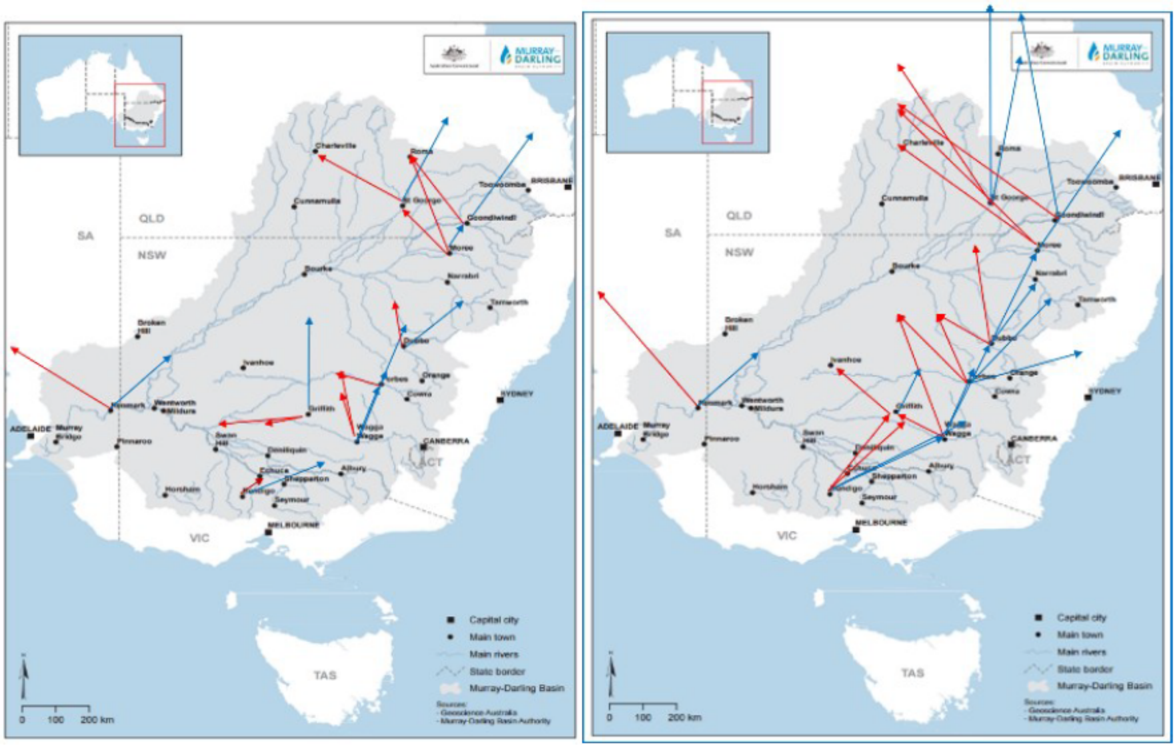

Figure 35. Map depiction of the climate analogues. Left panel 2030 and right panel 2050. Red arrows show the hottest and driest case, and blue arrows show the coolest and wettest case.

5.1.2 INCORPORATING CLIMATE CHANGE INTO THE BASIN PLAN

When the Basin Plan was adopted, the Murray-Darling Basin Authority accepted the climate change risk sharing that is embedded in existing State water resource plans, in order to preserve the reliability of entitlements.[205] Under this approach, water entitlement holders are better protected from any reduction in water availability due to climate change than non-entitlement users.

The environment bears a greater burden of reduced flows under climate change. As water becomes scarcer in the Basin, environmental water is reduced by about four times as much as reductions in surface water extractions by irrigators.[206] This is illustrated in the Murrumbidgee River during the last drought where water sharing rules resulted in negligible outflows into the River Murray between 1994 and 2005 while irrigation diversions remained above 1,500 GL (Figure 36). Planned environmental water is particularly vulnerable because it is not well protected and consists of 70-80% of the water available. CSIRO (2008) concluded “this policy represents a significant risk to the environment”.[207]

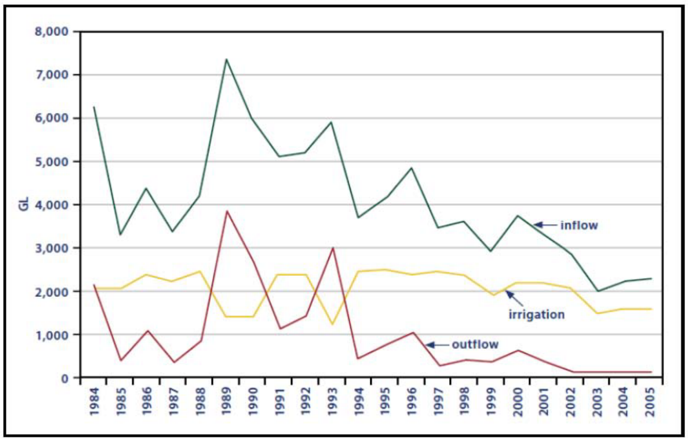

Figure 36. Murrumbidgee River inflow, outflow and water used for irrigation from 1984 – 2005.[208]

There is a need to re-assess management of water resources in light of the impact of climate change on water availability (see page 68). In 2016, the Victorian Government published guidelines for assessing the impact of climate change on groundwater resources, drought and operational planning, alternative water supply projects and demand projections.[202] The guidelines present four climate change scenarios in a risk based framework that considers the vulnerability of supply systems to climate variability and climate change. The report recommended "water corporations must assess the impact of climate change when developing long-term projections of water availability".

A robust way to rebalance the climate change risk is to periodically re-assess sustainable diversion limits under climate change projections and use the results as the basis for new sharing arrangements.[205] This approach enables environmental objectives and targets to be assessed within the envelope of projected water availability. A first step is to select the appropriate climate scenarios and prepare future flow projections. New modelling may be required as CSIRO Sustainable Yields projections do not extend beyond 2030.

5.1.3 DEVELOPING AN ADAPTATION FRAMEWORK

Governments need a framework to address long-term issues associated with climate change in the Murray-Darling Basin, including consideration of the impacts of sea level rise on the Murray mouth and barrages. A climate change adaptation framework would bring together communities and experts to agree on values to be conserved in the future (social, economic and environmental), identify thresholds for conserving these values, and determine triggers for changes in strategy.

Scenario planning is useful for 'stress testing' the Basin Plan in climate extremes, and addressing opportunities and risks under different futures. Scenario planning can also assist with understanding the necessary decisions, the lifetimes and flexibility of these decisions, and optimising short and long-term outcomes.[209]

A wide range of adaptation measures should be considered, including options that sit beyond the water sector. Tools such as the Climate Assessment Framework can be used to identify low risk adaptation measures, and adaptation pathways under different scenarios of future change. The adaptation potential of all management activities should be evaluated over the appropriate time scales. For example, the adaptation potential of floodplain infrastructure should be assessed over its economic life while the adaptation potential of environmental watering plans should be considered over their statutory time span.

COAG needs to agree to improve the scientific understanding of the potential future stresses caused by extreme weather events (e.g. more frequent and more severe drought and higher evaporation from rising temperature) and long-term changes in climate including water availability, supported by a climate change adaptation program for environmental assets, industries and public infrastructure.

5.2 Expand the mandate of the Basin Plan

Environmental water is a pre-requisite for restoring the health of the Basin's river systems but river health depends on more than just flow. Natural resource management measures are also important for delivering a healthy river system to complement (and not substitute for) water management. Measures include direct interventions such as invasive pest control and thermal pollution control, through to improved management systems such as riparian forest buffer zones, regional strategic planning and freshwater protected areas. The Basin Plan in its current form does not sufficiently incorporate natural resource management activities, nor does it control land use which is regulated by states, nor does it give the Commonwealth sufficient powers to effect changes to the broader planning and management frameworks in the Basin. Future iterations of the Murray-Darling Basin Plan should expand its mandate to deliver integrated land and water management including management of environmental water.

The Commonwealth needs to expand the mandate of the Basin Plan to integrate water planning with broader natural resource management to improve the overall environmental condition of the Basin.

5.3 Invest in knowledge and capacity

Australia is well placed for research excellence on agriculture, food security, catchment health and water supply systems in a variable and changing climate. As an international leader in water management and with best practice agriculture, Australia has opportunities to export this knowledge to countries globally who are grappling with the challenges of increasing competition over resources and food security. However, there has been a stagnation in research, development and extension services by federal and state agencies over past few decades (Figure 37). Organisations such as CSIRO and universities have cut their investment in field based services capable of advancing our competitiveness and sustainability across the triple bottom line.

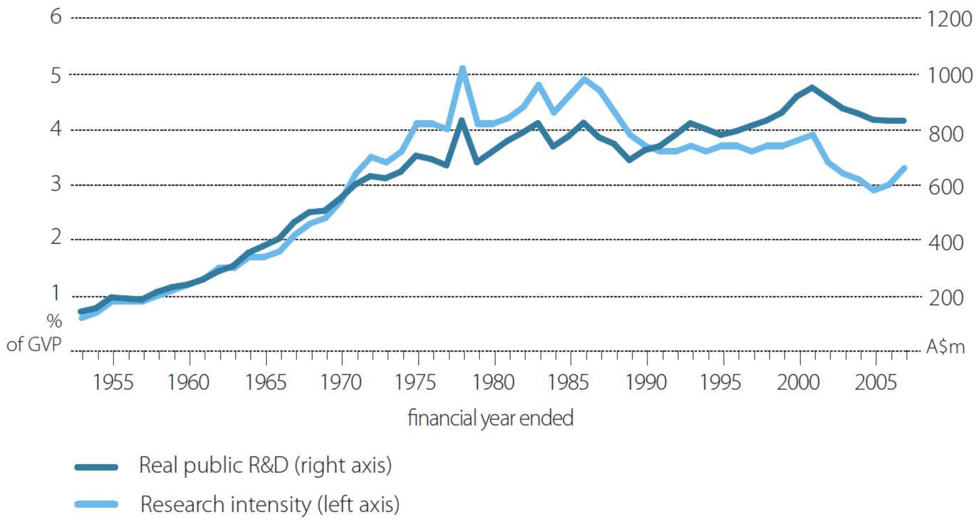

Figure 37. Real public research and development investment and research intensity (expressed as a percentage of gross value of agricultural production; GVP) in Australian agriculture, 1952-53 to 2006-07. (Source: Sheng et al, 2011)[210]

Research stations could offer assistance to farmers and others who seek to capture environmental benefits that underpin natural values and ecosystem services. For example, the Loxton Research Centre in South Australia has played a pivotal role establishing the horticulture sector since the early 1960s, and continues to support the growth of the premium food and wine industry. One option is to expand this model into a network of facilities across the Basin to provide an integrated approach to agricultural services, and in doing so, boost economic productivity and sustainability. Research programs could encompass fields such as agricultural science, farm management, ecosystems and climate change. Stations could support farm-based programs with landowners to demonstrate innovations such as new crops, grazing techniques and irrigation technology. Partnership with the agri-business sector can provide mutual benefits and help raise the profile of sustainable agriculture in Australia and overseas.

Governments should invest in knowledge and capacity to enhance agricultural productivity, sustainable production and food and water security, and protect the natural resource base in a variable and changing climate.

5.4 Reinvigorate national water reform effort

This review has demonstrated that progress has been made in many aspects of water reform in the Murray-Darling Basin. Unprecedented volumes of water have been recovered for the environment from consumptive use, environmental outcomes are being realised where this water is used, and significant investment has been made in modernising irrigation infrastructure. There has also been considerable improvements in the governance of water markets, which has led to irrigation water resources moving to higher value uses.

Other aspects of water reform in Australia have lost momentum and, in some cases appear to be in retreat. The COAG Standing Council on Environment and Water, the peak body for coordinated government action on water reform, was disbanded in 2013 without replacement, and the Sustainable Rivers Audit was abandoned in 2012. The independent review body, the National Water Commission, was abolished in 2014 and responsibilities were split amongst government agencies, leaving the "potential for diminished commitment to the [National Water Initiative] reform agenda" according to the Commonwealth Government's 2016 State of the Environment Report.[50] This Report also found that "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".[50] The erosion of the national capacity to monitor water reform has made for a difficult policy environment for implementing and progressing reforms in the Murray-Darling Basin. With growing demand for agricultural products[211] and increased risks from climate change, Australia urgently needs to reinvigorate the national water reform agenda to prepare the nation for the opportunities and challenges that lie ahead.

Basin governments should ensure water reform remains a permanent item on the COAG agenda, and recognise the long-term nature of national water reform via the establishment of an independent expert body to undertake regular reviews of progress.

Glossary

Allocation Water that is available to use or trade in any given year, often quoted as a percentage of the volume of each entitlement. For example, a 20% allocation in a particular season allows a water user with a 100 ML entitlement to take 20 ML of water.

Basin states For the purposes of the Basin Plan, the basin states are defined in the Commonwealth Water Act 2007 as New South Wales, Victoria, Queensland, South Australia and the Australian Capital Territory.

Carryover A way to manage water resources and allocations that allows irrigators to take a portion of unused water allocation from one season into the new irrigation season.

Constraint Impediment to the delivery of environmental water. Constraints can include physical features such as low lying bridges, or river channel capacity, but can also include policies and river management rules that impact on when and how much water can be delivered.

Constraints measure A measure which removes or eases a physical or other constraint on the capacity to deliver environmental water; and when combined into a package of supply, efficiency and constraint measures, allow environmental water to be used to maximum effect.

Consumptive use Use of water for irrigation, industry, urban, stock and domestic use, or for other private purpose.

Diversion Water that is taken from a water source for consumptive use.

Easement A grant of rights to deliver environmental flow over private land.

Efficiency measure Measures which provide more water for the environment by making water delivery systems for irrigation more efficient. This can include replacing or upgrading on-farm irrigation, or lining channels to reduce water losses within an irrigation network.

Entitlement A right to use water from a defined water source. Entitlements have different characteristics depending on where and how water is taken.

Environmental flow Any river flow pattern provided with the intention of maintaining or improving river health.

Environmental water requirements The amount of water needed to meet an ecological or environmental objective.

Environmental water (or environmental flow) Water used to achieve desired outcomes for the environment, including for ecosystem functions, biodiversity, water quality and water resource health.

Equivalent (or ecologically equivalent) Environmental outcomes which are commensurate with the outcomes achieved through environmental water but are achieved using measures aside from additional flows (e.g. evaporative savings, re-operating storages).

Floodplain harvesting The collection or capture of water flowing across floodplains for consumptive use.

Held environmental water Water that is available under a water access entitlement for the purpose of achieving environmental outcomes.

Interception Capture of run-off from human activities (e.g. plantations, farm dams, levees) before it reaches rivers and streams, which can reduce the flow of water in waterways.

The Living Murray program A 12 year partnership between the Murray-Darling Basin Authority and the New South Wales, Victorian, South Australian and Australian Capital Territory Governments established in 2002. Through a $650 million investment, the program has acquired almost 500 GL of environmental water and constructed a series of water management structures to be used for environmental watering of floodplains and wetlands.

Off-farm infrastructure modernisation Improvement of channels, pipes, pumps, meters, off-stream storages and aquifer storage and recovery, from the source (headworks on a river, storage reservoir or well head) to irrigator off-take.

On-farm infrastructure upgrades Upgrades of privately owned channels, pipes, pumps, meters, off-stream storages after the irrigator off-take.

Planned environmental water Water committed to the environment by rules in state water resource plans

Regulated A water system in which water is stored or flow levels are controlled through the use of structures such as dams and weirs.

Salt interception scheme Large-scale groundwater pumping and drainage projects that intercept saline groundwater inflowing to rivers, and dispose of the saline waters by evaporation and aquifer storage at more distant locations.

Shepherding (of environmental water) Delivery of a volume of environmental water available in one part of the river system to a more downstream location.

Supply measure A measure that either (1) increases the quantity of water available to be taken (e.g. by streamlining river operations or management rules) or (2) achieves equivalent environmental outcomes with less water than would otherwise be required (e.g. by building or improving river or water management structures so environmental water can be delivered directly to places that need it more or those which can achieve the best outcomes).

Surface water Includes water in a watercourse, lake or wetland, and any water flowing over or lying on the land after having precipitated naturally or after having risen to the surface naturally from underground.

Sustainable diversion limit The maximum long-term annual average quantity of water that can be taken for consumptive use, on a sustainable basis, from the Murray-Darling Basin’s water resources. Sustainable diversion limits will operate from 2019 and will replace the cap system.

Sustainable diversion limit adjustment mechanism Allows the sustainable diversion limit to be adjusted under certain circumstances.

Unregulated river A river system without major dams and weirs.

Water resource plans Statutory management plans developed for particular surface-water and groundwater systems, currently known by different names throughout the Murray–Darling Basin (e.g. 'water sharing plans' in New South Wales and 'water allocation plans' in South Australia).

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Review of Water Reform in the Murray-Darling Basin

Appendix 1. Progress on water recovery

Bradley Tucker

Review of progress on water recovery in the Murray-Darling Basin

Review for the Wentworth Group of Concerned Scientists

Bradley J Tucker

10-11-2016

Progress of water recovery:

Surface water

The overall targets for the reduction in consumptive use of water is from 13,623 gigalitres (GL) to a 'Sustainable Diversion Limit' (SDL) of 10,873GL per year, measured as a long term average. This translates to a 2,750 GL increase in the long term average volume of environmental water by 2019. An additional 450GL is to be acquired under the Basin Plan for enhanced environmental outcomes, bringing the total water recovery to 3,200GL.

There has been 2004.5GL recovered to date (30 Nov 2016), which is 72% of the 2,750GL (Table 1). None of the 450GL has been recovered to date. Nearly three quarters of the water recovery has occurred in four valleys of the southern Murray-Darling Basin: the Victorian Murray (397GL), Goulburn (362.3GL), NSW Murrumbidgee (389.5GL) and NSW Murray (318GL) (Table 2).

Most of the water (57%; 1,577GL) was recovered, or under contract to be recovered, prior to the Basin Plan between 2009 and 2012 (Table 1). A further volume of water (15%; 427.5GL) was acquired between 2012 and 2016. Progress on water recovery has slowed significantly since 2014 when the Government shifted the focus of water recovery from buybacks to on-farm efficiency investment to minimise socio-economic impacts of water recovery. Basin states have until 2024 to complete efficiency projects and recover the 450GL long term average annual water volume under the SDL adjustment mechanism.

Table 1. Progress of water recovery in Murray-Darling Basin

Date	LTAAY (GL) [1]	Percent Recovered	Source
30-Sep-12	1577	57%	DSEWPaC 2012 Environmental Water Recovery Strategy for the Murray-Darling Basin Draft for Consultation Department of Sustainability, Environment, Water, Populations and Communities
30-Jun-13	1658	60%	MDBA 2013 Annual Report 2012-13, Murray-Darling Basin Authority, Canberra.
30-Jun-14	1904	69%	MDBA 2014 Annual Report 2013-14, Murray-Darling Basin Authority, Canberra.
30-Jun-15	1950.5	71%	MDBA 2015 Annual Report 2014-15, Murray-Darling Basin Authority, Canberra.
29-Feb-16	1953.6	71%	MDBA 2016 Progress on water recovery http://www.mdba.gov.au/managing-water/environmental-water/progress-water-recovery
31-Mar-16	1955.3	71%	MDBA 2016 Progress on water recovery http://www.mdba.gov.au/managing-water/environmental-water/progress-water-recovery
30-Nov-16	2004.5	72%	DAWR 2016 Progress towards meeting environmental needs under the Basin Plan http://www.agriculture.gov.au/water/mdb/progress-recovery/progress-of-water-recovery

[1] Consists of water entitlements recovered or under contract to be recovered.

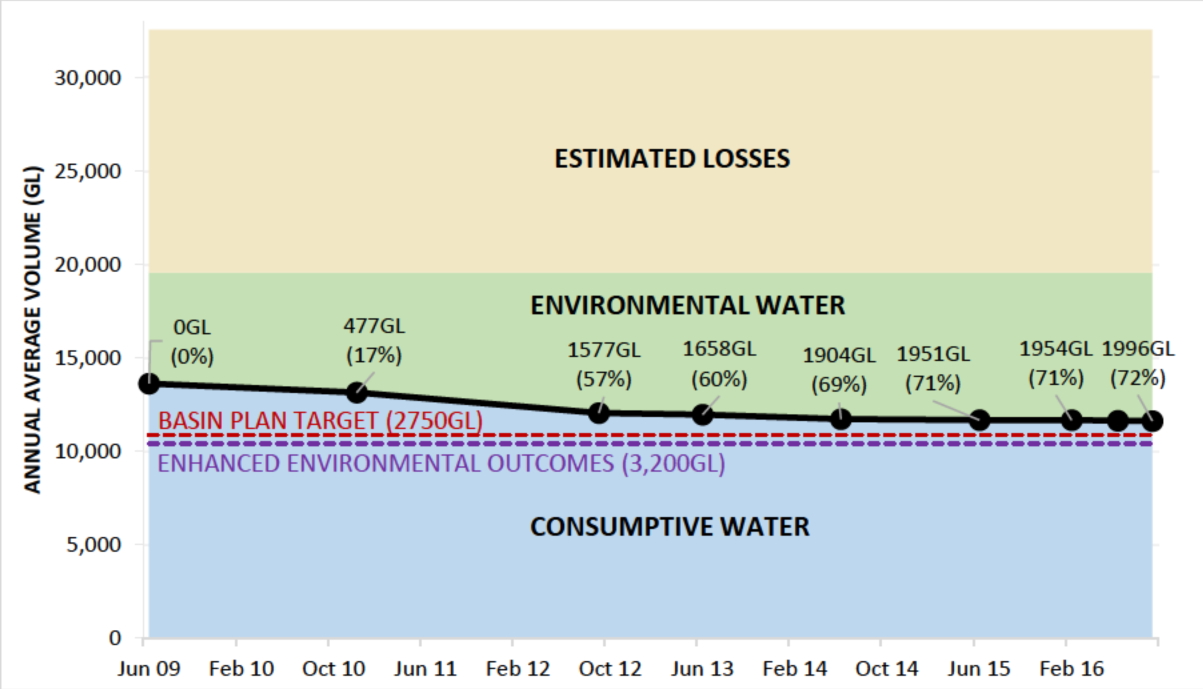

Figure 1. Long term average annual volumes of consumptive water, environmental water and estimated losses (e.g. evaporation, groundwater) in the Murray-Darling Basin from June 2009 to September 2016. Progress towards the 2,750GL and 3,200GL of water recovery under the Basin Plan is shown in black dots.

The summary in Table 2 below sets out water recovery targets across the Basin, current progress toward meeting the targets, and the balance of recovery required.

There are 2 key aspects of water recovery targets in the Basin Plan. These are:

- local targets, known in the Basin Plan as a 'local reduction amount', which apply at the SDL resource unit level.
- shared targets, known in the Basin Plan as a 'shared reduction amount', which apply at the shared zone level.

The terminology used in the Basin Plan, 'reduction amount', refers to the amount of reduction in water diversions for consumptive purposes (ie. BDL reduction). This 'reduction' is a condition of the water recovery contributing to the 2,750 GL water recovery target.

Most valleys have reached their local reduction targets as of November 2016 (Figure 2). Exceptions were the Condamine-Balonne (38.3GL remaining), Lachlan (0.1GL remaining), Wimmera-Mallee (0.4GL remaining), NSW Border Rivers (3.7GL remaining) and the Lower Darling (5.7GL remaining). These valleys were mainly in the northern Basin. SDLs in the northern Basin could change if the proposed amendments to the Basin Plan are successful.

Only the ACT zone has reached its shared reduction targets (Figure 3). In the southern Basin, the VIC zone has 251.7GL remaining, the NSW zone has 332.4GL remaining and the SA zone has 39.9GL remaining. The northern Basin zone has 73.2GL remaining.

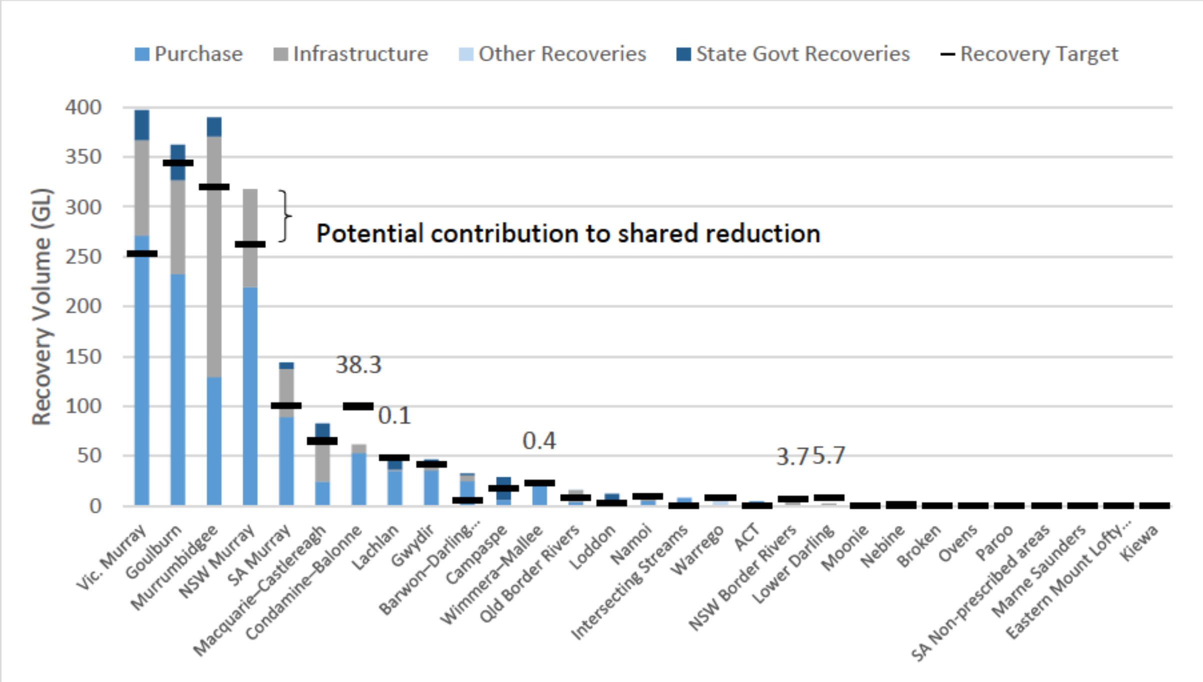

Figure 2. Water recovery relative to local targets (black lines) within valleys of the Murray-Darling Basin.

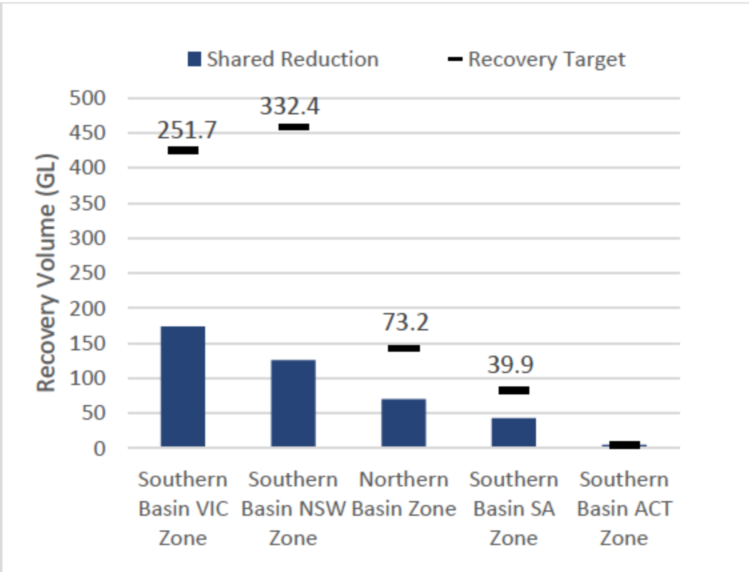

Figure 3. Water recovery relative to shared targets (black lines) within zones of the Murray-Darling Basin.

Table 2. Basin scale water recovery by SDL resource unit. (adapted from MDBA http://www.mdba.gov.au/managing-water/environmental-water/progress-water-recovery)

SDL Resource Unit (within zones)	**Total BDL (GL)**	**BDL (GL) excluding interception**[1]	**Total reduction target in GL (local plus shared)**	**Commonwealth recovery under the SRWUIP program**		**Other Commonwealth purchases**[6] **(GL)**	**State recovery**[3] **(GL)**	**Total recovery (GL)**	**Total recovery (local plus shared) still required (GL)**
				Purchased by Tenders[5] **(GL)**	**Infrastructure Projects (GL)**				
Barwon-Darling Watercourse	197.5	198		24.6	6.2		1.5	32.3	
Condamine-Balonne	978.3	713.3		52.7	5.6		0	58.2	
Gwydir	450.2	325.2		35.5	5.1		6.2	46.9	
Intersecting Streams8	114	3		8.1	0		0	8.1	
Macquarie-Castlereagh	734.3	424.3		24.6	37.3		20.6	82.5	
Moonie	84.2	33.2		0	0.7	1.1		1.8	
Namoi	508.3	343.3		4.8	6.8		0	11.5	
Nebine	31.2	6.2		0	0	1		1	
NSW Border Rivers	302.6	207.6		0	3.3		0	3.3	
Paroo	9.9	0.2		0	0	0		0	
Queensland Border Rivers	320.1	242.1		3.6	11.3	0.5		15.3	
Warrego	127.7	44.7		0	0	8		8	
Total Northern Basin Zone	**3858**	**2541**	**390**	**153.8**	**76.2**	**10.6**	**28.4**	**269**	**121**
Lower Darling	60.5	55.0		1.0	1.3		0.0	2.2	
Murrumbidgee - NSW	2501.1	2000.1		129.2	208.9	2.4	19.0	359.6	
NSW Murray	1811.7	1707.7		219.5	86.7		0.0	306.2	
Total Southern Basin NSW Zone	**4373**	**3763**	**1048**	**349.6**	**296.9**	**2.4**	**19.0**	**668.0**	**380.0**
ACT (surface water)	52.5	40.5		4.9	0.0			4.9	
Total Southern Basin ACT Zone	**52.5**	**40.5**	**4.9**	**4.9**				**4.9**	**0.0**
Broken	56.2	13.2		0.0	0.2		0.0	0.2	
Campaspe	152.6	112.6		6.3	0.1		22.6	29.0	

Goulburn	1689.4	1580.4		232.6	94.3		35.4	362.3	
Kiewa	24.6	11.0		0.0	0.0		0.0	0.0	
Loddon	178.6	88.6		2.8	0.6		8.6	11.9	
Ovens	83.4	25.4		0.1	0.0		0.0	0.1	
Victorian Murray	1707.1	1662.1		271.0	96.6		30.1	397.7	
Total Southern Basin Victoria Zone	**3892**	**3493**	**1052**	**512.7**	**191.8**		**96.7**	**801.2**	**251.1**
Eastern Mount Lofty Ranges	28.3	15.3		0.0	0.0				
South Australian Murray	665.0	665.0		86.3	13.0	36.0	6.4	141.7	
Marne Saunders	2.9	2.9		0.0	0.0				
SA Non-Prescribed	3.5	0.0		0.0	0.0				
Total Southern Basin South Australia Zone	**700**	**683**	**184**	**86.3**	**13.0**	**36.0**	**6.4**	**141.7**	**42.1**
Lachlan[7]	618.4	302.4		35.0	1.5		11.4	48.0	
Wimmera-Mallee (surface water)	128.5	66.5		22.6	0.0			22.6	
TOTAL	**13623**	**10890**	**2750**	**1164.9**	**579.4**	**49.0**	**161.9**	**1955.3**	**794.7**

Notes:

1. Watercourse diversions under the Baseline Diversion Limit - arrangements as at 30 June 2009 under conditions from 1895 to 2009.

3. Includes NVIRP Stage 1.

5. Includes water purchased from the Wimmera and Murray Irrigation Irrigator Led Group Proposals, water acquired from the New South Wales Government relating to its purchase of Toorale Station, the Commonwealth water purchase from the Victorian Government relating to the Goulburn-Murray Water Connections Program and water purchased from ACTEW Corporation (Australian Capital Territory).

6. Includes Commonwealth water recoveries from the South Australian River Murray Sustainability Program (SARMSP, which is funded separately from SRWUIP), water gifted by the Queensland Government to the Commonwealth, and Commonwealth water recoveries secured through the Water Smart Australia Program.

Notes on surface water recovery not included in the estimates -

7. Lachlan - the amount of water estimated to have been recovered exceeds the local reduction amount by 1.707GL. As the Lachlan is a disconnected SDL resource unit the over-recovery cannot be used to meet to meet the 2750 GL reduction. To address this over-recovered volumes are excluded from the recovery estimates above (i.e. volumes of 0.863GL in SRWUIP and 0.844GL in State recoveries are excluded).

Intersecting Streams - this data includes unregulated water entitlements acquired from the NSW Government relating to its purchase of Toorale Station. As part of the Intersecting Streams Unregulated and Alluvial water sharing plan, an additional entitlement has been issued to the Commonwealth – unregulated river special additional high flow entitlement. This is a new class of entitlement and at this time there is no long-term diversion limit equivalent factor available to estimate the long-term diversion limit for this entitlement. At this stage, the unregulated river special additional high flow entitlement has not been counted towards 'bridging the gap'.

Groundwater

The target for groundwater recovery under the Basin Plan is 40.4GL and is to be recovered from two SDL resource units. There was 2.7GL (6.7%) recovered as of 30 November 2016. There is 37.7GL (93.3%) left to be recovered.

	Sustainable Diversion Limit Reduction Amount			*Recovery Progress*		*Remaining*
SDL Resource Unit (or Shared Zone)	Local Target (GL)	Shared Target (GL)	Total Target (GL)	Purchase (GL)	Total Recovery (GL)	Total recovery remaining (GL)
Upper Condamine Alluvium (Central Condamine Alluvium)	35.4	N/A	35.4	2.7	2.7	32.7
Upper Condamine Alluvium (Tributaries)	5.0	N/A	5.0	0.0	0.0	5.0
Total Basin	40.4	N/A	40.4	2.7	2.7	37.7

Remaining water recovery

There is 754GL of surface water recovery remaining (27% of the 2,750GL), plus 450GL to recover for enhanced environmental outcomes. There is also 37.7GL of ground water recovery remaining (93.3% of the 40.4GL). There are considerable challenges in recovering this water because:

1. 1500GL cap will limit opportunities for buybacks;
2. Remaining water recovery could be more expensive because (a) infrastructure is more expensive than buybacks (b) the low hanging fruit (i.e. best sites) are already taken. Thus there is a risk of running out of money before we can recover all the water;
3. Not certain there will be suitable locations for upgrading irrigation infrastructure (a) relies on voluntary uptake, and people may be concerned of the risks of economic impacts to individuals despite gains on the larger scale (i.e. some farms cut off completely from water supply), and (b) locations where water recovery is required may not be suitable for upgrading infrastructure;
4. Regarding the 450GL, basin states have provided little clarity around exactly what projects will be put forward, how much water will be delivered under these projects and how much these will cost.

Also potential changes to the SDLs may mean less water recovery altogether (see figure below):

1. SDL adjustment – a net change in the SDL of up to ±544GL (5% of SDL), depending on the final package of supply and efficiency measures;
2. Proposed changes to SDLs in the Northern Basin– 70GL increase in SDLs.
3. Proposed changes to groundwater SDLs – a total increase of 160GL in three groundwater resource areas.

With these changes, there is a possibility that the water recovery amount could be as low as 2,136GL. This is less than the 2,400GL minimum requirements, which according to ESLT modelling "was insufficient to achieve a number of key environmental objectives for the River Murray downstream of the Murrumbidgee junction (including the Coorong, Lower Lakes and Murray Mouth)."

These figures are modelled on average historical rainfall and runoff. Long term average water availability under climate change may be less than historical averages, particularly in the southern Basin where average inflows could change by -10 to +5% in the south and -11 to +8% in the north by 2030. Volumes available for the environment under a changing climate will need to be revisited in future reviews of the Basin Plan.

It is critical that the MDBA's estimate of water recovery is accurate and up to date. The volume of water recovered (Table 1) is estimated by converting entitlements to long term average annual water yield based on the reliability of entitlements (also known as a 'cap factor'). Changing the cap factor will not change the amount of water that needs to be recovered, only the estimate of what has been recovered so far. The MDBA will need to ensure that cap factors are frequently reviewed in light of changing resource availability, management rules and other factors influencing reliability, so that the Commonwealth can acquire the appropriate entitlements and meet recovery targets.

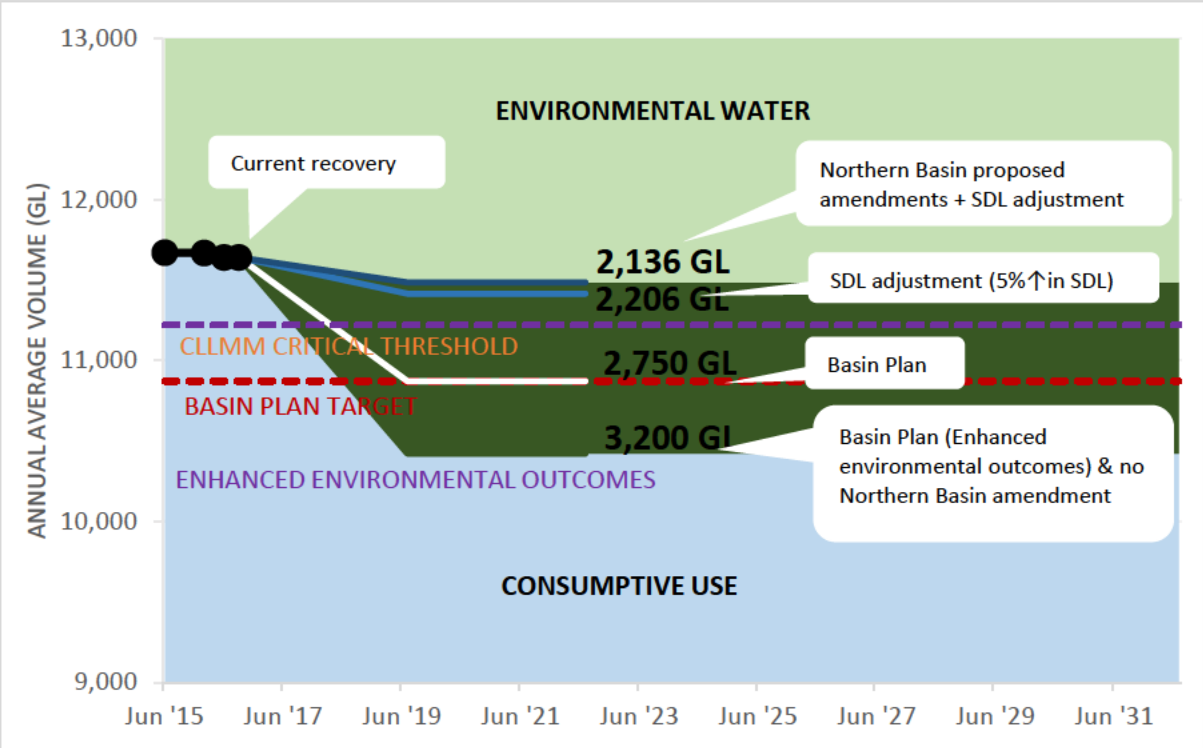

Figure 4. Alternative scenarios for surface water recovery depending on how the SDL adjustment and proposed amendments in the Northern Basin are progressed.

Recovery strategies:

The Australian Government's Water Recovery Strategy for the Murray-Darling Basin (June 2014) prioritises water recovery for environmental purposes through infrastructure investment over water buybacks. Prior to the release of this strategy, in November 2013 the Australian Government introduced a 1500 gigalitre cap on surface water buybacks to address community and industry stakeholder pressure over the potential adverse social and economic impacts on irrigation dependent communities that may arise from water purchases. The cap means that currently the only option to recover the remaining water is via infrastructure projects that reduce water use and loss by industry. These projects have been summarised by SDL resource unit in Table 2.

Overall, $13 billion has been committed by the Commonwealth Government for a suite of programs (Table 3). Of this, $7.1 billion (55%) has been spent and $5.9 billion remains. Some of these programs are explained in more detail below.

Table 3. Expenditure under the Water for the Future program.

Program	Commitment ($bn)
Enhanced environmental outcomes for Water for the Environment Special Account	1.775
On- and off-farm irrigation efficiency and infrastructure projects and related activities	5.6
Water purchase	3.1
Supply or offset measures	1.3
South Australian River Murray Sustainability Program	0.265
South Australian Riverland Floodplains Integrated infrastructure Program	0.155
Murray-Darling Basin Regional Economic Diversification Program	0.1
The Living Murray Initiative	0.184
Water Smart Australia projects	0.332
Water for Rivers	0.038
Lower Lakes Remediation	0.009
Hume Dam remedial works	0.01

Program	Expenditure
Total expenditure	13
Expenditure to date	7.1
Remainder	5.9
% spent	55%

Water for the Environment Special Account

In addition to the 2,750GL recovery, the Commonwealth government established a Water for the Environment Special Account to recover an additional 450GL and ease or remove constraints to delivery of environmental water. This $1.76billion fund is established via Part 2AA of the *Water Act 2007.* Water access rights acquired by the Commonwealth using funds from the Water for the Environment Special Account form part of the Commonwealth environmental water holdings. According to the Australian Government Special Accounts Balances and Cash Flows Report for year ended 30 June 2015, the Department credited $15 million but nothing was spent in this year. Accounts for year ended 30 June 2016 are not available at the time of writing.

See http://www.finance.gov.au/resource-management/appropriations/special-accounts/

Yearly payments		
Item	**Financial year**	**Amount for financial year**
1	2014-2015	$15,000,000.00
2	2015-2016	$40,000,000.00
3	2016-2017	$110,000,000.00
4	2017-2018	$430,000,000.00
5	2018-2019	$320,000,000.00
6	2019-2020	$350,000,000.00
7	2020-2021	$315,000,000.00
8	2021-2022	$105,000,000.00
9	2022-2023	$60,000,000.00
10	2023-2024	$30,000,000.00

Figure 5 Amounts credited to the Water for the Environment Special Account (s86AG Water Amendment (Water for the Environment Special Account) Act 2013

The Sustainable Rural Water Use and Infrastructure Program (SRWUIP)

The Sustainable Rural Water Use and Infrastructure Program (SRWUIP) has been the key platform for water recovery and consists of 3 components – irrigation infrastructure projects, water purchase measures and supply measures.

Water infrastructure projects funded under the SRWUIP that are expected to contribute to the reduction to SDLs are detailed in Table 4. Market multiple and contracted values for each project are provided, however it is not clear at what price the market multiple was determined. A static market multiple at project commencement does not account for the significant opportunity cost lost during time for infrastructure completion when the water is physically recovered. This is demonstrated by the low completion rate of projects shown in Annexure A of the water recovery strategy.

Table 4 Australian Government investment in Murray-Darling Basin gap bridging water infrastructure projects (Water Recovery Strategy for the Murray-Darling Basin, Commonwealth of Australia 2014)

State	Programme/Project	Contracted ($m)	Water recovery towards Bridging the Gap (GL LTAAY)	Market Multiple
NSW	SPP[1]—NSW—Private Irrigation Infrastructure Operators Program (PIIOP)	642	**113**	2.4
	SPP—NSW Water Metering Scheme (Pilot Project)	22	**4**	3.5
	SPP—NSW Water Metering Scheme (excluding pilot)	199	**28**	2.3
	SPP—NSW Basin Pipes (Stock and Domestic)	137	**30**	2.5

	SPP—Irrigated Farm Modernisation (Border Rivers-Gwydir Pilot Project)	7	**0.5**	2.3
	SPP—Irrigated Farm Modernisation Project	85	**12**	2.5
	Nimmie Caira Enhanced Environmental Water Delivery Project	180	**133**	2.4
Qld	SPP—On Farm Water Use Efficiency Project (Healthy Headwaters)—rounds under contract to date	51	**7**	2.0
Vic	SPP—NVIRP Stage 2 Project (now known as Goulburn-Murray Water Connections Project Stage 2)	956	**102**	4.9
	SPP—NVIRP on-farm component	44	**10**	2.3
	Victorian Farm Modernisation Project (assuming all three tranches proceed)	100	**30**	1.9
	Sunraysia Modernisation Project	103	**7**	7.1
SA	SPP—SA Private Irrigation Infrastructure Program (PIIP-SA)	14	**3**	2.6
	South Australian River Murray Sustainability Program (SARMSP)—irrigation efficiency component[2]	80	**16.8**	2.5
Southern Basin	On-Farm Irrigation Efficiency Program—including pilot projects and first three rounds under contract.	296	**83**	2.3
Total 'bridging the gap' infrastructure water recovery[3]			**560[4]**	

Notes

1 SPP = State Priority Project—funds for which were committed under the 2008 Intergovernmental Agreement on Murray-Darling Basin Reform.
2 SARMSP is funded separately from SRWUIP.
3 'Bridging the gap' water recovery from infrastructure investments is reported at the point at which water savings have been received, estimated or agreed in signed project works contracts. Until water transfer contracts have been exchanged however, these figures may be subject to change. The recovery volume is shown in gigalitres (GL) and expressed as long term average annual yield (LTAAY)), and is subject to rounding.
4 A further 17 gigalitres of Disconnected Basin (Lachlan River) water has been recovered through infrastructure initiatives but is not 'gap bridging'.

The strategy of water recovery by floodplain manipulation via infrastructure has been pursued contrary to evidence that suggests direct market intervention is a more cost effective and faster way

to recover water. In 2010 the Productivity Commission detailed the following recommendations on water recovery in the MDB:

Purchasing water products from willing sellers is generally the most effective and efficient means of acquiring water, where governments are liable for the cost of recovering water for the environment – Finding 6.3

Funding irrigation infrastructure upgrades is generally not a cost-effective way for governments to recover water for the environment – Finding 6.4

Rather than having a $5.8 billion program focused predominately on infrastructure upgrades, it would have been more effective and efficient to:

- *use the sustainable diversion limits from the Basin Plan to determine the targets for reallocation in each catchment*
- *use the buyback program as the sole means of easing the transition to those targets*
- *consider establishing a much smaller program to assist irrigators and related communities adjust to a future with less water, through the most effective means available (not just subsidies for irrigation infrastructure)* – Finding 6.5

Subsidising these projects is an attractive approach for decision makers and politicians because modernising irrigation infrastructure and rationalising water use can result in water savings which are then allocated to the Commonwealth Environmental Water Holder for environmental purposes. Furthermore, recovery in this way has been promoted as a way to assist communities adjusting to socio-economic impacts resulting from exiting irrigation and reductions in consumptive water entitlements. For the remaining taxpayers, recovering water through subsidising efficiency improvements is significantly more expensive than direct water buybacks. Others suggest that this difference is likely to widen as cost per ML of water recovered increases, further diminishing marginal returns (see Figure 6).

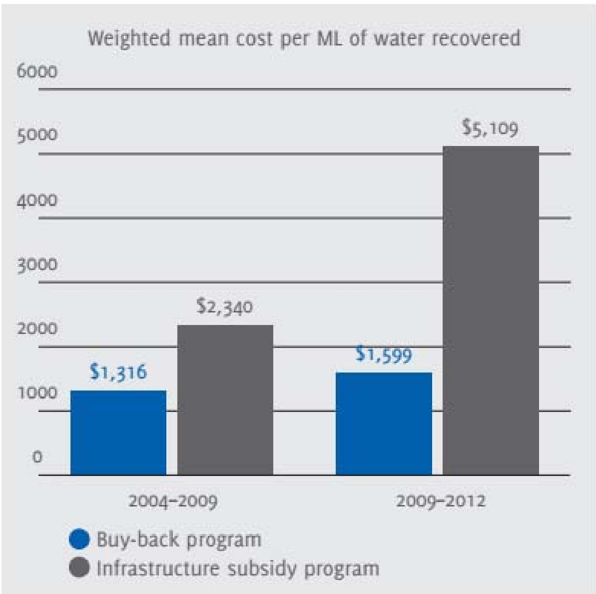

Figure 6 Comparison of market buy-back vs infrastructure subsidies. (Taken from Loch et al. 2014).

<u>Restoring the Balance in the Murray Darling Basin (water entitlement buyback)</u>

The Restoring the Balance in the Murray-Darling Basin Program is the market buy back of water entitlements component of SRWUIP. The latest water purchase information by SDL resource unit is available from http://agriculture.gov.au/water/markets/commonwealth-water-mdb/progress-water-purchases

Table 5. Total water recovery from buy backs in the Murray-Darling Basin (as of 31 August 2016). Taken from http://agriculture.gov.au/water/markets/commonwealth-water-mdb/progress-water-purchases

SDL resource unit (catchment)	Water purchase tenders—entitlement (ML)	Water purchase tenders—LTAAY (ML)	Other purchases—LTAAY (ML)[1]	Purchases exempt from 1500 GL Limit - LTAAY (ML)	Total LTAAY (ML)[2,3]
All catchments	1 359 149	1 016 883	148 641	2 880	1 168 403

1. Other purchases include water purchased from the Wimmera and Murray Irrigation Irrigator Led Group Proposals, water acquired from the NSW Government relating to its purchase of Toorale Station, water purchased from the Victorian Government relating to the Goulburn–Murray Water Connections Program and water purchased from ACTEW Corporation (Australian Capital Territory).

2. Data includes unregulated water entitlements acquired from the NSW Government relating to its purchase of Toorale Station. An additional new entitlement (unregulated river special additional high flow entitlement for 9.720 GL is part of the *Water sharing plan for the intersecting streams unregulated and alluvial water sources*) has been issued to the Commonwealth. This recovery is not shown in the table because there is currently no long-term diversion limit equivalent factor available to estimate the long-term average annual yield (LTAAY) recovery volume for this entitlement.

3. Consistent with the Water Act 2007 (s85B, C and D), the 2.9 GL LTAAY of water secured from the SA Government in May 2016 is exempt from the 1500 GL limit on water purchases.

The average prices of offers pursued from recent water purchasing initiatives under the Restoring the Balance in the Murray-Darling Basin Program are reported in the website below.

http://agriculture.gov.au/water/markets/commonwealth-water-mdb/average-prices

For example, the average price of offers pursued from the November 2015 – February 2016 Queensland Upper Condamine Alluvium groundwater tender was $1,736.13 per ML.

The Commonwealth Environment Water Office is responsible for management of Commonwealth environmental water holdings under the Basin Plan. Commonwealth water holdings are the direct result of government purchases of entitlements and a substantial investment in more efficient water infrastructure in the Murray Darling Basin. The portfolio of water entitlements by catchment is updated periodically and available through the website below.

https://www.environment.gov.au/water/cewo/portfolio-mgt/holdings-catchment

The CEWO has accumulated a large and diverse range of entitlements, including significant quantities of low yielding entitlements (e.g. General, low, supplementary). In some catchments the Long Term Average Annual Yield (LYAAY) represents less than half the total registered entitlement volume (e.g. Gwydir, Lachlan, Macquarie). Accumulation of water entitlements and LTAAY are shown in Figure 7.

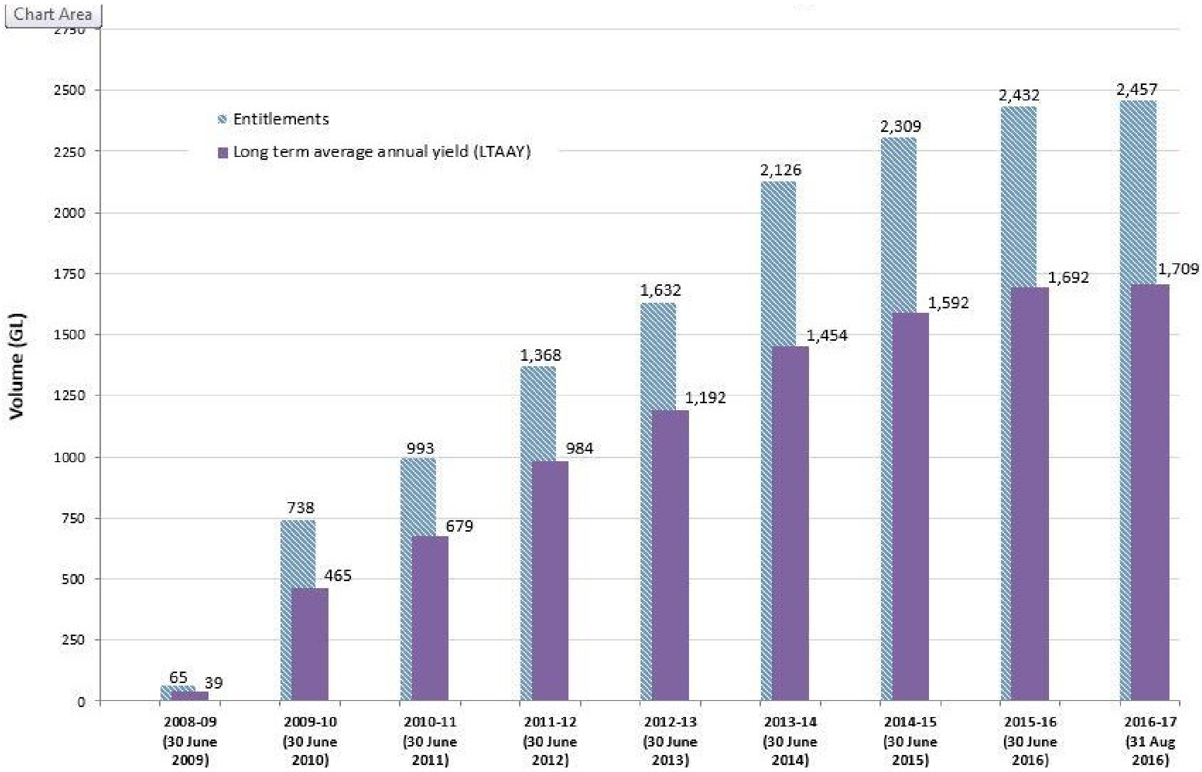

Figure 7. Total entitlements and Long term average annual yield of Commonwealth Environmental Water Holdings (from CEWO)

Water allocation and use

The MDBA is required to keep a register of consumptive water diversions based on data provided by the states. This register is to be used as the basis for ensuring compliance with SDLs. The Cap register has been prepared up to 30 June 2014. However at the time of writing the *Transition Period Water Take Reports* have not yet been published so we were not able to determine compliance with the SDLs under the Basin Plan.

Total water allocations and diversions for the Murray-Darling Basin between 1997-98 and 2014-15 are shown in Figure 8. Average annual allocations during this period were 9,450GL and average annual diversions were 8,507GL. There was a declining trend in allocations and diversions between 1997-98 and 2008-09 during the drought period. This was followed by an increasing trend between 2008-09 and 2012-13 during a relatively wet period. There was a subsequent decline in total allocations and diversions from 2012-13 to 2014-15 in the drier period and under the Basin Plan. Variability was due to a number of factors including water availability, management rules and behaviour of irrigators. Diversions may exceed allocations in a given year because of carryover and trade.

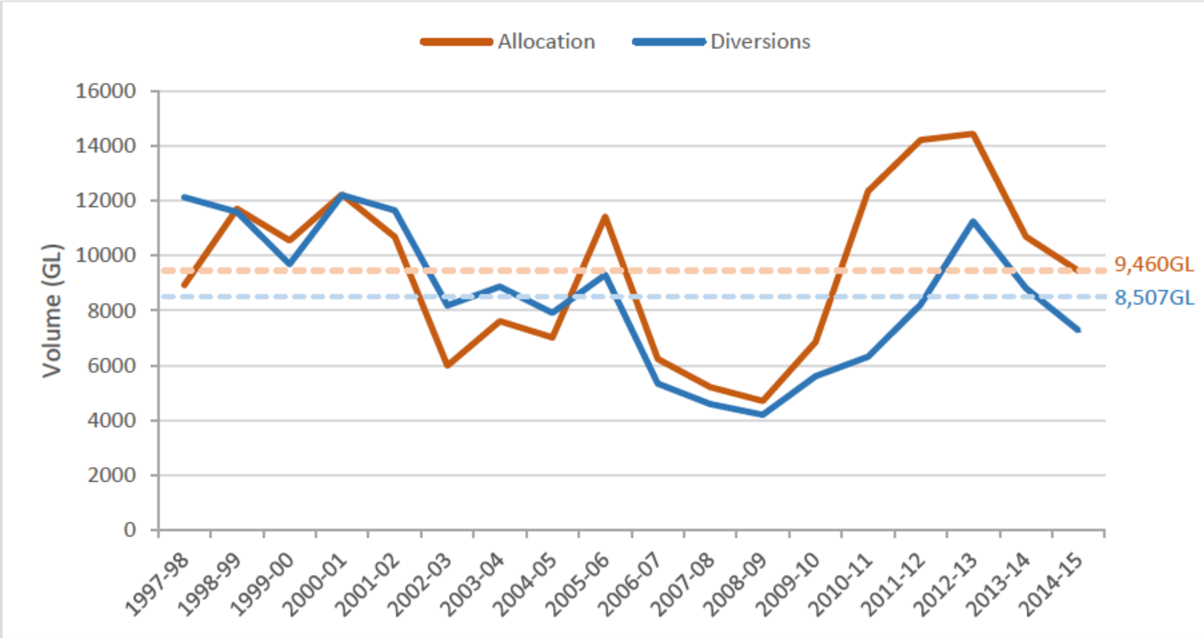

Figure 8. Overall water allocations and diversions for the Murray-Darling Basin based on the Cap register (MDBA, 2016).

At the valley scale, trends in diversions varied (Figure 9). There were clear long term declines in diversions in some valleys including the ACT, Broken and Campaspe. In other valleys, diversions were variable and showed no strong trends e.g. the Barwon-Darling, Namoi, NSW Border Rivers and Victorian Murray.

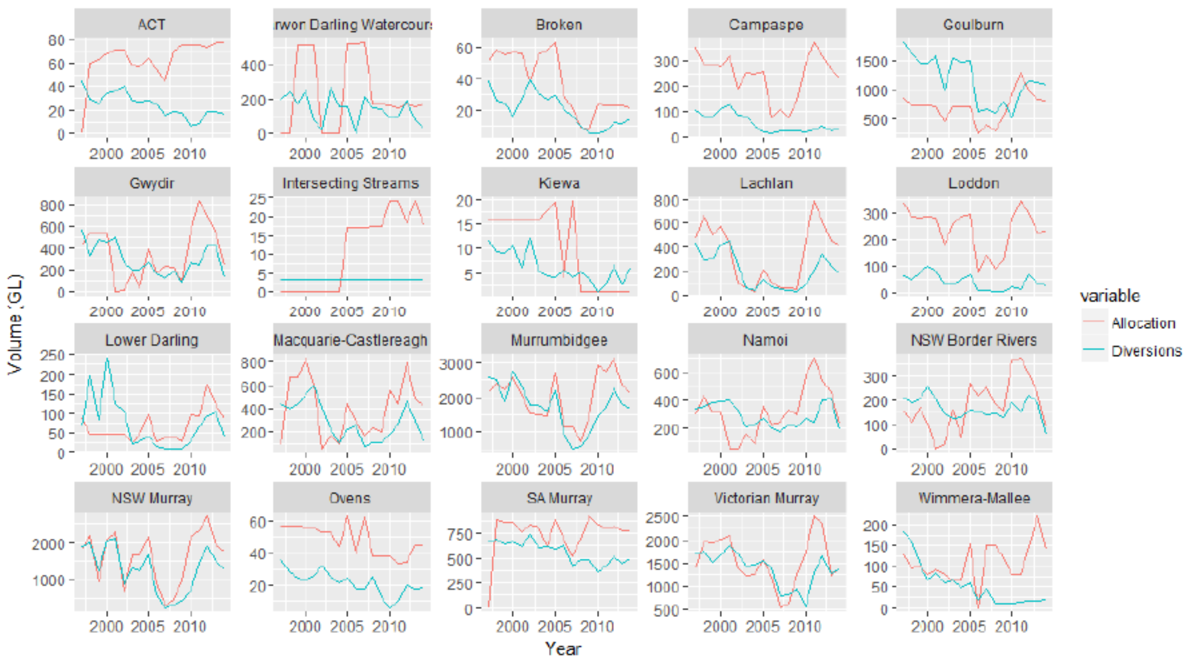

Figure 9. Allocations and diversions each year in valleys of the Murray-Darling Basin between 1997-98 and 2013-14.

<u>Adjusting the SDLs</u>

Environmental works and measures projects involve the manipulation of water via infrastructure to achieve similar or better environmental outcomes using less water than previously estimated in the Murray-Darling-Basin Plan. The types of projects proposed by the States include the installation of regulators and ancillary infrastructure such as pumps and pipes to enable broader seasonal floodplain or wetland inundation , and the removal of physical constraints to facilitate the delivery of environmental flow.

Some environmental works and measures are also considered suitable as a supply measure, as defined in the Murray-Darling Basin Plan. Supply measures are works, river operations or rule changes that enable the use of less water but still achieve the Plan's environmental outcomes.

On 22 April 2016 the Murray-Darling Ministerial Council Ministers agreed to a package of supply, efficiency and constraints measures that will result in changes to the sustainable diversion limits (SDL) of the Murray–Darling Basin Plan. As of April, the MDBA had modelled 15 of the 37 nominated projects and estimated these projects will offset 370GL of water (long term annual average yield).

The Ministerial Council also requested that the Commonwealth amend the Basin Plan to provide for a second SDL adjustment step by 30 June 2017. This amendment was passed by parliament in 2016. This has allowed for a second tranche of projects to be developed to further offset water under the Basin Plan.

Ministers also reiterated their request for Basin officials, after 30 June 2016, to consider opportunities for a wider range of complementary projects, such as carp control, to provide triple bottom line benefits under the Basin Plan. This is a concerning direction to provide to the states developing SDL adjustment projects because it legitimises effort and resources to be spent on unintended impacts resulting from the delivery of these projects rather than focusing on tangible water recovery. This has the potential for an evolving acceptance of complementary measures as substitutes for physical water recovery.

There are several issues with regard to the offsetting of water with infrastructure projects and other non-flow activities:

1) Use of constructed infrastructure cannot replicate all the functions that occur when a river naturally floods. Hence, sole reliance on site-specific management using works and measures could lead to a failure to achieve many of the management objectives for the floodplain and wider region. This is because:
    a. Objectives proposed for infrastructure usually deal with comparatively simple cause/effect relations which are relatively well understood at the relevant scale, while relationships between flow and elements of the ecosystem are part of a highly complex cause/effect system.
    b. Most infrastructure projects are aimed at a limited range of outcomes such as the provision of water regimes mimicking the irrigation requirements of eucalypts, with limited attention to other biota.
    c. Infrastructure projects are designed to produce a limited suite of hydrological outcomes in a prescribed landscape. Purchased water, on the other hand, is more versatile. In theory it can be used to produce a wide range of hydrological regimes (and therefore ecological outcomes) and its use is not limited to the valley or year in which it was harvested. Not only does it provide the flexibility to create multi -site (and/or multi-outcome) events, as evidenced by the recent series of trials managed by MDBA, but it allows new knowledge to be easily translated into river operations programs.
2) Construction and use of infrastructure could increase the risk of unintended consequences for ecosystems and land and water users, such as disconnecting parts of the floodplain from inundation or enhancing the risk of blackwater events;

3) Requires ongoing cost and maintenance;
4) Any offset of water from the river system will result in reduced in-channel flows and flows at the end of system which is counteractive to objectives for the Coorong, Lower Lakes and Murray Mouth;
5) The idea that you can engineer a floodplain ecosystem that will support existing and new species is not yet scientifically proven (known as the 'field of dreams' hypothesis). There is little scientific evidence of the long-term benefits of interventions. Ecological benefits expected from these interventions are based on hypothetical relationships between hydrology and the aquatic ecosystem. Leaving aside the possible risks from non-hydrological factors, operation of infrastructural interventions will require a period of experimentation and monitoring as part of an adaptive management program.

This report focuses on the benefits and risks associated with works and measures. Delivery of any infrastructure project requires mitigation of environmental risk, in particular where complex and sensitive ecological systems are impacted. Cumulative impacts from the array of potential projects - including an understanding of benefits or increased risks of delivering combinations of projects - is missing. At the basin scale, science-based strategic assessment of the suite of preferred projects is critical for understanding of water recovery benefits and ecological consequences. Analysis has shown that environmental works based projects in effect compete for available environmental water. It is also possible that some non-works proposals could compete (Martin and Turner 2015). Until such time all proposed state projects have developed detailed business cases including modelling and sensitivity analysis on configurations of preferred projects, it is impossible to understand whether the SDL adjustment mechanisms ill deliver end-of-system flow requirements, and other targets set out in the Basin Plan.

At the time of writing this report, only 10 project business cases from Victoria and 5 project business cases from South Australia were available to the Wentworth Group. Analysis and summaries of key issues relating to the delivery and operation of these proposals is provided in the Appendix. The review also considered the previous 2015 stocktake assessment commissioned by the Murray-Darling Basin Ministerial Council, which included nine Victorian environmental works and measures projects (Martin and Turner 2015).

Some consistent key risk issues across projects include:

- Poorly defined project governance arrangements considering the complex planning, operational and management procedures that will involve the collaboration and cooperation of Federal and State government agencies.
- Private land impacts from flooding are known for 5 … of the Victorian projects, with no comprehensive assessment of third party impacts for another 2 projects
- Increases in carp and other pest fish species are expected to affect all of the projects.
- Stranding of native fish during/after watering or lack of flow cues for exit. General adverse impacts on ecological function and connectivity for aquatic species.
- Demands on water infrastructure design to operate effectively through a wide range of hydrological regimes. Associated episodic reduction in hydrodynamic diversity (eg lentic habitat creation, prolonged inundation of vegetation)
- Finalisation of infrastructure design (see above point), construction and ongoing operation and maintenance cost and ownership have not been addressed in business cases. Smaller projects are likely to yield a low supply volume benefit at very high cost. Plausible supply

contribution for nine Victorian environmental works and measures projects was estimated at 40-50GL with a moderate certainty (Martin and Turner 2015).

- Sensitivity analysis on the operation of infrastructure and linkages to other projects is missing and will affect estimates of supply contribution.
- Adverse water quality impacts when water ponded on floodplains eventually returns to the channel (salt migration; anoxic blackwater; eutrophication).

Chowilla TLM Ecological Principles

The Basin Plan requires at least equivalent environmental outcomes to be achieved by supply measure projects. Projects are assessed under an ecological elements method developed by CSIRO and commissioned by the MDBA as per its responsibilities under Schedule 6 of the Basin Plan.

The Chowilla TLM business plan utilised conceptual models of the expected responses to managed inundation of the Chowilla Floodplain operating the Chowilla Regulator and the ancillary structures (see Monitoring Strategy for Chowilla Creek Regulator and ancillary structures, DEWNR 2014). While using conceptual models provides a useful simplification of key processes, it should be noted that management for one objective will directly or indirectly affect the ability to achieve other objectives. Hence, achieving successful managed inundations will not be as simple as just add water (DEWNR 2014).

Therefore, a set of ten Ecological Principles have been established to guide management actions. These are:

1. Managed inundations are not a substitute for natural floods

2. The scale of management actions will be adaptively managed so as to maintain conditions within the Basin Plan and other statutory water quality targets

3. Management will strive for a balance between maximising benefit and minimising the likelihood of identified hazards causing harm

4. Flow regime, history and components of pulses will be used in planning management actions

5. Management actions will be synchronised to river hydrology

6. Maintaining water exchange is a key priority

7. The source of water used in management actions will be taken into account

8. Outcomes from multi-site watering will be taken into account

9. Operating regimes will be flexible and responsive to emerging conditions

10. Management shall strive for a resilient, sustainable ecosystem

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APPENDIX 1– Victorian business case summaries and ecological risks

Project	**Type**	**Total cost & ownership/operation responsibilities**	**Stage**	**Complexity of works**	**Ecological Objectives**	**Changes in river hydrology**
Belsar Yungera	Supply measure	Approx. $55.6 million Ongoing maintenance costs estimated to be maximum $2.324 million annually Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)	New project→ Measures proposed will work in conjunction with proposed altered river operations and existing environmental infrastructure Seeking 100% of funding Mallee Catchment Management Authority (MCMA)	-Construction of 3 large regulators, 12 smaller supporting regulators, 2 culverts, 3.6km of track raising, a 4km low pressure pipeline and a fish passage which connect parts of the floodplain through tiered watering events -Operational by 2024	Inundation will promote the germination of aquatic plants which provide understory habitat for aquatic fauna, maintain the health and promote growth of tree communities and the important habitats they provide Key environmental outcome is to maintain the productivity and structure of Black Box Woodland which requires inundation on average 5-6 years in 10 for 4-8 weeks → this is not met under the current hydrologic regime Restore and enhance habitat linkages between the river and Narooyia Creek for Murray cod and other native fish : **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,1,14** Restore and enhance native fish habitat by improving the productivity of riparian zones and wetlands: **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,11,13, 14** Restore and enhance semi-permanent wetlands capable of supporting growling grass frog : **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,11,13,14** Maintain lignum shrubland as a frequently flooded and productive habitat for fish and	-The Basin Plan will primarily affect flows less than that required for floodplain watering -E.g. flows of 30,000ML/day will occur 6 times in 10 years under baseline, 8 times under basin plan and 9.5 naturally -By comparison flows of 80,000ML/day will occur 1.7 times in 10 years under baseline, 2 times under Basin Plan and 5 naturally -The measure can provide equivalent inundation to that of a 50,000ML/d flow event and the frequency of this event will increase from 3.8 to 7.2 events in 10 years - -

					waterbirds: **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,11,13, 14** Restore and enhance floodplain productivity to maintain resident populations of vertebrate fauna including carpet python and bats: **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,11,13, 14** Intermittently provide productive lake habitat for hundreds of waterbirds: **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,11,13, 14** Contribute to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 1,2,4,5,6,7,8,9,10,11,13, 14**	
Burra Creek	Supply measure	Approx. $12.1 million Ongoing maintenance and operation costs are estimated at a maximum of $500,000 annually Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government	New project Seeking 100% of funding MCMA	-Construction involves multiple regulators, raised track and levees and a drop structure (this will provide a plunge pool for a downstream fish passage) -Water controlled by B1. B2 and B4 regulators and a levee -Construction occurs on public	The project will address deficiencies in the water regime in the northern section of Burra Creek and adjacent lignum and black box floodplain vegetation Flooding the adjacent floodplain will improve vegetation health, productivity and connection with the River Murray and enable biota and nutrient exchange Restore seasonal aquatic habitat to Burra Creek: **meets associated Basin Plan objective 1,2,4,6,7,8,9,10,11,14** Restore floodplain productivity to maintain resident populations of vertebrate fauna including bats, sugar glider and lace monitor: **meets associated Basin Plan objective 1,2,4,6,7,8,9,10,11,14**	-Contribute towards bridging the gap between natural and baseline conditions -Environmental watering will occur for 3 main water regime classes: seasonal anabranch and billabongs, lignum shrubland and woodland and black box and red gum woodland -Inundation area of 407ha

		approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)		land with 76ha of private land inundated at the maximum level -Contingency forms 48% of the total costings	Contribute to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 1,2,4,6,7,8,9,10,11,14**	-The works would allow for frequency of inundation equivalent to 20,000ML/d with a maximum of 30,000ML/d flow events which would inundate 407ha of the Burra North floodplain
Goulburn	Constraints measure	Approx $140.12 million Ongoing cost of $1.1 million annually for operation and maintenance Delegation of asset ownership and operation cannot be confirmed at this time. Victoria currently has agreed arrangements in place through the BSOG to resolve asset ownership for its nine	New project→ complemented by a range of ongoing in stream and riparian works and the establishment of national parks Seeking 100% of funding Goulburn Broken Catchment Management	-Works enabling delivery of flow are relatively straightforward, including improved modelling and forecasting tools and the development of revised operational procedures -Cost of these actions are approx. $5 million	Increase the abundance, spatial distribution and size class diversity of key native fish species Increase the abundance and richness of aquatic and flood dependent native vegetation species Increase macroinvertebrate biomass and diversity Protect and promote natural channel form and dynamics (.e.g sediment diversity, rates of sediment transport and bank erosion rates) Increase instream physical habitat diversity (.e.g shallow and deep water habitats)	-Project would deliver target flows of up to 25,000ML-30,000ML/d at Shepparton during a controlled flood event -This would flood up to 12,000ha of the Goulburn floodplain which includes a maximum of 8,700ha of private land and 562 properties -Project aims to restore the frequency

		works-based supply measures and this would inform any arrangements that are finalised for the project	Authority (GBCMA)	-Cost of program management = $8.4 million -Cost of community and landholder engagement = $12.0 million -Majority of costs are associated with the mitigation of third party impacts (see risks table) **<u>Other:</u>** Key uncertainties are: -Actual frequency, timing and duration of environmental flows -Potential errors in inundation modelling -Economic assumptions -Appropriate balance between easement and infrastructure-based mitigation measures -Costs of engineering works	Provide sufficient rates of in-stream primary production and respiration to support native fish and macroinvertebrate communities Increased discharge from the Goulburn River through bank-full and overbank flows could also contribute to flow targets set for the central Murray system and further downstream as far as the Lower Lakes and Murray mouth In combination with other measures proposed for the River Murray channel, the project could offset operational constraints caused by the Barmah Choke	of minor flow peaks in the lower Goulburn River by delivering an additional 1 to 3 overbank flows (25,000ML/d) per decade for short durations -Target flows could be achieved by additional releases from Lake Eildon (limited to a maximum of 10,000ML/d to reduce impacts on the mid-Goulburn reach) and additional releases by ceasing diversions to Waranga Basin and passing these flows downstream over Goulburn Weir

Gunbower	Supply measure	$12.8 million Ongoing annual operation and maintenance costs estimated at $902,726 during operating years and $386,120 during non-operating years Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach'	New project Seeking 100% of funding North Central Catchment Management Authority (NCCMA)	-Infrastructure package involves the construction of a regulator, diversion weir, pump pads, short pipeline, remedial works, access tracks, irrigation channel, upgrade to three road culvert crossings and a forest regulator -Package designed to be operationally flexible, minimise adverse ecological and third party impacts and be cost-effective **<u>Other:</u>** -The project aims to connect the forests to an alternative water supply: the Torrumbarry Irrigation Area so the success of the	Enhance water-dependent ecosystems that support numerous listed threatened species and ecological communities Provide opportunities for connectivity between the River Murray and permanent wetlands within the forest (Black Charlie Lagoon) Provide wetting and drying phases that enhance ecological community structure and stimulate species interactions and food webs- this will also be tailored to meet the hydrological requirements of water-dependent values within the range of tolerance to maintain overall ecosystem resilience Provide Gunbower National Park with a watering regime that sustains the ecological character of the forest as without the project the area cannot be watered outside natural flood events (which are of an inadequate frequency and duration even under the proposed Basin plan) Protect and enhance a diversity of habitat types across the forest which will be critical to biota under a drying climate Healthy River Red Gum flood dependent understory and temporary wetlands Drought refuge habitat provided for fauna (particularly small-bodied native fish) in Black Charlie Lagoon	-Project will mimic a natural flood event of up to 50,000ML/d within the upper zone and up to 45,000ML/d in the central section across 500ha of the Gunbower National Park -This will be achieved by delivering water to the forest through 2 new supply inlets: Camersons Creek supply inlet (upgrade of natural connection) and Old Cahuna Main Channel supply inlet (construction of new connection to the existing irrigation system) -Prior to river regulation, flow events of 50,000ML/d occurred 52 in every 100 years and now occur 25 in every 100 years

				project depends on the physical capacity of the system to deliver the required flows, time of year and demand from other customers	Healthy wetland bird community through improved access to food and habitat that promotes breeding and recruitment	

Guttrum and Benwell	Supply measure	$28,449,309 (approx. $28.4 million) Estimated annual cost of $1.2 million of ongoing operation and maintenance Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach'	New project Seeking 100% of funding North Central Catchment Management Authority (NCCMA)	-Infrastructure package includes; construction of 2 inlet channels, connecting channels and regulator and levee works -17 landholders adjacent to project site -Main costs are associated with construction and ancillary works and risk management -Costs include estimated changes for delays due to weather, approvals and contingency	Maintain and restore healthy floodplain communities across Guttrum and Benwell Forests, to ensure that indigenous plant and animal species and communities survive and flourish Reinstate a more natural flooding regime that protects and enhances the ecological values within the Guttrum and Benwell Forests Restore the health of semi-permanent wetlands Restore the health of River Red Gum FDU Restore healthy wetland bird community, through improved access to food and habitat that promotes breeding and recruitment Enhance River Murray native fish populations by increasing access to productive floodplain outflows	-Works would inundate approx. 719ha in Guttrum Forest and 481ha in Benwell Forest through mimicking a 26,000ML/d flood event in the River Murray for Guttrum forest and a 24,000ML/d flood event for Benwell forest -Environmental water will be delivered via the irrigation channel system
Hattah Lakes North	Supply measure	$8,811,408 (approx. $8.8 million) -Maximum ongoing annual cost of	Project would complement existing works undertaken as	-Infrastructure package involves the construction of 2 regulators, a	Protect and restore floodplain productivity to maintain resident populations of vertebrate fauna including carpet python, lace monitor and bats: **meets associated**	-Up to 1,130ha will be inundated, including red gum and black box

		$695,000 for operation and maintenance Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)	part of the Living Murray Scheme Seeking 100% of funding MCMA	causeway and 1.7km of levees on track alignment -The project will build on infrastructure built under TLM scheme -Project site is part of 2 national parks, both of which are managed by Parks Victoria and 112ha of private land	**Basin Plan objective 1,2,4,6,7,8,9,10,11, 12, 13,14** Provide occasional breeding habitat for waterbirds: **meets associated Basin Plan objective 1,2,4,6,7,8,9,10,11,12** Maintain the health and age structure of red gum and black box trees: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Maintain a plant community of drought-tolerant wetland species in infrequently inundated areas: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Contribute to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 2,7** (Table 5-2, see below)	woodland vegetation communities -Inundation of black box woodlands requires flow events of 140,000ML/d -Operation of the measure and inundation will be via releases of water from the central lakes area behind the existing Oateys Regulator, constructed as part of TLM initiative -Other regulators will control flooding across floodplains and privately owned land

Table 5-2. Comparison of water regimes provided by natural, baseline, Basin Plan and the Hattah Lakes Natural, baseline, Basin Plan (Gippel, 2014)

Threshold (ML/d)	WRC	Scenario	Frequency Mean (/100 yrs)	Duration Median (days)	Event start date Median (day of year, 1 Jan = 1)
80,000	Red Gum Forest and Woodland	With Measure[1]	60	50	244
		Natural	50.9	55	252
		Baseline	17.5	40	258
		Basin Plan 2750 without measure	21.9	37	259
120,000	Black Box Woodland	With Measure[1]	25	30	244
		Natural	27.2	27	256
		Baseline	8.8	40	242
		Basin Plan 2750 without measure	9.6	41	237
140,000	Episodic Wetlands	With Measure[1]	15	30	244
		Natural	17.5	29	257
		Baseline	6.1	62	237
		Basin Plan 2750 without measure	7	37	236

[1] based upon interpretation of the preliminary operations plan adapted from Ecological Associates 2014c

Lindsay Island	Supply measure	$72, 831, 526 (approx. $72.8 million) -Annual operating and maintenance cost approx. $2.7 million Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)	New project → will work in conjuction with Mulcra Island and Chowilla infrastructure and other existing environmental infrastructure (e.g. TLM infrastructure such as Upper Lindsay inlet regulators, Lake Wallawalla regulators and Websters Lagoon) Seeking 100% of funding MCMA	-Construction of one main regulator with supporting works - The work involves construction of a regulator at Berribee, one vertical slot fish-way, 5 containment regulators and 2.6km of raised tracks in the 'primary component', the 'secondary component' involves 13 additional regulators, 4.9km of raised track and ancillary works at 5 locations	'To protect and restore the key species, habitat communities and functions of the Lindsay Island ecosystem by providing the hydrological environments required by indigenous plant and animal species and communities' (Ecological Associates 2014) Enhance Murray cod habitat by improving the productivity of connected riparian zones and wetlands while maintaining fast-flowing habitat: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Maintain resident populations of frogs and small fish in wetlands: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Provide reliable breeding habitat for waterbirds, including colonial nesting species: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Frequently provide habitat for thousands of waterbirds: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Protect and restore floodplain productivity to maintain resident populations of vertebrate fauna including carpet python, insectivorous bats and Giles' plaingale: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Contribute to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14**	-The primary component will inundate 3546ha of the Lindsay Island floodplain -Watering will occur mimicking flows of 40,000ML/d to greater than 120,000ML/d

Nyah Floodplain	Supply measure	$10,942,589 (approx. $10.9 million) -Ongoing annual cost of $525,046 for operation and maintenance Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)	New project Seeking 100% of funding MCMA	-Construction involves 4 new regulators and 1.648km of low level track raising to form a levee -Located entirely on Crown Land, managed by Parks Victoria	Restore the vegetation structure of wetland plant communities: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Re-establish resident populations of frogs and small fish: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Provide seasonal feeding and reproductive opportunities for riverine fish species: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Provide reliable breeding habitat for waterbirds, including colonial nesting species: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Restoring floodplain productivity to maintain resident populations of vertebrate fauna including carpet python, sugar glider and grey crowned babbler: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Contribute to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14**	-The works will allow a natural water regime (up to 25,000ML/d) to be replicated across 488 hectares of inundation dependent habitat -Proposed works allow for this inundation to be achieved at much lower River Murray flows -Project aims to affect the following water regimes: seasonal anabranch, seasonal wetland, red gum swamp forest and red gum forest and woodland

Vinifera Floodplain	Supply measure	$9,122,148 (approx. $9.1 million) Ongoing maintenance and operation costs at a maximum of $472,692 annually Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)	New project Seeking 100% of funding MCMA	-Primary infrastructure works include 2 box regulators and a levee with overflow sills and a drop structure (much like the Nyah Floodplain/Burra Creek cases) -Located entirely on Crown Land within Vinifera Park	Restore vegetation structure of wetland plant communities: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Re-establish resident populations of frogs and small fish: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Provide reliable breeding habitat for waterbirds, including colonial nesting species: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Restoring floodplain productivity to maintain resident populations of vertebrate fauna including carpet python, sugar glider and grey-crowned babbler: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Contribute to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14**	-Project will result in the inundation of 350ha of inundation-dependent habitat through the replication of flows of up to 20,000ML/d -This event would require 2,743ML of volume -Without the proposed works, inundation of the area would require more substantial River Murray flooding events -Watering regime will benefit seasonal wetlands, red gum swamp forest and red gum forest and woodlands

Wallpolla Island	Supply measure	$59,523,808 (appox $60 million) Ongoing maintenance and operation costs expected to be maximum $2,508,572 million annually Delegation of asset ownership and operation, including any financial responsibility cannot be formally ascertained at this time as it requires a 'whole-of-government approach' (ie. Would be managed by a Victorian agency such as DEPI, Mallee CMA, North Central CMA, Parks Victoria or G-MW)	New project Seeking 100% of funding MCMA	-Works include construction of 4 main regulators, a fishway, 22 containment and regulation support structures and 4.5km of raised track -Works comprise 3 main components, Mid Wallpolla, Upper Wallpolla and Wallpolla South with each area having a different target inundation level -Works are also designed to complement weir pool manipulation activities	Increase resident populations of frogs, waterbirds and small fish in wetlands: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Provide reliable breeding habitat for waterbirds, including colonial nesting species: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Enhance local populations of channel specialist fish by augmenting anabranch habitat and improving the productivity of connected riparian zones and wetlands: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Frequently provide habitat for thousands of waterbirds: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Protect and restore floodplain productivity to maintain resident populations of vertebrate fauna including carpet python, insectivorous brats and Giles planigale: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14** Contributing to the carbon requirements of the River Murray channel ecosystem: **meets associated Basin Plan objective 1,2,3,4,6,7,8,9,10,11,12,13,14**	-The project would inundate 2,651ha of Wallpolla Island floodplain, wetlands and river benches -Flows of 30,000ML/d up to 120,000ML/d -Key watering objective is to maintain productivity and structure of black box woodlands which require inundation 3 years in every 10 for 2-6 weeks, requiring a flow of 100,000ML/d -This is not currently being achieved -There will be 4 different environmental watering infrastructure for Wallpolla Island to manage operational scenarios -Watering will mainly be managed through 2 main regulators and infrastructure

BUSINESS CASE ASSESSMENT OF ECOLOGICAL RISK FOR VIC PROJECTS
Belsar Yungera

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Adverse salinity impacts or water quality outcomes as a result of watering actions; particularly hypoxic blackwater events -Rise in river salinity from salt migration from floodplain soils as a result of works is considered a high risk without mitigation and a moderate risk with mitigation. Involves additional groundwater monitoring bores	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic areas and watering will commence as early as possible to move organic matter from the floodplain -Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration	Moderate
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp -Use time water manipulations to drown non-native seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and	Moderate/Low (moderate risk of an increase of carp and pest animals and low risk of proliferation of pest plants)

			support partner agencies to seek further funding for targeted weed control programs if necessary	
The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of river red gum in open wetlands/watercourses	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate
Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish and other aquatic fauna movement	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Develop a 'fish exit strategy' to ensure a fish passage is maintained for as long as possible for fish to move off the floodplain during the drawdown stage	Low

Burra Creek (same as Belsar Yungera)

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Adverse salinity impacts or water quality outcomes as a result of watering actions; particularly hypoxic blackwater events	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic areas and watering will commence as early as possible to move organic matter from the floodplain -Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration	Moderate
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp -Use time water manipulations to drown non-native seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and support partner agencies to seek further funding for targeted weed control programs if necessary	Moderate/Low (moderate risk of an increase of carp and pest animals and low risk of proliferation of pest plants)

The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of river red gum in open wetlands/watercourses	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate
Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish and other aquatic fauna movement	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Develop a 'fish exit strategy' to ensure a fish passage is maintained for as long as possible for fish to move off the floodplain during the drawdown stage	Low

<u>Gunbower</u>

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Abundance of pest fish species	Almost certain	Very high	-Watering regime will provide temporary inundation of areas which will be dried out and targeted flows rather	High

			than a single large flow means pest fish cannot disperse from the forest into Gunbower Creek or the River Murray downstream and will be retained in the temporary wetlands as food for wetland birds -Proposed screening of adult pest fish for forest inlets -Carp screen on the inlet regulator to Black Charlie Lagoon/Baggots Creek area -Young carp are still able to enter the system and grow to adult size -Residual risk after the addition of a carp screen on one inlet regulator is still high as other crossings have fish passages which would be blocked by a screen	
Adverse impacts on water quality and salinity downstream	High	Low	-Salinity impact at Morgan under the operating scenarios was estimated at <0.01 µS/cm EC) (negligible) -Potential of blackwater events due to floodplain watering scenario but the risk of causing ecological impacts is considered low -No formal understanding of any potential cumulative impacts -No mention of mitigation strategies to avoid or manage blackwater events	Not stated
Impaired river connectivity	None	-	-Project does not alter the existing connectivity between the River Murray and Gunbower National Park -All through-flows and return flows to the River Murray are retained at their current rates/levels -Important to note that delivery of environmental water to the central forest floodplain will be from Old Cohuna Main Channel rather than the River Murray (this option	N/A

			was investigated under TLM) which means it will not provide connectivity with the River Murray -This connectivity will occur through natural and hybrid events (where environmental water tops up natural inflows)	

Guttrum and Benwell

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Abundance of pest fish species	Almost certain	Very high	-Due to semi-permanence of wetlands the risks of carp are temporary and short-lived as the floodplains will dry -Screening of adult pest fish for forest inlets -Carp screens with rotating screens (self-cleaning) will be considered for installation to minimise operational maintenance requirements -Main mitigation measure will be control of water releases and consideration of drying/wetting patterns and pest fish species habitats	High
Fish stranding	Likely	High	-Coarse screens at the inlets to prevent entry of large-bodied fish into forests -Sequencing water to maximise cues and exit routes -Recent evidence from Gunbower Forest suggests the above style of fish exist strategy is very successful with flow changes cueing native fish to leave the floodplain -Routine monitoring	Low
Giant Rush colonisation	Possible	High		Moderate

			-Maintain strong seasonal profile to flooding regimes with peaks in spring and a recession over late spring and summer will reduce risk as giant rush invasion is influenced by seasonal conditions -Monitoring and consideration of other plans/modifications to operating scheme	
River Red Gum encroachment	Unlikely	High	-Can reduce diversity and is influenced by damp soils and warm temperatures -Flooding regimes that include prolonged inundation, high temperatures over summer and frost during the winter provide the best conditions for preventing encroachment -Extending the drawdown period to late summer/early autumn in lie with natural drawdown periods will counteract encroachment -Red Gum's could also be physically removed but this is labour intensive and a last resort	Low
Water quality/Blackwater/Salinity downstream -High risk of blackwater events, however, these are unlikely to affect water quality in the Murray River due to small outflows and a full assessment of impacts on downstream water quality would be undertaken should the project be approved	Likely	High	-Estimated salinity impact expected to be negligible at Morgan -Blackwater events would be localised and this would be managed through the operating and watering scheme -Managing inflows/outflows and dilution from the River Murray -Cumulative impacts and downstream impacts cannot be ascertained	Low

Hattah Lakes North (same as Belsar Yungera)

Mitigation measures to be undertaken are detailed and have been effective in previous environmental infrastructure projects undertaken in the region under TLM scheme

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Salinity -A preliminary salinity assessment has been completed which suggests groundwater levels are currently higher than historic levels and that successive watering events coupled with natural floods would not significantly increase salt loads	Likely	Moderate	-Avoid watering salinity hotspots identified through the use of AEM datasets, instream nanoTEM and other salinity investigations -Monitor the salinity of ground and surface water salinity before, during and after watering events to inform management and ensure sufficient volumes are available for mitigation such as dilution	Low
Adverse water quality outcomes as a result of watering actions; particularly hypoxic blackwater events	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic areas and watering will commence as early as possible to move organic matter from the floodplain	Moderate

			-Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration	
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp -Use time water manipulations to drown seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and support partner agencies to seek further funding for targeted weed control programs if necessary	Moderate/Low (moderate risk of an increase of carp and pest animals and low risk of proliferation of pest plants)
The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of river red gum in open wetlands/watercourses	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate

Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish and other aquatic fauna movement	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Develop a 'fish exit strategy' to ensure a fish passage is maintained for as long as possible for fish to move off the floodplain during the drawdown stage	Low
Consideration of significant, threatened or listed species	N/A	N/A	-The project is expected to benefit these species by increasing the frequency, duration and extent of floods -Construction will result in temporary and permanent vegetation removal and habitat disturbance -Detailed ecological assessments will be carried out during the design process to inform construction activities	

Lindsay Island

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Salinity	Likely	Moderate	-Avoid watering salinity hotspots identified through the use of AEM datasets, instream nanoTEM and other salinity investigations -Monitor the salinity of ground and surface water salinity before, during and after watering events to	Low

			inform management and ensure sufficient volumes are available for mitigation such as dilution	
Adverse water quality outcomes as a result of watering actions; particularly hypoxic blackwater events	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic areas and watering will commence as early as possible to move organic matter from the floodplain -Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration	Moderate
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp -Use time water manipulations to drown seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and support partner agencies to seek further funding for targeted weed control programs if necessary	Moderate/Low (moderate risk of an increase of carp and pest animals and low risk of proliferation of pest plants)

The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of river red gum in open wetlands/watercourses	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate
Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish and other aquatic fauna movement	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Incorporate fish passage requirements into regulator design which includes a vertical slot fishway at Berribee regulator and fish-friendly designs to allow passive passage at other regulators	Low
Episodic reduction in hydrodynamic diversity -Installation of regulators within waterways will affect flows and create lentic ones in regulator pools when in	Likely	High	-Design structures to minimise waterway obstruction -Develop operational protocols to maintain hydraulic diversity -Assess the response of species of concern during and after managed watering events and adjust operational arrangements if required	Moderate

operation which may reduce the extent and variety of aquatic habitat and change the structure and diversity of wetland floodplain communities -In particular, regulator operation is likely to reduce or eliminate fast-flowing habitat that is particularly important to some fish species e.g. Murray cod				
Prolonged inundation of vegetation within the Berribee Regulator pool -May damage vegetation health and result in death of less tolerant species	Possible	Moderate	-Ensure through-flow when operating structures to more closely replicate a more natural hydraulic gradient -Incorporate information on operations, potential impacts and tolerance of inundation regimes and the role of natural floods in ecosystem function into operational plans to minimise impact	Low
Consideration of significant, threatened or listed species	N/A	N/A	-The project is expected to benefit these species by increasing the frequency, duration and extent of floods -Construction will result in temporary and permanent vegetation removal and habitat disturbance -Detailed ecological assessments will be carried out during the design process to inform construction activities -The Mullaroo Creek and Lindsay River are widely acknowledged for their significant native fish populations (particularly Murray Cod) which may be affected by operation	

			-The design of minor regulators allow for passive fish passage and a vertical slot fishway that matches the specification of the fishway on the Mullaroo Creek Regulator (under construction through TLM) is proposed at the Berribee Regulator -The hydraulic model mirrors the approach taken for the recently commissioned Chowilla Floodplain Living Murray works where fish ecologists have worked in conjunction with hydraulic modellers to develop appropriate operational scenarios	

Nyah Floodplain

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Salinity	Likely	Moderate	-Avoid watering salinity hotspots identified through the use of AEM datasets, instream nanoTEM and other salinity investigations -Monitor the salinity of ground and surface water salinity before, during and after watering events to inform management and ensure sufficient volumes are available for mitigation such as dilution	Low
Adverse water quality outcomes as a result of watering actions; particularly hypoxic blackwater events	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic	Moderate

			areas and watering will commence as early as possible to move organic matter from the floodplain -Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration -Should water quality be affected, water can be disposed within the site (pump to higher wetlands)	
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp -Use time water manipulations to drown seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and support partner agencies to seek further funding for targeted weed control programs if necessary	Moderate/Low (moderate risk of an increase of carp and pest animals and low risk of proliferation of pest plants)
The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate

river red gum in open wetlands/watercourses				
Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish and other aquatic fauna movement	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Develop a 'fish exit strategy' to ensure a fish passage is maintained for as long as possible for fish to move off the floodplain during the drawdown stage	Low
Consideration of significant, threatened or listed species	N/A	N/A	-The project is expected to benefit these species by increasing the frequency, duration and extent of floods -Construction will result in temporary and permanent vegetation removal and habitat disturbance -Detailed ecological assessments will be carried out during the design process to inform construction activities	

<u>Vinifera Floodplain (same as Lindsay Island)</u>

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Salinity	Likely	Moderate	-Avoid watering salinity hotspots identified through the use of AEM datasets, instream nanoTEM and other salinity investigations	Low

			-Monitor the salinity of ground and surface water salinity before, during and after watering events to inform management and ensure sufficient volumes are available for mitigation such as dilution	
Adverse water quality outcomes as a result of watering actions; particularly hypoxic blackwater events	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic areas and watering will commence as early as possible to move organic matter from the floodplain -Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration	Moderate
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp -Use time water manipulations to drown seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and	Moderate/Low (moderate risk of an increase of carp and pest animals and low risk of proliferation of pest plants)

			support partner agencies to seek further funding for targeted weed control programs if necessary	
The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of river red gum in open wetlands/watercourses	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate
Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish and other aquatic fauna movement	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Incorporate fish passage requirements into regulator design which includes a vertical slot fishway at Berribee regulator and fish-friendly designs to allow passive passage at other regulators	Low
Episodic reduction in hydrodynamic diversity	Likely	High	-Design structures to minimise waterway obstruction -Develop operational protocols to maintain hydraulic diversity	Moderate

-Installation of regulators within waterways will affect flows and create lentic ones in regulator pools when in operation which may reduce the extent and variety of aquatic habitat and change the structure and diversity of wetland floodplain communities -In particular, regulator operation is likely to reduce or eliminate fast-flowing habitat that is particularly important to some fish species e.g. Murray cod			-Assess the response of species of concern during and after managed watering events and adjust operational arrangements if required	
Consideration of significant, threatened or listed species	N/A	N/A	-The project is expected to benefit these species by increasing the frequency, duration and extent of floods -Construction will result in temporary and permanent vegetation removal and habitat disturbance -Detailed ecological assessments will be carried out during the design process to inform construction activities	

Wallpolla Island

Risk	*Likelihood*	*Risk without mitigation*	*Mitigation*	*Risk after mitigation*
Adverse salinity impacts including saline mounds	Likely	Moderate		Low

-High risk that increases in salinity may breach Basin Salinity Management Strategy requirements			-Avoid watering salinity hotspots identified through the use of AEM datasets, instream nanoTEM and other salinity investigations -Monitor the salinity of ground and surface water salinity before, during and after watering events to inform management and ensure sufficient volumes are available for mitigation such as dilution -5 new bore sites and upgrades and maintenance of existing water monitoring systems	
Adverse water quality outcomes as a result of watering actions; particularly hypoxic blackwater events	Likely	High	-Involves planning, operations and managing consequences phases -Firstly, a consideration of seasonal conditions and monitoring of antecedent floodplain conditions are taken into account before watering events -Secondly, during a watering event through-flows will be maintained where possible, DO and water temperature will be monitored to identify hypoxic areas and watering will commence as early as possible to move organic matter from the floodplain -Finally, if blackwater events do occur this will be managed by delaying outflows if river flows are low or otherwise managing outflows and river flows to dilute low DO water, disposing of hypoxic water by pumping to higher wetlands and agitating water using infrastructure to increase aeration	Moderate
Increase in pest species	Certain	Very High	-Tailor watering regimes to provide competitive advantage for native fish over carp -Dry out wetlands that contain large numbers of carp	Moderate/Low (moderate risk of an increase of carp and pest animals and low

			-Use time water manipulations to drown seedlings, minimise growth, germination and seed set and to promote native species -Control current populations of pest plants and animals via existing management strategies and support partner agencies to seek further funding for targeted weed control programs if necessary	risk of proliferation of pest plants)
The potential to favour certain species to the detriment of others or to adversely affect certain species -Through the destruction of habitat or habitat disturbance or invasion of river red gum in open wetlands/watercourses	Certain	Moderate to Very High	-Utilise existing access tracks, ensure clear on-site delineation of construction zones, ensure adequate supervision during works and design and locate infrastructure to minimise the extent of clearing wherever possible to minimise construction impacts on habitat -Remediate site on completion of construction activities	Low to moderate
Adverse impacts on ecological function and connectivity -Prolonged inundation of vegetation, increase in fire frequency/intensity, flow regimes do not match requirements for key species, stranding of fish on floodplains, barriers to fish	Possible	Moderate	-No mitigation actions identified for fire management -Assess the response of certain species of concern to watering events and adjust operations if required -Target different taxa at different times -Ensure through-flows replicate a more natural hydraulic gradient -Design structures for maximum operational flexibility -Incorporate fish passage requirements into regulator design which includes a vertical slot fishway at Berribee regulator and fish-friendly designs to allow passive passage at other regulators	Low

and other aquatic fauna movement				
Episodic reduction in hydrodynamic diversity -Installation of regulators within waterways will affect flows and create lentic ones in regulator pools when in operation which may reduce the extent and variety of aquatic habitat and change the structure and diversity of wetland floodplain communities -In particular, regulator operation is likely to reduce or eliminate fast-flowing habitat that is particularly important to some fish species e.g. Murray cod	Likely	High	-Design structures to minimise waterway obstruction -Develop operational protocols to maintain hydraulic diversity -Assess the response of species of concern during and after managed watering events and adjust operational arrangements if required	Moderate
Mismatch between vegetation requirements and internal regulator pool operation -Vegetation in the deepest part of the Mid-Wallpolla Weir pool may receive excessive inundation (duration and depth) if the	Possible	Moderate	-Ensure through-flow when operating structures (including consideration of raising the upstream head via Lock 9) to more closely replicate a more natural hydraulic gradient -Incorporate information on operations, potential impacts and tolerance of inundation regimes and the role of natural floods in ecosystem function into operational plans to minimise impact	Low

inundation requirements of vegetation at the perimeter of the pool are met→ this would cause localised impacts on vegetation health and possible death of less tolerant species				
Consideration of significant, threatened or listed species	N/A	N/A	-The project is expected to benefit these species by increasing the frequency, duration and extent of floods -Construction will result in temporary and permanent vegetation removal and habitat disturbance -Detailed ecological assessments will be carried out during the design process to inform construction activities -Operation of the project could have adverse impacts on threatened species as the waterways and wetlands of Wallpolla island support significant native fish populations -Design allows for passive fish passages through minor structures and a vertical slot fishway at the structure 1 regulator and these measures will allow the movement of small and large bodied fish during a range of operational scenarios -All structures designed to allow fish movement even when not in operation -The approach to hydraulic modelling is taken from the Chowilla Floodplain Living Murray works	

Third Party Risks: including reliability in a range of scenarios, risk to items of national significance and also public/private land impacts

Project	*Third Party Impacts*	*Reliability of structure in a range of scenarios*

Belsar Yungera	-770ha of private land inundated during the maximum inundation event, some of which is protected under conservation covenants or as an offset → no agreements have been made, however, preliminary discussions have been generally supportive of the project	-The works have been designed to provide maximum operational flexibility and 6 scenarios have been developed; Default: default configuration when there are no watering events Seasonal fresh: aimed at allowing water to flow through Narcooyia creek during Basin Plan flows (>10,000ML/d) Belsar intermediate: enable watering of Red Gum forest and woodland on lower floodplains (30,000-50,000ML/d) Belsar Island maximum: broadscale of inundation of areas mentioned above and also Black Box Woodland (50,000-90,000ML/d) Lakes Powell and Carpul : As above (170,000ML/d with Belsar Maximum) Natural inundation: all structures are open during natural floods to allow full connectivity -High operational flexibility and assurance the irrigation supply and access to irrigation infrastructure is maintained at all times
Burra Creek	As the area of private land inundated in the maximum flow event is relatively low (76ha) and operation would mostly occur under the maximum, this factor is not considered critical to the feasibility of the project	-5 watering scenarios; default, seasonal fresh (20,000ML/d), Burra intermediate (20,000-30,000ML/d), Burra maximum (30,000ML/d) and natural inundation (>30,000ML/d) -Watering decisions and operating scenarios will be based on water availability, floodplain water requirements, ecological targets, operational risks and regional context
Goulburn	-High cost of private and public land and infrastructure mitigation actions totaling approx. $113 million -Mitigation of third party impacts involves acquisition of easements over private land and other works which would cost an estimated $32 million (included in above figure)	Not stated

	-Total project cost also included inundation modelling, groundwater and hydrologic modelling and risk studies which have not yet been conducted and current costing are based on assumptions -The Shepparton Irrigation region has a long history of land and water management so there is considerable knowledge of groundwater and salinity in the area -The risk assessment panel deemed salinity risks associated with the project to be low as; the floodplain contains relatively fresh groundwater, groundwater levels are deep and there is only moderate potential for vertical infiltration or lateral movement → mitigation includes upgrades in water table monitoring and assessments	
Gunbower	-High risk of third party impacts; including loss of recreation, heritage and flooding but these are localised -Feasability assessment states the project has minimal adverse ecological and third party impacts, is non-intrusive and is low in cost to construct and operate	-The project will be operationally flexible -There are 2 separate, parallel scenarios -These are permanent wetland watering and forest floodplain watering -These scenarios can be delivered either as standalone watering events or as 'hybrid events' to enhance unregulated flows -The project must consider the demand of irrigation and all scenarios have acknowledged the issue of capacity availability and believe the impact would be negligible but it has not been modelled
Guttrum Benwell	-Third party flooding expected only if existing levees fail and would be	-Watering events will occur in 3 phases: filing phase, maintenance phase and drawdown phase

	mitigated by ongoing maintenance and potential upgrades→ low risk -Levees provide protection from floods of a greater level than the 26,000ML/d maximum of the project	-There are 3 operating scenarios: river red gum watering, semi-permanent wetland watering and hybrid events **Other:** -Return flows to the River Murray will occur under the forest floodplain watering scenarios in each forest and environmental water will be retained within the wetland systems before gradually infiltrating and evaporation
Hattah Lakes North	-Does inundate private land but agreements with landowners would not be made until project approval	-Four operating scenarios; default, river red gum, black box, natural flood Default: all regulators open allowing natural flows River red gum: involves synchronisation between existing TLM works and proposed works to deliver flows of 80,000ML/d Black box: managed by regulators, TLM operations and temporary pumps >120,000ML/d Natural flood: all regulators open to allow full connectivity and minimise impact of infrastructure on natural flooding patterns -Decisions to initiate watering events will be based on water availability, water requirements, operational risks and regional context
Lindsay Island	-No comprehensive evaluation of the extent and impacts of inundation on third parties ie. Private landowners	-Variety of operational scenarios Default: default configuration during normal regulated flows Seasonal fresh: utilises Upper Lindsay and Mullaroo creek regulators and the raising of Lock 7 and aims to stimulate spawning of golden perch, silver perch and Australian smelt and maintains fast-flowing habitat for Murray cod (>10,000ML/d) Berribee intermediate: targets lower floodplains with all regulators open except for Berribee and Lock 7 raised above normal operating level; aims are to provide wetland habitat for aquatic fauna and good conditions for red gum and lignum (30,000-50,000ML/d) Berribee maximum: maximum inundation; targets upper floodplain; all regulators open but waterflow monitored and released gradually; suitable for watering red gum and black box communities (50,000-90,000ML/d)

		Berribee maximum and pumping: variation of above scenario; utilises temporary pumps to increase flooded area by 1000ha; enables large areas of black box woodland to be watered (170,000ML/d) Natural inundation: all regulating structures open to allow connectivity; outcomes depend on the magnitude and duration of river flows Watering is seasonably based and subject to water availability, water requirements, operational risks and regional context
Nyah Floodplain	-No comprehensive evaluation of the extent and impacts of inundation on third parties ie. Private landowners	-5 operating scenarios Default: default configuration of water management structures (all structures open) Seasonal fresh: all environmental regulators open; ideal for seasonal anabranch (>13,000ML/d) Nyah intermediate: intermediate operation of the Nyah regulators and their associated support structures to enable watering of Parnee Malloo Creek, low level floodplain wetlands and lower floodplains without inundating upper flood plain areas; ideal for seasonal wetland (up to 17,500ML/d) Nyah maximum: maximum operation of regulators and support structures to enable flooding to upper floodplains; ideal for red gum swamp forest (up to 20,000ML/d) Natural flooding: full connectivity; ideal for red gum forest and woodland (>20,000ML/d) -High degree of operational flexibility in situations relevant to water availability, water requirements, operational risks, regional context -Mimicking natural variability allows for a diverse range of inundation events which restores patterns of vegetation present pre-regulation conditions
Vinifera Floodplain	-No impacts on private land -Impacts on public land are related to recreational uses and easily mitigated	-Watering will be monitored and facilitated by the V1, V2 and V4 regulators -5 operating scenarios Default: normal regulated flows and all environmental structures open Seasonal fresh: provide flow along Vinifera Creek and is achieved through suitable Murray River flows; all environmental regulators in default position; ideal for Vinifera Creek (>13,000ML/d) Vinifera intermediate: intermediate operation of Vinifera regulators to enable watering of creek and lower floodplain; ideal for creek and seasonal wetland (up to 17,500ML/d)

		Vinifera maximum: maximum operation of Vinifera regulators to enable watering of creek and upper floodplain areas; ideal for red gum swamp forest (up to 20,000ML/d) Natural inundation: all regulating structures open to allow connectivity; ideal for red gum forest and woodland (>20,000ML/d) -High degree of operational flexibility -Environmental watering scenarios and timing based on water availability, water requirements, operational risks and regional context
Wallpolla Island	-At maximum inundation, the project would flood 817ha of private land with a single landholder who's land has previously been watered by the MCMA and a letter of support was provided in the appendix -Flooding of private land can also be avoided by not operating at the maximum level	-6 operating scenarios Default: normal regulated flows; all structures open Seasonal fresh: targets in-channel flows and is achieved by opening all structures to allow water to flow through Finnigans and Wallpolla Creek; ideal for watercourses (up to 40,000ML/d) Mid Wallpolla maximum: structure 1 and associated structures operating to maximum height to enable inundation of Mid-Wallpolla; this scenario also takes advantage of high river flows; ideal for watercourses, semi-permanent wetlands and temporary wetlands (60,000ML/d) Mid and Upper Wallpolla maximum: structure 1 and 4 regulators and associated structures operated to maximum height to inundate mid and upper Wallpolla; ideal for watercourses, semi-permanent wetlands and temporary wetlands (80,000ML/d) Mid and Upper Wallpolla and pumping: variation of above scenario; additional water delivered to Wallpolla South through temporary pumps; ideal for black box woodland and occasionally, alluvial plain (100,000ML/d) Natural inundation: all environmental operating mechanisms open to allow connectivity -Transitions between scenarios influence by mitigation management; inflows; natural flooding events and ecological opportunities -Environmental watering scenarios and timing based on water availability, water requirements, operational risks and regional context

APPENDIX 2 - SA business case summaries and ecological risks
Project: Chowilla floodplain Supply measure

Summary	**Total cost & ownership/operation responsibilities**	**Stage**	**Complexity of works**	**Ecological Objectives**	**Changes in river hydrology**	**Third Party Impacts**
Chowilla Floodplain contains the largest remaining area of natural river red gum. The area is compromised of 100km of anabranch creeks, which spread into a series of temporary wetlands during high river flows creating an area of outstanding environmental significance. Flows through the anabranch system result in a mosaic of flowing water habitats now rare in the lower Murray. Flow regulation and diversions have reduced flooding frequency and elevated saline groundwater levels. A number of works have already been undertaken on the Chowilla Floodplain as part of the TLM scheme, this proposal aims to use these in conjunction with the River Murray locks and weirs to provide a mechanism to enable areas of the floodplain to be inundated.	The Environmental Water Operations group within River Murray Operations and Major Projects branch of the SA DEWNR is responsible for delivering TLM program at Chowilla. SA Water is the 'operational agent' of the Minister for Water, thereby operating and maintaining works on the Chowilla Floodplain. No costings for the particular project provided in the documents. Construction as part of TLM scheme is funded through the MDBA Environmental Works and Measures Program. Cost and budget for ongoing works can be seen in the MDBA Corporate Plan.	Phase 2 Assessment for consideration as part of existing TLM Environmental Works and Measures at Chowilla Floodplain. SA Water, Murray Darling Basin Authority (MDBA) & Government of South Australia (Department of Environment, Water and Natural Resources) (DEWNR)	Complex planning, operations and management procedures which involves the collaboration of a variety of government agencies. Environmental watering proposals will be presented to land managers from SA and NSW (DEWNR & NSW Office of Water) and SA Water (involves collaboration between SA and NSW). Involves using existing, new and upgraded structures to manage the delivery of water to the Chowilla Floodplain. No additional construction.	3 broad ecological objectives: High value wetlands maintained Current area of river red gum maintained At lest 20% of the original area of black box vegetation maintained. Improve the health, abundance and distribution of fauna and flora species. Maintain or increase the diversity and extent of distribution of native fish species and restrict the abundance and biomass of introduced fish species. Ensure water quality is maintained through avoiding unacceptable salinity levels and monitoring biogeochemical processes, turbidity and dissolved oxygen levels. Restore and enhance floodplain connectivity through improving and maintaining carbon processes, flow regimes and sedimentation and erosion. Establish groundwater conditions conducive to improving vegetation condition & avoid fringe degradation due to soil salinization in areas where ground water levels fluctuate in the absence of inundation.	The real-time management of water required by SA for all purposes (including environmental water) is coordinated by DEWNR in liaison with SA Water and the MDBA. Operation of the Chowilla Floodplain infrastructure may occur in conjunction with other icon sites and environmental water activities-> floodplain restoration projects are underway downstream at Pike and Katarapko floodplains and future Chowilla watering would need to be planned in conjunction with these sites. Up to 15 structures can be used to manage environmental watering on the Chowilla Floodplain. Water management actions include; No action Delivery of water to individual wetlands (pumping and/or gravity) Weir pool manipulation- raising of the Lock 6 weir pool in conjunction with operation of the Chowilla regulator to inundate the floodplain	Range of land tenure applies for the Chowilla Floodplain; SA Government are the landowner for the SA portion (excluding 17.3ha of freehold land), which consists of several land tenures including; Chowilla Game Reserve (gazetted under the National Parks and Wildlife Act 1972 (SA), Chowilla Station, Freehold, Kulcurna (NSW portion)

					Pulse flows via Pipeclay and Slaney weirs In-channel rise (using the regulator) Managed inundations (using the regulator) and; Manage hydrograph recession (using the regulator). Low floodplain inundation= approx 50,000ML/day Mid-floodplain inundation= approx 75,000ML/day Maximum-floodplain inundation=approx 90,000ML/day At flows >50,000ML/day river operations are in 'flood' mode, meaning structures may need to be deactivated to avoid damage to the structures. The limit at which flows will have inundated access tracks and precluded ability to access structures in order to manager the recession of the hydrograph is approx 60,000ML/day	

Project: South East Flows Restoration Project (SERFP) Supply measure

Summary	**Total cost & ownership/operation responsibilities**	**Stage**	**Complexity of works**	**Ecological Objectives**	**Changes in river hydrology**	**Water Saving**
Broad scale land clearance, drainage networks and drought have severely impacted on the ecological health of the Coorong and Lakes Alexandrina and Albert Wetland (which have international importance). These have caused dramatically reduced water levels and years without flows over the barrages resulted in low water levels, habitat destruction and hypersaline conditions in the Coorong South Lagoon. Due to the extreme salinity, the Coorong South Ecosystem collapsed and key aquatic plant species were loss and small-bodied fish species withdrew to the North Lagoon and Murray Mouth. Since 2010, significant flows over the barrages have restored salinity	The $60 million SEFRP is fully costed and funded through the Coorong, Lower Lakes and Murray Mouth Recovery Project Schedule SA-07 to the South Australian and Commonwealth Water Management Partnership Agreement No additional Commonwealth funding is required through the SDL adjustment mechanism for project delivery (this document) The State of SA is responsible for managing the existing South East Drainage system which includes existing drains (e.g. Tilley Swamp, Taratap and Blackford), wetlands and environmental assets through the South Eastern Water Conservation and Drainage (SEWCD) Board. While DEWNR is delivering the project in agreement with the SEWCD Board, the SEWCD will ultimately be the managing authority once construction is completed.	Submission of the SEFRP for Phase 2 Assessment by the SDL Adjustment Assessment Committee Project delivery already underway The SEFRP is a sub-project of the SA Government's priority project Murray Futures: CLLMM Recovery Project	The SEFRP project will construct the SEFRP channel which will use a combination of widening existing drains (totalling 81km) and newly constructed drains (totally 12km) to divert additional water from the Upper South East into the Coorong South Lagoon. This includes the upgrade to the existing Tilley Swamp and Taratap drains, and the construction of a section of new drain connecting the Blackford Drain to the Taratap drain to allow the Taratap and Tilley Swamp Conservation Park wetlands to be more frequently inundated The fresh water delivered to Coorong Lagoon will be in addition to the estimated median	Overriding ecological objectives are to; -Help maintain salinity between the target-management ranges of 60g/L and 100g/L in order to ensure that the lethal effects of high salinity on the ecosystem are mitigated during periods of low barrage flows -The Tilley Swap and Taratap ('en route') wetlands benefit from the provision of additional flows Increase the resilience of the Coorong South Lagoon ecosytem Restablish lost species, such as the aquatic plant Ruppia tuberosa to pre-drought extent It is important to note that post-drought when high barrage flows were reintroduced to the region, this had a significant impact on the improvement of ecosystem health- specifically the regrowth of Ruppia tuberosa and reintroduction of macroinvertebrate species as well as reduced salinity.	Depending on the water requirements of the Coorong South Lagoon; delivery of water will be managed by- -Ancillary structures to deliver flow from the proposed channel to local en route wetlands (Taratap & Tlley Swamp) -The weir on Blackford Drain to divert flow into the proposed drain -Releases made from Morella Basin to the Coorong South Lagoon at the end of the system With the construction of new and upgrade of existing drainage channels, channel capacity will range between 1,300ML/day and 800ML/day and has the potential to deliver and additional 5-45.3GL of environmental water per year directly into the Coorong South Lagoon, with a median volume of up to 26.5GL/year.	The project will deliver increased fresh flows directly into the lagoon, potentially reducing the frequency of periods where the salinity exceeds 100g/L. This has the potential to reduce requirements for barrage flows. Two scenarios for barrage flow inflows: -SDL Adjustment Benchmark run, representing a water recovery volume of 2750 GL -BP2400 model run, representing a water recovery of 2400 GL and a possible reduced water recovery volume resulting from the SDL Adjustment Mechanism

within the ranges required to support the key biota that represent a healthy ecosystem, however, it has been slow to respond and the long-term impacts of hypersalinity are visible The SEFRP aims to enhance flows to wetlands in the Upper South East and to provide flows to the South Lagoon of the Ramsar listed Coorong to help manage salinity and enhance ecosystem resilience. The SEFRP is part of the Coorong Lower Lakes and Murray Mouth (CLLMM) Recovery Project and the area is listed as a Ramsar wetland of International Importance and the many threatened and migratory species that inhabit the site are protected under the Commonwealth EPBC Act 1999.	This means the SEWCD is responsible for managing the infrastructure to meet set objectives (which will be developed by the South East Natural Resource Management board)		flow of 29.7 GL/yr from existing projects 75-week construction period	This suggests that high barrage flows in this area is essential for ecosystem health and resilience.		

Progress towards environmental outcomes in the Murray-Darling Basin

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Report for the Wentworth Group of Concerned Scientists

November 2017

Contents

Summary

The Basin Plan 2012 is a bipartisan agreement by the Australian Parliament to achieve a healthy, working Murray-Darling Basin. A central objective of the Basin Plan is protecting and restoring freshwater ecosystems of the Murray-Darling Basin. This is achieved by recovering up to 3,200 GL of water for the environment from consumptive use, then using this water and other management actions, to achieve agreed outcomes.

We analysed publicly available reports on environmental water recovery, allocation, delivery and monitoring since the Basin Plan was enacted in 2012 to evaluate the following questions:

1. **Hydrological outcomes:** Has the delivery of environmental water resulted in a hydrological regime that is expected to support agreed ecological objectives?
2. **Ecological outcomes:** Does environmental watering produce the expected ecological responses?
3. **Water quality outcomes**: Does environmental watering result in improvements to water quality?
4. **Ecological outcomes at the Basin scale:** Is the condition of each valley and the overall Basin improving?

The volume of environmental water entitlements grew from 1,577 GL in 2012 to almost 2,000 GL by mid-2015. Together they yielded about 9,000GL of environmental flow in the river in this period. There was evidence of coordination among environmental water holders, with 1 in every 5 events undertaken by two or more jurisdictions. Nearly all watering events were reported to align with annual environmental watering priorities.

With respect to hydrological outcomes, some environmental watering activities were reported to produce in-channel variations which helped to reinstate key components of the flow regime including baseflows, freshes and bankfull flows, along with unregulated flow in the system. Environmental watering supported periods of re-connection of isolated reaches along river channels and periods of connection with the end of the valley or Basin. A small proportion of environmental watering activities resulted in overbank flows. Inundation extent increased as a result of environmental watering of floodplains and wetlands for some valleys. Overall, inundation extents were relatively small due to the low volumes of environmental water and constraints, emphasising the need for strategic approaches to maximise outcomes given the amount of water available.

Freshwater ecosystems receiving environmental water benefitted from environmental flows, with measurable improvements in surveyed valleys for vegetation, native fish, waterbirds and frogs following individual watering events. Data from strategic combinations of watering actions over larger space/time scales are yet to be assessed. Environmental and other flows delivered to the Lower Lakes have resulted in improvements in condition since the Millennium drought. Very few environmental watering activities reported negative outcomes, and most of these were short lived, or not harmful to biota in the long term. Some environmental watering activities did not produce any measurable ecological response. This was mainly due to failure to provide the intended flow regime (hydrological objectives) through insufficient overall flows, or factors aside from flow volumes such as temperature and seasonality. Our assessment was limited by gaps in monitoring of impacts on groundwater-dependent ecosystems, threatened species and endangered ecological communities.

While positive localised outcomes of environmental watering were recorded as part of monitoring programs, it is too early to determine whether these outcomes will lead to achievement of ecological objectives in the Basin Plan in the future. The extent to which these outcomes will contribute to overall long-term improvements in the Basin's environment will become apparent over coming years as the Basin Plan is implemented fully, monitoring and reporting on targets is completed, and lag effects play out across the Basin.

Our review identified challenges and risks that could affect the achievement of Basin Plan outcomes. These include physical and policy constraints which have impeded or prevented delivery of environmental flows to target assets, and inadequate protection of environmental flows from consumptive use. Addressing these issues is critical to give the best chance of maximising ecological outcomes, delivering the Basin Plan's ecological objectives and ensuring the highest return on the multi-billion dollar public investment to restore the health of the Murray-Darling Basin.

Introduction

Water in the Murray-Darling Basin sustains more than 30,000 wetlands in the Basin, including 16 of Australia's 65 Ramsar-listed wetlands, 46 species of native fish, 98 species of waterbirds, 85 species of mammals, 53 species of native frogs, 3 species of freshwater turtle, and 124 families of macro-invertebrates, including many species that are nationally threated or protected by international agreements (MDBA 2016b).

Water also has a range of benefits for industries and communities of the Basin. Economic benefits of restoring health to the Murray-Darling Basin ecosystems alone was estimated to be between $3-8 billion (CSIRO 2012). In addition, irrigated agriculture in the Basin is dependent on access to clean water, and environmental flows help to maintain acceptable levels of salinity, nutrients and sediment for irrigation. Floodplain inundation boosts plant growth and increases soil fertility in grazing landscapes. Environmental flows provide improved recreational and fishing opportunities through improved amenity and fish stocks. Aboriginal cultural values are also intimately linked to healthy ecosystems (CSIRO 2012).

The Basin Plan is an agreement to restore 3,200 GL of environmental water or equivalent to rivers and ensure groundwater extractions are within sustainable limits. Recovery, protection and delivery of environmental water is the main mechanism used to achieve ecological benefits and deliver the objectives of the Murray-Darling Basin Plan.

Environmental objectives and outcomes in the Basin Plan

The environmental outcome of the Basin Plan as a whole is a "healthy and working Murray-Darling Basin that includes […] healthy and resilient ecosystems with rivers and creeks regularly connected to their floodplains and, ultimately, the ocean" (Basin Plan 5.02 (2) (c)). The Basin Plan specifies further objectives, outcomes and targets for ecosystems, water quality and salinity. Ecological objectives of the Basin Plan are (1) to protect and restore water-dependent ecosystems of the Murray-Darling Basin, (2) to protect and restore the ecosystem functions of water dependent ecosystems, and (3) to ensure that water-dependent ecosystems are resilient to climate change and other risks and threats (5.03).

The Environmental Watering Plan (EWP; Chapter 7) sets out in more detail the ecological objectives for the Basin including the Lower Lakes, Coorong and Murray Mouth, along with targets for measuring progress. The 'Basin-wide environmental watering strategy' published by the Authority in 2014 sets long-term ecological objectives for the Basin focusing on hydrology, fish, waterbirds and vegetation. An additional set of 'enhanced environmental outcomes' (Schedule 5) will be pursued under the Commonwealth's program to increase the volume of water used by 450GL per year. The Basin Plan also specifies objectives for water quality and salinity to ensure that water is fit for environmental, social, cultural and economic purposes. Finally, an objective for the Basin Plan as a whole is to give effect to relevant international agreements through the integrated management of Basin water resources.

To measure progress towards Basin Plan objectives, the Murray-Darling Basin Authority has proposed using four main indicators (Table 1). The Commonwealth Environmental Water Holder and state governments are also monitoring additional indicators for the valleys where this water was delivered (Table 2).

Table 1. Key indicators used for Basin-wide monitoring, baseline data to be used and expected timeframe for outcomes to be achieved (MDBA 2015a).

Key indicator	Baseline	Timeframe for success
River flows and connectivity	Modelled flows using data from 1895-2009 across all MDB catchments	Achievement of the outcomes for river flows and connectivity are expected by 2024
Vegetation	The extent of vegetation in 2013 that is or may be able to be inundated on the managed floodplain	Achievement of the outcomes for vegetation are expected by 2024
Native fish	Modelled flows using data from 1895-2009 across all MDB catchments Sustainable Rivers Audit (SRA) data from 2004-2010 The distribution and abundance baseline for short lived fish is pre 2007	Achievement of the outcomes for native fish are expected by 2024
Waterbirds	Historic correlations between surveyed waterbird populations and flow in the MDB at June 2009 South Eastern Australian Waterbird Survey data 1983-2012 The baseline for migratory waterbirds in the Coorong is between 2000 and 2014	Achievement of the outcomes for waterbirds are expected from 2024 on-wards Achievement of the outcomes for migratory shorebirds waterbirds (i.e. maintain populations) are expected to occur by 2019

Table 2. Indicators measured in valleys as part of the Commonwealth Environmental Water Holder's Long Term Intervention Monitoring program.

Indicator	Lachlan	Lower Murray-Darling	Gwydir	Mid-Murray	Murrumbidgee	Victorian Rivers	Northern Unreg. Rivers
Bank condition						●	
Blackwater baseline				●			
Blackwater events				●			
Ecosystem type							●
Fish Movement			●	●		●	
Fish Populations	●	●	●	●	●	●	●
Frogs/Tadpoles	●			●	●		●
Hydraulic modelling						●	
Hydrology	●	●	●	●	●	●	●
Inundation modelling				●			
Macroinvertebrates			●			●	
Matter transport		●					
Microinvertebrates		●			●		●
Stream metabolism	●	●		●	●	●	●
Turtles					●		
Vegetation diversity	●		●	●	●	●	●
Water quality			●				●
Waterbird breeding	●				●		
Waterbird diversity			●		●		●
Wetland productivity					●		

Aim and methods

We analysed publicly available reports on environmental water recovery, allocation, delivery and monitoring since the Basin Plan was enacted in 2012 to evaluate the following questions:

1. **Hydrological outcomes:** Has the delivery of environmental water resulted in a hydrological regime that is expected to support agreed ecological objectives?
2. **Ecological outcomes:** Does environmental watering produce the expected ecological responses?
3. **Water quality outcomes**: Does environmental watering result in improvements to water quality?
4. **Ecological outcomes at the Basin scale:** Is the overall condition of each of the river valleys and the overall Basin improving?

We sourced information from publically available reports which included data and surveys undertaken after the Basin Plan was enacted in November 2012. Reports were published or commissioned predominantly by government agencies including environmental water holders. Reports focused on a sample of valleys where environmental water was delivered. Most reports did not document the influence of other water sources and management interventions, nor were they exhaustive reports of all outcomes of environmental watering across the Basin. Further data is required to make assessments for unregulated streams and groundwater.

Recent conditions in the Basin

Climate conditions and water availability have a significant long term influence on ecosystems, so they need to be considered when interpreting changes to environmental conditions in the Basin. The Millennium drought brought sustained periods of low rainfall in the Basin from 2000 to 2010, with the years 2002 and 2006 among the five driest years on record (Figure *1*a) (BOM 2016). Drought-breaking rains in 2010 resulted in the highest ever annual rainfall recorded in the Murray-Darling Basin (809mm; Figure *1*b). However runoff was surprisingly low due to the antecedent drought, long-term changes in climate variability, changes in seasonality and increased potential evapotranspiration (Potter and Chiew 2011). The wet year of 2010 was followed by two more years with above-average rainfall (2010 – 2012). Drier conditions return to the Basin in 2013, with below average rainfall conditions coinciding with the implementation of the Basin Plan. Two more years of below average rainfall followed (2014-2015). This period was exacerbated by the El Niño in 2015 that saw extremely low rainfall across large parts of NSW and Victoria. Runoff in the Basin declined considerably between 2010 and 2014 (BOM 2014). The El Niño broke down by mid-2016, with wet conditions returning to the Basin.

The Basin's ecosystems were severely impacted by the Millennium Drought (2000 – 2010), and the effects continue to shape the condition of assets in the Basin today (Watts *et al.* 2015). Ecosystems experienced severe stress with major declines in biota, particularly the Coorong and Lower Lakes which were severely affected by acid sulphate soils. Over half of the valleys of the basin were in a poor to very poor health by the end of the decade as a result of the drought, river regulation and water extraction (Figure 2) (Davies *et al.* 2012). With increased flow from the wet period of 2010-2012, some parts of the Basin including the Coorong and Lower Lakes showed modest signs of recovery (Davies *et al.* 2012; Ye *et al.* 2016). However, there were ongoing challenges. Flooding and blackwater events in 2010 and 2011 in the Edward Wakool significantly affected fish communities, resulting in localised disappearance of native fish species and proliferation of invasive fish such as carp and goldfish (Watts *et al.* 2013). Drier conditions from 2013 to 2015 resulted in localised drying of floodplain wetlands and many aquatic and semi-aquatic vegetation communities returning to terrestrial assemblages.

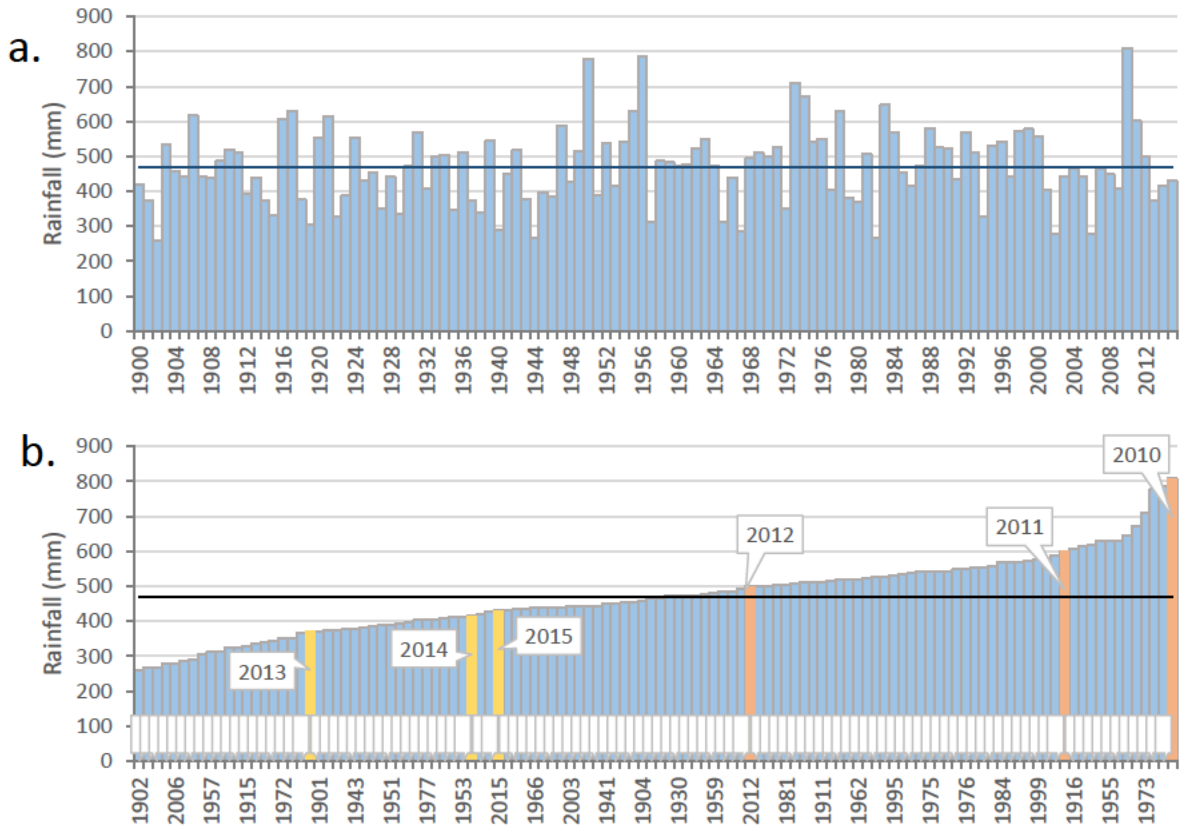

Figure 1. Average annual rainfall (mm) in the Murray-Darling Basin, arranged chronologically (a) and by amount (b) (BOM 2016).

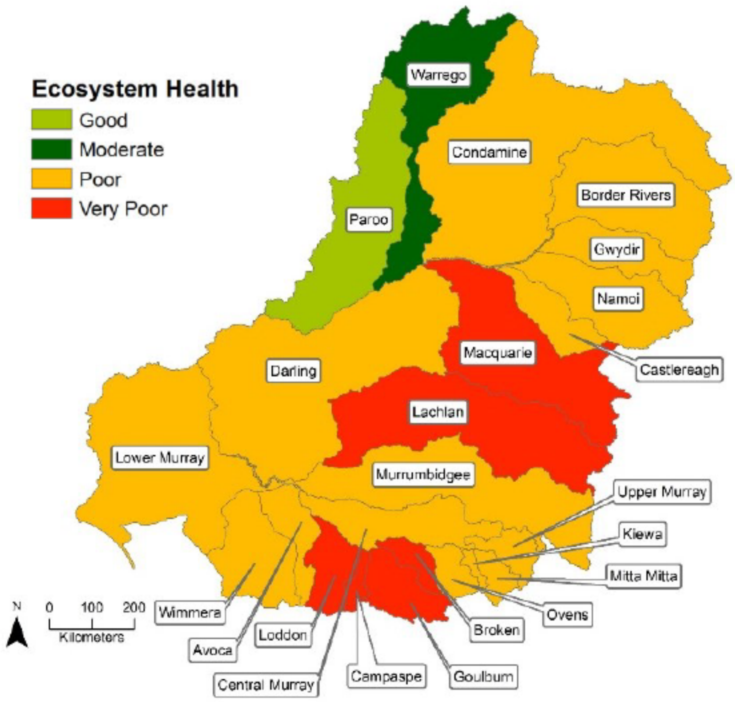

Figure 2. Ecosystem health as reported in the Sustainable Rivers Audit 2 (2008 - 10).

Environmental water delivery

Since the Basin Plan was enacted, an estimated 8,977GL of environmental water was delivered to valleys in the Basin in 407 environmental watering events from July 2012 to June 2015 (Table 3). The Commonwealth Environmental Water Holder delivered the largest volume of water (4,602GL, 51%), followed by New South Wales (1,272GL, 14%) and the Murray-Darling Basin Authority under The Living Murray program (1,059GL, 12%). Volumes mainly comprised of held environmental water, planned environmental water, return flows and other environmental allocations. Most of this water was delivered in five regions of the southern connected system: South Australian Murray, Goulburn, Victorian Murray, Murrumbidgee and New South Wales Murray (92% in 2013-14 and 86% in 2014-15, Figure 3).

Table 3. Volume of environmental water (GL) delivered by Basin jurisdictions between July 2012 and June 2015.

Year	Volume delivered (GL)							
	CEWH	MDBA	NSW	QLD	VIC	SA	Other	Total
2012-13[1]	1,272	277	670	n/a	364[2]	n/a	n/a	2,583
2013-14[3]	1,663	295	300	15	210	801	232	3,516
2014-15[3]	1,667	488	302	97	198	43	83	2,878
Total	4,602	1,059	1,272	112	772	844	315	8,977

[1] Calculated based on reports by CEWO (2013); MDBA (2013); NSW DPC (2013); VEWH (2013). Queensland did not report water delivered. South Australia reported 1,076GL but it was excluded from this table as the proportion held by South Australia was not known.

[2] Includes some CEWH and TLM water.

[3] Environmental water use reporting requirement under Schedule 12 Matter 9.3 of the Basin Plan. Reports available at www.mdba.gov.au/publications/mdba-reports/basin-plan-annual-report-2013-2014 and www.mdba.gov.au/publications/mdba-reports/basin-plan-annual-report-2014-15

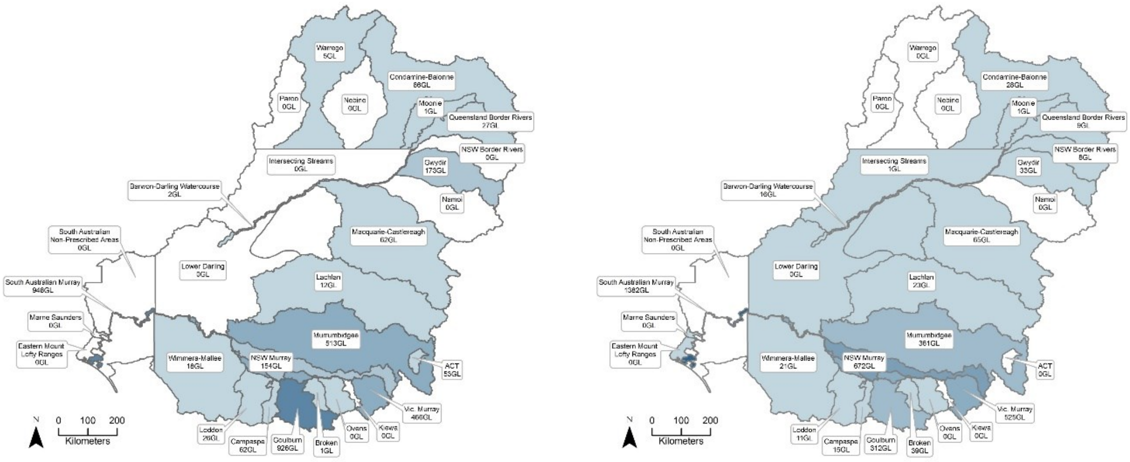

Figure 3. Environmental water delivered by Commonwealth and states in valleys of the Murray-Darling Basin in the (a) 2013-14 and (b) 2014-15 water years (compiled from Schedule 12 Matter 9 reports) (MDBA 2016c). Valley-specific data was unavailable for 2012-13.

Environmental water use reports showed evidence of coordination of environmental watering among Basin jurisdictions. One in every 5 watering events between 2013 and 2015 was undertaken through coordinated delivery of environmental water held by more than one jurisdiction, usually a state and the Commonwealth. A single event in the lower Murray in 2013-14 was coordinated among four agencies: Victoria, NSW, the Commonwealth and the Authority. The remaining four of every 5 events were delivered by a single water holder.

Nearly all of the environmental watering actions reported between 2013 and 2015 were reported to align with Basin Plan priorities. Over the 2 years, 31% of the volume of environmental flows was primarily targeted at outcomes for connectivity, 25% for vegetation outcomes, and 14% for fish outcomes. The remainder was primarily targeted at ecosystem resilience, population resilience, water quality and waterbird outcomes. Very few environmental flows were targeted at ecosystem diversity, habitat diversity, ecosystem function or frogs as their primary purpose. Some deliveries were not undertaken in line with the annual priorities due to constraints, bushfire and lack of natural cues or water availability (2016-17).

Hydrological outcomes

Nearly all environmental watering events between 2013 and 2015 were reported to have positive outcomes for flow variability, longitude and lateral connectivity. Most environmental watering activities were delivered in-channel and helped to reinstate key components of the flow regime including baseflows, freshes and bankfull flows, along with other water sources in the system. Environmental watering supported periods of re-connection of isolated reaches along river channels and periods of connection with the end of the valley or Basin. A small proportion of environmental watering activities resulted in overbank flows. Inundation extent increased as a result of environmental watering of floodplains and wetlands for some valleys. Overall, inundation extents were relatively small due to the low volumes of environmental water and constraints. Of the three events that did not produce positive outcomes, two reported no significant hydrological response and one reported a reduction in slackwater habitat due to increased flow velocity.

Flow variability

Environmental flows reinstated different components of the instream flow regime from cease-to-flow, base flows, freshes to bank-full events. In periods of low flow, environmental flows helped to maintain permanent waterholes in channels of the lower Balonne in 2012-13 (CEWO 2013), provide baseflows along channels of the Gunbower forest in 2012-13 (DOE 2014), break periods of low flow in the Warrego in 2014-15 (CEWO 2015), and extend periods of wetting of in-channel habitats in the Namoi in 2012-13 (CEWO 2013). Small fresh flows were reinstated with environmental flows in the Barwon-Darling in 2012-13 (CEWO 2013), the Edward Wakool in 2012-13 and 2013-14 (CEWO 2014; Watts *et al.* 2013), and the Lower Balonne in 2014-15 (DOE 2015). Freshes improved connectivity between rivers and creeks, mobilised sediment and nutrients, created slackwater habitat and promoted movement of native fish (Webb *et al.* 2015b). The Great Cumbung Swamp in the Lachlan reached maximum capacity in 2012-13 and 2013-14 with the contribution from environmental watering (CEWO 2013; OEH 2014b). Environmental flows extended the tail of an unregulated flow peak in late 2013 at the South Australian border (Figure 4).

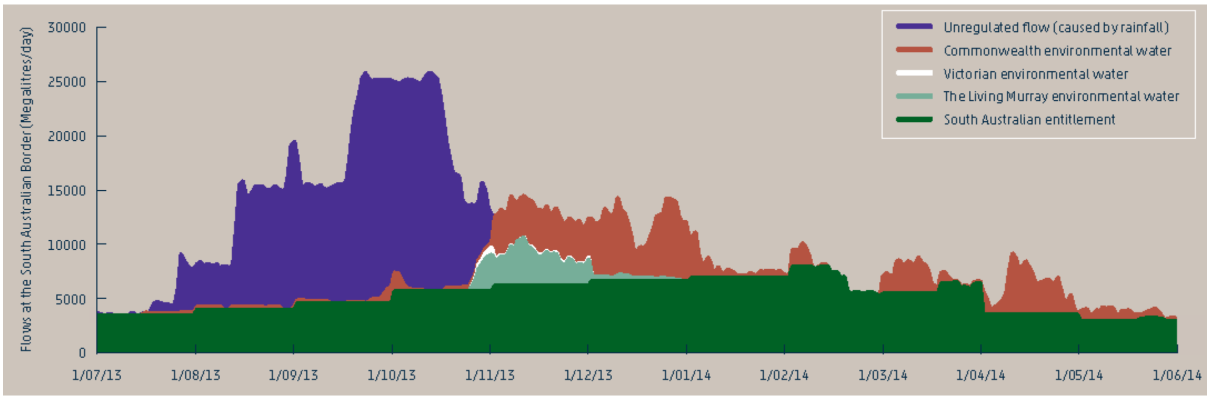

Figure 4. Hydrograph of flows at the South Australian border from July 2013 to June 2014 indicating the contribution of unregulated flow, environmental water held by Basin jurisdictions, and South Australian entitlement flow (CEWO 2014).

Variability of water levels, flow velocity and wetted area for some valleys increased as a result of environmental watering. Environmental watering raised water levels in weir pools of the Lower Murray by 0.05 to 0.8m (Ye *et al.* 2016), and in channels of the Lachlan River between Willandra Weir and Booligal by 1.5m (CEWO 2015), Broken Creek (Stewardson *et al.* 2014) and the South Australian Murray by 0.2m (CEWO 2015; Ye *et al.* 2016). It also increased in flow velocity in Broken Creek (OEH 2014b) and the Lower Murray in South Australia by up to 0.07m/s compared to without environmental flows (CEWO 2015; Ye *et al.* 2016). There was an increase in wetted benthic area associated with environmental water in the Edward Wakool (14% in Colligen Ck, 22% in Yallakool Ck) (Watts *et al.* 2013). Environmental watering was reported to increase natural flow variability in Broken Creek (CEWO 2013), Moonie (CEWO 2013) and Edward-Wakool (Watts *et al.* 2015). In the Gwydir, environmental water delivery mimicked the target flow hydrographs more successfully at gauges towards the end of each channel, because upstream irrigation extraction affected the duration of receding flows (Southwell *et al.* 2015c).

In a few valleys, environmental flows were delivered but no significant effects on variability or other hydrological outcomes were observed. In the Lower Balonne, 22GL of environmental water was delivered in 2013-14 but due to high evaporation losses only a small proportion reached the Narran Lakes (DOE 2014). In the Goulburn, environmental water delivery in summer and autumn of 2015 had only a marginal effect on inundation and negligible impact on bank condition (Webb *et al.* 2015b). The only reported negative response was observed in 2014-15 in Yallakool Creek of the Edward Wakool, where there was a reduction in the area of slackwater habitat during watering actions compared to area of available slackwater during base flows (Watts *et al.* 2015). This probably occurred as a result of environmental watering in other locations but was not systematically reported.

Longitudinal connectivity

Longitudinal connectivity was another important outcome of environmental watering, with reports of environmental flows contributing to the re-connection of isolated reaches of river channels and full connection with the end of valleys and the Basin. Environmental flows in the Lachlan connected over 620km of river system in 2012-13 and 2013-14, filling ecologically important swamps (Lake Waljeers, Peppermint, Baconian swamps) and reaching Lake Ita (CEWO 2013; OEH 2014a; b). Longitudinal connectivity was achieved throughout the lower Gwydir channels in 2013-14 between 36% and 53% of the time, however this was mainly attributed to irrigation water delivery rather than environmental flows (Southwell *et al.* 2015c). Delivery of environmental flows in the Culgoa in 2012-13 and 2014-15 (CEWO 2013; DOE 2015) and Gwydir in 2013-14 and 2014-15 (Ecological and UNE 2015) resulted in full connection with the Barwon-Darling downstream. Environmental watering in South Australian Lower Murray reached the Lower Lakes and Coorong in 2012-13, improving the connections of waterways to the sea (CEWO 2013; Ye *et al.* 2015). Commonwealth environmental water contributed 100% of the flows over the barrages into the Coorong from November 2014 to June 2015 (CEWO 2015).

Lateral connectivity

Monitoring of wetland area from aerial surveys showed a long term decline in wetland area, with a particularly steep decline since the peak of 2010, reaching a record low in 2015 (Figure 5). Water observed from satellite imagery is shown for the Murray-Darling Basin and key wetlands during a similar period (1987 – 2016; Figure 6) (Geoscience Australia 2016). Environmental flows delivered during this period have made a minor contribution to flood extent in some valleys, but the effects on duration and frequency are not well documented. Environmental flow spilled overbank and inundated floodplain wetlands (Table 4). Environmental flows were pumped to isolated wetlands in the mid-Murrumbidgee in 2014-15, with secondary benefits for in-channel habitats (Wassens *et al.* 2016). Inundation of important habitat was observed in the Mallowa Creek in the Gwydir (2013-14), where environmental water inundated 1,545 ha of Coolibah-River Cooba-Lignum Association, 337 ha of Coolibah woodlands and around 1,288 ha of cultivated land.

Environmental watering in the Great Cumbung Swamp on the Lachlan floodplain inundated core reed-beds, filled most open water bodies, and spread through river red gum and fringing black box communities (OEH 2014b).

Table 4. Inundation events which benefitted from environmental water between 2012 and 2015.

Region	Area (ha)	Year	Duration & Frequency	Reference
Gingham and Lower Gwydir	6,342	2014-15	4-6 months	(CEWO 2015; DOE 2015; Ecological and UNE 2015)
Mallowa Creek	1,600 2,011	2012-13 2013-14	n/a	(CEWO 2013; Southwell *et al.* 2015c)
Macquarie Marshes	15,484 9,323	2013-14 2014-15	n/a	(OEH 2014b; 2016)
Lachlan floodplain	63,000	2013-14	n/a	(OEH 2014b)
Edward Wakool	n/a	2014-15	n/a	(Watts *et al.* 2015)
Lower Murray River, South Australia	~600	2012-13	n/a	(CEWO 2013)

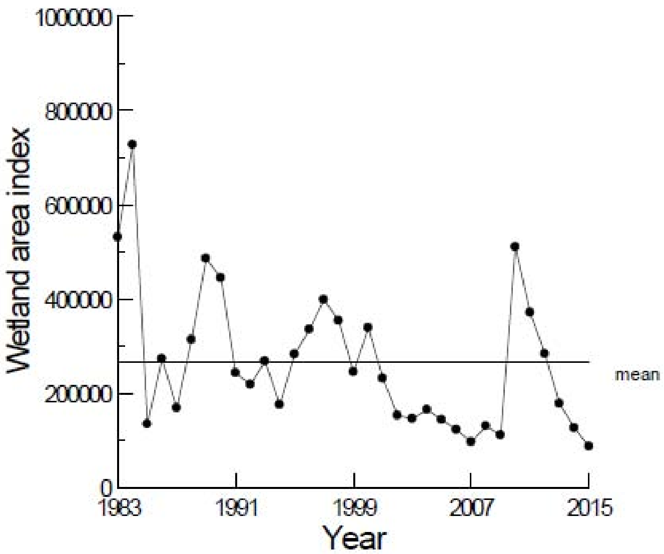

Figure 5. Wetland area index representing 13.5% of the Murray-Darling Basin between 1983 and 2015 (Porter et al. 2016).

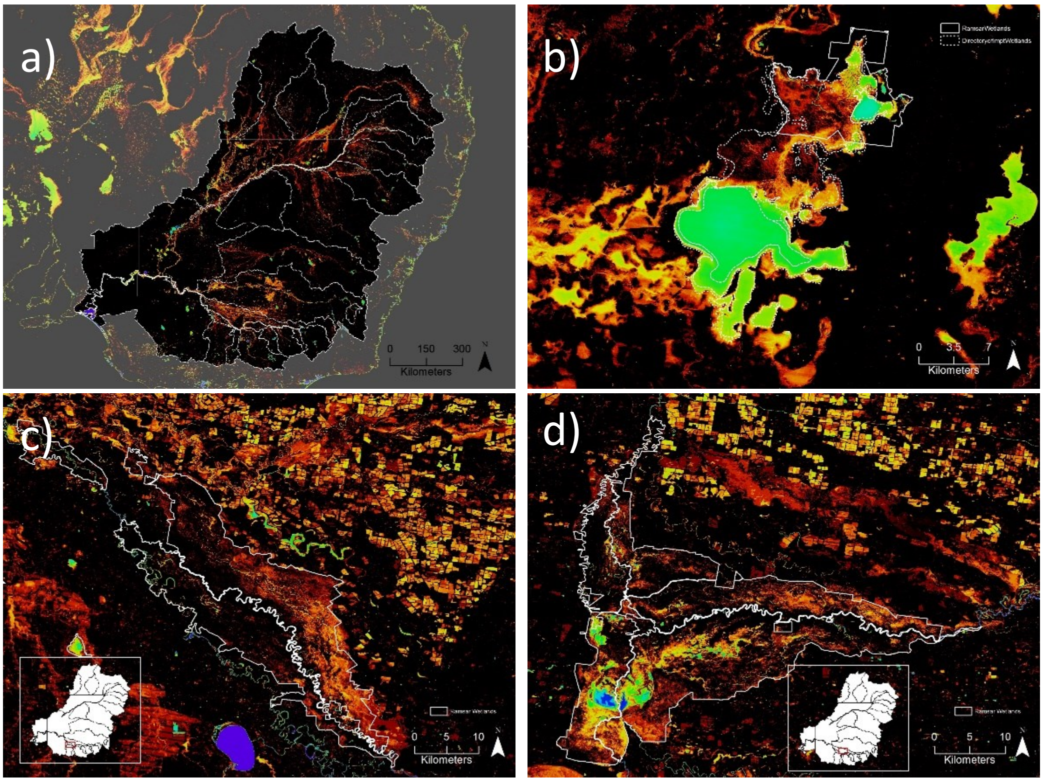

Figure 6. Historical surface water observations based on satellite imagery (Landsat 5 and 7) for the period 1987 to 2016 for the (a) Murray-Darling Basin; (b) Narran Lakes; (c) Gunbower and Koondrook forest; and (d) Barmah-Millewa forest (Geoscience Australia 2016).

Groundwater levels

Groundwater levels reported by the Bureau of Meterology show the status and trend of groundwater levels upper, middle and lower aquifers in the Basin (Figure 7) (BOM 2015). Status of aquifers in 2015 varied across the Basin, reflecting local climate, geology and water use. Trends between 2010 and 2015 also varied, with rising levels of some bores particurlarly in the Shepparton irrigation region, and declines in the level of bores in the Great Artesian Basin in Northern NSW. Compliance with groundwater provisions in the water resource plans will be an important source of data for assessing the contribution of the Basin Plan to changes in the condition of groundwater and dependent ecosystems (MDBA 2014b).

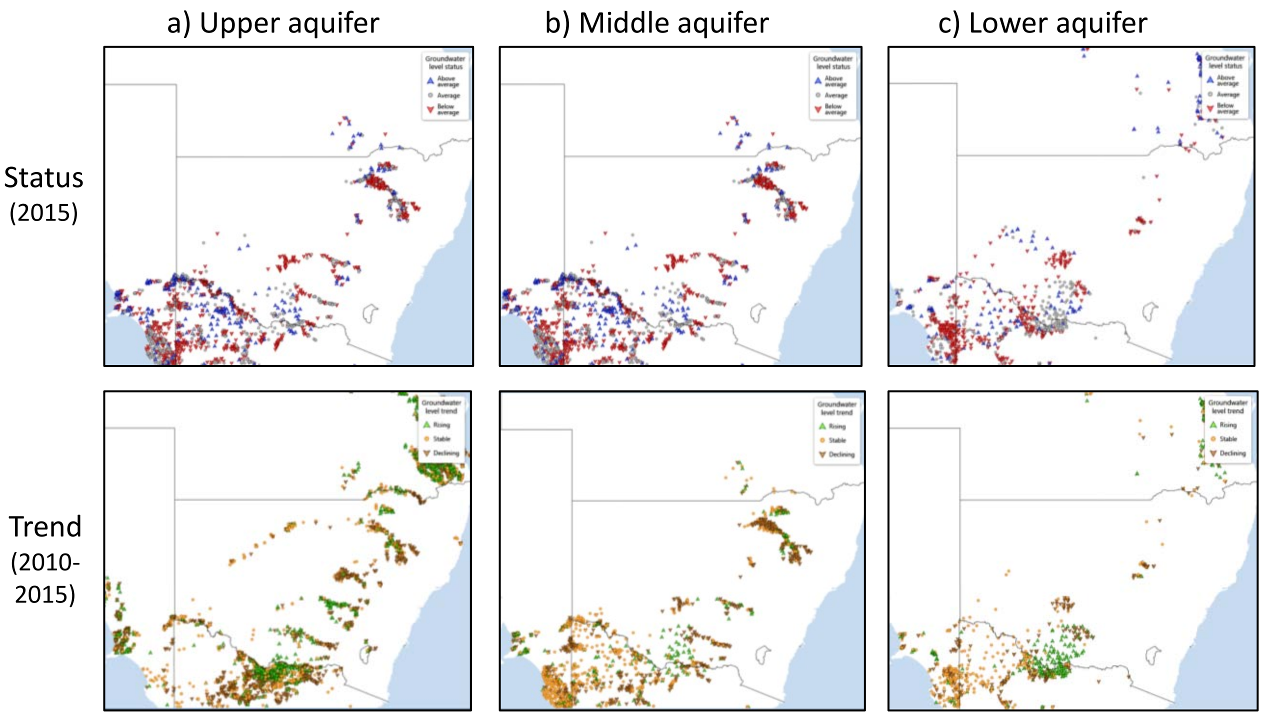

Figure 7. Recent status (2015) and five-year trend (2010-2015) of bores in the (a) upper aquifer, (b) middle aquifer and (c) lower aquifer in the Murray-Darling Basin region (BOM 2015).

Ecological outcomes

After four years of implementation of the Basin Plan and delivery of nearly 9,000GL of environmental water across the Basin, our assessment of preliminary outcomes indicates that the Basin's environment was in better ecological condition than it would have been without the Basin Plan in place. Environmental flows produced mostly positive outcomes in key indicators related to hydrological, ecological and water quality. Environmental water delivery, aligned with natural flow events, helped to extend the duration of flow events and taper the recession of flow events to better mimic naturally receding flows. This resulted in important local benefits for flow-dependent species, such as completion of waterbird nesting events. It also helped to alleviate the impacts of low water availability as ecosystems in the Basin transitioned from a wet to dry phase around 2012. As dry conditions prevailed through to 2015, environmental water contributed to maintaining suitable water quality, providing refuge habitat for species and compensating for drought-related impacts (VEWH 2016). In the absence of environmental water, these positive responses would not have occurred (Wassens *et al.* 2014).

Very few environmental watering activities between 2012 to 2015 produced negative outcomes. Four known instances were documented following environmental watering: macroinvertebrate abundance reduced in the Goulburn River due to dilution from environmental water (Stewardson *et al.* 2014); carp recruitment increased in the Macquarie Marshes (DOE 2015; OEH 2016; Stocks *et al.* 2015); shrimp recruitment declined due to decreased slackwater habitat availability (CEWO 2014; OEH 2014b; Watts *et al.* 2014); and oxygen concentrations reduced because of increased respiration rates in the Chowilla floodplain (CEWO 2015; DOE 2015; Ye *et al.* 2016). Most of these effects were short lived or not harmful to aquatic biota in the long term. They represent examples of threats the mitigation of which should be part of on-going risk management. Such risks may also be expected to be reduced as environmental water holders and river operators gain experience in delivering water under different conditions for a range of outcomes.

Some environmental watering activities did not produce any measurable response. For example, recruitment of frogs was anticipated following environmental flow delivery in the Edward-Wakool in 2013-14 however there was no evidence of spawning at surveyed sites (Watts *et al.* 2014). Macroinvertebrate biomass did not change in the Goulburn River following environmental flows in 2014-15 (Webb *et al.* 2015a). There was no expected waterbird breeding response in the Lachlan River in 2014-15 (DOE 2015). Absence of responses were mainly due to insufficient overall flows, or factors aside from flow volumes that influenced outcomes such as temperature and seasonality, and therefore probably reflected failure to achieve the required watering regime (hydrological objectives) rather than an error in the assumed water/ecology relationships underlying the setting of ecological objectives. This is an important distinction in applying adaptive management in learning from management actions. Assessing the extent to which the reported outcomes can be attributed to the Basin Plan is difficult due to confounding factors such as seasonality, invasive species, land management and unregulated flow. Disentangling the influence of the Basin Plan from these factors requires further work in establishing an adequate baseline or reference condition data, scientifically robust sampling techniques and proper analytical techniques such as control-treatment analysis, statistical analyses, scenario modelling and longitudinal analysis.

Native vegetation

There are currently no Basin-wide surveys of native vegetation condition. The Authority has been monitoring the condition of woody vegetation (river red gum, black box and coolabah) at icon sites in the River Murray System since 2008 using RapidEye satellite imagery, and is scoping the application of the method to the northern Basin (MDBA 2015a). Using field measurements and satellite imagery, the project allows conditions across the sites to be compared, as well as change to be assessed within the sites and across the Murray system over time. Intervention monitoring of vegetation in response to environmental watering has been undertaken by environmental water holders for 16 regions in the Murray-Darling Basin: Campaspe, NSW Murray, Goulburn, Gwydir, intersecting streams, Lachlan, Loddon, Macquarie, Murrumbidgee, Victorian Murray, SA Murray, Ovens, Warrego, Lower Darling and Broken.

Vegetation outcomes resulting from environmental watering between 2013 and 2015 are summarised below.

- A large-scale survey of vegetation in the Basin, undertaken in the Lower Murray in 2013-14, revealed less than 20% of the area of vegetation was in good condition, 53% was in moderate condition and 27% was in poor, degraded and severely degraded condition (Hughes *et al.* 2016). The extent of vegetation in good and poor condition declined since 2011-12, with a corresponding increase in the area in Moderate condition. About 40% percent of fringing river red gum forests were in good condition while only 5% of black box woodlands were in good condition.
- Vegetation responded well to environmental watering, with the establishment of aquatic species and increased condition of flow-tolerant vegetation in many flooded sites.
- Extent of aquatic species increased in valleys in sites where environmental watering occurred over consecutive years.
- In areas that did not receive environmental watering, monitoring showed aquatic species in decline and transitioning to terrestrial or exotic communities.
- Environmental watering stimulated recruitment of a number of wetland species as indicated by fresh foliage, mass flowering, seeding, and recruitment.
- Wetland plant and community diversity increased in response to environmental flows at some sites.
- Monitoring results were consistent with scientific understanding of the role of environmental water in reducing or suppressing the growth of terrestrial and exotic species in wetlands.

Condition

Intervention monitoring showed improved condition of floodplain trees in areas receiving environmental flows, with the canopy showing less dead material and canopy foliage cover generally increasing (Darling anabranch in 2013-14, Lachlan in 2014-15, Murrumbidgee floodplain in 2012-13, 2013-14, NSW Murray in 2013-14, Gunbower forest (2014-15), Koondrook-Perricoota (2014-15) (CEWO 2015; Dyer *et al.* 2015; MDBA

2015a; OEH 2014b; 2016; Stewardson *et al.* 2014). Fringing vegetation benefited from in-channel environmental water, with increased canopy coverage and emergence of plants at the waters edge (e.g. Tuppal Creek in 2014-15). Vegetation on the inner floodplain remained in good condition following inundation from environmental water (e.g. River red gums in the Macquarie River 2013-14, 2014-15). Black box communities on Bottle Bend Reserve in the Murrumbidgee (2012-13) and in Hattah Lakes (2014-15) responded positively to inundation, with new growth on trees and groundcover dominated by native species (CEWO 2013; OEH 2014a). Wetland plants also responded positively to environmental watering in the Broken valley in 2014-15 (Stewardson *et al.* 2014), Campaspe in 2012-13 (CEWO 2013), intersecting streams in 2014-15 (CEWO 2015), Lachlan in 2012-13 (OEH 2014a), Loddon in 2014-15 (Stewardson *et al.* 2014), and the Edward-Wakool on the NSW Murray in 2014-15 (CEWO 2015; Watts *et al.* 2015).

Many areas that did not receive flooding between 2012 and 2015 declined in condition. These included areas of the Murrumbidgee in 2012-13 (CEWO 2013; OEH 2014a), Macquarie in 2013-14 (OEH 2014b) and Mulcra Island in 2014-15 (MDBA 2015a; Stewardson *et al.* 2014) where dead and water stressed trees and declines in condition of flood-tolerant species were observed.

Extent

Aquatic and flow-tolerant vegetation extent increased in floodplains inundated with environmental water. These results were reported in valleys where flooding had occurred in two or more consecutive years. In the Goulburn valley, environmental watering in 2012-13 followed by spring freshes in 2013-14 saw the return of vegetation on the lower Goulburn River to flow-adapted species, with terrestrial species becoming less prevalent (CEWO 2014; Webb *et al.* 2015b). Subsequent delivery of environmental water in 2015 maintained vegetation abundance and diversity in the regions inundated in the previous year (CEWO 2015; Webb *et al.* 2015a). Similarly, vegetation in the Lower Gwydir and Gingham wetlands responded positively to environment watering in 2012-13 and 2013-14 with an increase in area of vegetation communities and increased biomass production, with up to 25 times more biomass in flooded areas compared to non-flooded areas (OEH 2014a). Similar observations were made in the Edward-Wakool where there was gradual improvement in vegetation at sites that have received environmental water over three years, with greater persistence of submerged aquatic habitat with slow recession of flows (CEWO 2014; Watts *et al.* 2014; Watts *et al.* 2015).

Overall, flood extents were relatively small and localised in the period between 2012 and 2015 compared to the previous wet years. Monitoring results suggest that wetland extent in some valleys contracted during this period as flood-tolerant vegetation communities declined in extent and condition and were encroached by terrestrial and exotic species. In the absence of environmental flows in the Lower Lachlan river system, few flow-tolerant species were observed by the end of the 2014-15 water year, and vegetation communities within the floodplains, wetlands and billabongs were dominated by terrestrial species (Dyer *et al.* 2015). Significant declines in the cover of aquatic species were observed in the mid-Murrumbidgee wetlands in the absence of environmental water, with concurrent increase in the percentage cover of terrestrial species (Wassens *et al.* 2014). River red gums in the mid-Murrumbidgee have encroached into previously wetted areas and risk forming dense stands without successive watering events to promote ecological thinning (Wassens *et al.* 2016). Monitoring in the Broken Creek weir pools showed very strong zonation in vegetation from aquatic plants to terrestrial species due to attenuated flow variability which was atypical of a natural flow regime (Webb *et al.* 2015b). Sites on the Goulburn River exhibited a more natural, gradual zonation from aquatic plants to terrestrial species where environmental flows have reinstated a more natural flow regime (CEWO 2014; Webb *et al.* 2015b).

Recruitment

Floodplain vegetation showed signs of growth and recruitment in response to environment watering in the Lower Gwydir and Gingham wetlands (2012-13), Lachlan (2013-14, 2014-15), Lower Darling (2013-14), Murrumbidgee (2012-13) and Chowilla floodplain (2014-15), indicated by fresh foliage, mass flowering and seeding of many species or sapling emergence (OEH 2014a; b). Environmental flows and high natural flows in 2013-14 in the Barmah-Millewa Forest icon site produced the strongest response in Moira grass in seven years, with reports of growth, flowering and seeding (DOE 2014). Monitoring in the Goulburn River found summer environmental flows in 2014-15 had encouraged the establishment of plants on banks and increased bank stability (GBCMA 2015).

Diversity

Vegetation monitoring revealed a higher degree of diversity of native vegetation species and communities in areas receiving environmental flows. Increased species diversity was recorded in the Lowbidgee floodplain (CEWO 2015; DOE 2015; Wassens *et al.* 2016) and the Loddon where local indigenous plant species at Lake Yando increased from 60 to 97 after environmental watering in 2014-15, including twelve species of rare or threatened plants (Stewardson *et al.* 2014). There were more riverbank and aquatic vegetation species recorded in areas receiving environmental water in the Edward-Wakool in 2013-14 (CEWO 2015; Watts *et al.* 2015), and similar observations were made in the Warrego in 2014-15 where species diversity at four inundated sites increased after surface water had receded, particularly species that were able to respond quickly to changes in water availability (Southwell *et al.* 2015b).

Invasive species

Monitoring results were consistent with scientific understanding of the role of environmental water in reducing and suppressing the growth of terrestrial and exotic species in wetlands. Environmental water in the Warrego in 2014-15 was associated with a reduction in the diversity of terrestrial species which are intolerant to flooding (Southwell *et al.* 2015b). Environmental water also suppressed the growth of azolla in the Broken River, an aquatic plant which can cover the surface and decrease oxygen levels for fish (Stewardson *et al.* 2014). In the Gwydir, exotic species such as Lippia (*Phyla canescens*) were observed in low abundances in plots studied in the Mallowa in 2013-14, and their abundance remained relatively stable (Southwell *et al.* 2015a). Environmental water assisted native plants to outcompete weeds (CEWO 2014; OEH 2014b; Southwell *et al.* 2015c). Environmental flows helped to maintain the percent of native understory vegetation in the Lachlan at more than 60%, a reasonably high degree of vegetation nativeness across sites (CEWO 2015; Dyer *et al.* 2015; OEH 2016). There was no evidence that environmental watering promoted the growth of invasive species in flooded areas. Long term and systematic collection of data on the presence of weeds will be important in assessing their threat over time, as is demonstrated through the use of the ‘nativeness’ indicator in the Sustainable Rivers Audit (Davies *et al.* 2012).

Native fish

Condition of fish has not been reported across the Basin since the Sustainable Rivers Audit (SRA) 2, although the Authority is currently undertaking annual Basin-wide monitoring of fish species at 145 sites in the Basin (MDBA 2015a). At a sub-Basin scale, NSW has assessed fish community status across the state by consolidating 20 years of biological survey data using methods which align with those used in the SRA (NSW DPI 2015). Annual surveys are conducted to monitor fish response to environmental water delivery. Environmental water holders recorded fish responses to environmental flows in 12 valleys in the Basin between 2012 and 2015: Broken, Campaspe, Goulburn, Gwydir, Lachlan, Loddon, Macquarie, Murrumbidgee, NSW Murray, SA Murray, Vic Murray and Wimmera Mallee. Fish response in the Coorong, Lower Lakes and Murray Mouth was also reported (MDBA 2015a). Monitoring largely focused on flow-responding species, where specific stages of their life-history were tied to hydrology.

Native fish outcomes resulting from environmental watering between 2013 and 2015 are summarised below.

- Native fish responded positively to environmental flows delivered between 2012 and 2015, with outcomes reported for spawning and movement of native fish.

- The presence of a range of fish species suggested flow conditions had been suitable for fish in a number of valleys.
- There is insufficient evidence to date suggesting that spawning events resulting from environmental flows have translated into recruitment of juveniles into the local population.
- Most monitoring was focused in-channel rather than on the floodplain, given fewer environmental flow events occurred on the floodplain.
- Spawning activity is reported but the flow-on effects for fish population and diversity metrics are not widely reported. Ongoing monitoring of outcomes for abundance and diversity at a species and community level is important.
- Environmental watering appeared to encourage native fish whilst disadvantaging invasive species, particularly carp.
- Environmental watering during cooler months was less favourable to carp (Dyer *et al.* 2015).
- Environmental flows may reduce shrimp population by reducing the available slackwater habitat, and therefore by inference, reduce microinvertebrate food for larval native fish.
- Environmental watering decisions need to reconcile the full benefits of providing environmental flows to native fish and managing threats (e.g. aquatic weeds) against the consequences of providing flows to alien species (NSW DPI 2015; Southwell *et al.* 2015a). This is a key step in adaptive management.
- The Sustainable Rivers Audit measures of expectedness and nativeness should be calculated on an ongoing basis to assess trends in fish community data.
- Care is required to assess the drivers and origins of a spawning event because eggs or larvae may have been transported from another location by flows.
- Monitoring has helped to refine our understanding of the importance of seasonality and water temperature in addition to the volume of flows in determining the breeding and movement of fish species particularly Murray Cod (temperature-cued spawner), golden and silver Perch (flow-cued spawner) (Webb *et al.* 2015a).
- Monitoring is largely focused on the two species in the Basin which require discharge to initiate spawning (golden and silver perch), even though other important species also benefit from environmental flows (Ye *et al.* 2015).

Condition

Poor condition of native fish remains an ongoing concern in rivers across the Basin. In the southern Basin, native fish populations in the Murray River have declined to about 10% of the pre-European level over the last 100 years (Ye *et al.* 2015). In the northern Basin, fish communities in most valleys are in extremely poor to poor condition, with the exception of the Border Rivers (moderate), Condamine (moderate) and Paroo (good) (NSW DPI 2015). Low condition scores for the Lower Lachlan were attributed to a number of native species predicted to have historically occurred within the area that were absent (50% of species absent) and because recruitment within the population was observed to be very low (Dyer *et al.* 2015). Results also showed the condition of fish communities changed within valleys, for example in the Macquarie River, where fish condition declined along a downstream gradient from 'poor' below Burrendong Dam to 'extremely poor' in the Macquarie Marshes and downstream to the Barwon River confluence (Stocks *et al.* 2015). There was a small improvement in trend of the native fish communities in some valleys (e.g. from 'very poor' to 'poor' in the Edward-Wakool (Watts *et al.* 2014).

Twelve out of 57 species of fish in the Basin are alien (Lintermans 2009). Alien fish contributed to over 70% in number and 80% to 90% of the biomass in the Basin, and half of the total fish biomass in most catchments of the Northern Basin including the Macquarie-Castlereagh, Darling, Namoi and Gwydir (Lintermans 2009; NSW DPI 2015). Key drivers of declining fish condition include flow regulation, migration barriers, thermal pollution, alien species and disease (Lintermans 2009).

Spawning

Environmental watering coincided with spawning events in valleys across the Basin between 2012 and 2014. Following environmental watering in 2012-13, fish spawning and recruitment increased for carp gudgeon, Australian smelt and Murray cod in the Murrumbidgee (CEWO 2013; OEH 2014a; Wassens *et al.* 2013) and golden perch in the South Australian Murray (Ye *et al.* 2015). Spawning of golden perch was directly attributed to environmental flows in the Goulburn River in 2013-14 (CEWO 2014; Webb *et al.* 2015b), and bony bream and spangled perch in the Mehi and Carole Creek of the Gwydir valley respectively (CEWO 2014; OEH 2014b; Southwell *et al.* 2015c). The following year (2014-15), environmental freshes after natural flows in the Goulburn River supported the largest golden perch spawning event in 4 years since the 2010 floods, as well as spawning of the critically endangered silver perch (CEWO 2015; DOE 2015; Stewardson *et al.* 2014; Webb *et al.* 2015a). Other golden perch spawning events in 2014-15 occurred in the Lower Murray (DOE 2015; MDBA 2015a; Ye *et al.* 2016) and Murrumbidgee (CEWO 2015; OEH 2016; Wassens *et al.* 2016).

Environmental watering in some valleys did not trigger an expected native fish spawning event due to failure to provide the required water regime and therefore achieve hydrological objectives. In the Lachlan valley, spawning of golden and silver perch probably did not occur because environmental water was too cold and watering occurred too early in the season (CEWO 2015; Dyer *et al.* 2015; OEH 2016). In the Macquarie River, environmental flows were insufficient in magnitude to trigger native fish spawning (DOE 2015; OEH 2016; Stocks *et al.* 2015). In the Edward-Wakool system, flows were provided in two consecutive years (2013-14 (Watts *et al.* 2014) and 2014-15 (Watts *et al.* 2013)) but little effects on spawning and recruitment of native fish were observed, possibly because of the reduction in slackwater habitat during watering actions (Watts *et al.* 2013). Similarly, shrimp did not benefit from environmental flows in the Edward-Wakool system in 2012-13 (Watts *et al.* 2013) or 2013-14 (Watts *et al.* 2014), potentially because of the reduction in slackwater habitat and their sensitivity to higher flows.

Recruitment

Long term success of spawning events was not clear from monitoring results, suggesting that spawning may not necessarily translate into recruitment of juveniles into the local population. Recruitment of juvenile fish following spawning events was not observed in the Goulburn River in 2014-15, possibly because eggs and larvae drifted downstream (CEWO 2013; 2015; DOE 2015; Webb *et al.* 2015a). No strong relationships existed between golden perch spawning and recruitment of juvenile fish in the Goulburn and Murray regions (CEWO 2015; DOE 2015; MDBA 2015a; Stewardson *et al.* 2014; Webb *et al.* 2015a; Ye *et al.* 2016), suggesting the recruitment events were unsuccessful or lagged in response. In the Gwydir valley, fish recruitment following spawning was detected, but this did not translate to higher order shifts in fish assemblage structure (CEWO 2014; OEH 2014b; Southwell *et al.* 2015c). These results could be because population measures were not sufficiently sensitive to changes in recruitment or because spawning and recruitment are separated in time and space and are driven by a different set of drivers which may not have arisen. Further studies are necessary to evaluate the long-term outcomes of environmental watering events at appropriate spatial and temporal scales.

Movement

There was increased movement and use of fishways by golden perch in Broken Creek (Stewardson *et al.* 2014), by Murray cod in the Murrumbidgee (Wassens *et al.* 2013) and by Murray cod, golden perch, silver perch in the NSW Murray (Watts *et al.* 2013). There was no clear and consistent influence of environmental water on native fish movement through wetlands along the South Australian Murray River (Ye *et al.* 2015). Fish movement during periods of environmental flows was reported for Murray cod, golden perch and silver perch in the Broken River, rainbow fish in the Campaspe River and golden perch in the Goulburn River (Stewardson *et al.* 2014). Environmental flows activated the Brewarrina fishway on the Barwon-Darling in 2014-15 (Ecological and UNE 2015). Increased numbers of congolli, lamprey and common galaxids moved through the barrages from the Lower Lakes into the Coorong and Southern Ocean. Lamprey were also detected moving through the barrages upstream into the River Murray between 2013 and 2015 (MDBA 2016a). Numbers of

Murray hardyhead and other small-bodied native fish species increased in Lake Alexandrina in response to environmental water delivered between 2013 and 2015 (MDBA 2016a).

Invasive species

There was mixed evidence to suggest environmental flows benefited invasive species. The Macquarie Marshes was the only site where carp recruitment was prolific following environmental flows (DOE 2015; OEH 2016; Stocks *et al.* 2015). Monitoring showed no significant carp spawning or recruitment resulting from environmental water along the South Australian Murray (Ye *et al.* 2015) and the Murrumbidgee River main channel (Wassens *et al.* 2013). Carp spawning in the Mehi River and Carole Creek in the Gwydir in 2013-14 appeared to be related to initial low-level flow rises in early October, before the provision of environmental flows (CEWO 2014; OEH 2014b; Southwell *et al.* 2015c). Monitoring by environmental water holders focused mainly on carp, and spawning responses for goldfish and gambusia remain unknown.

There was no conclusive evidence that environmental water stimulated carp movement in the Basin. No clear consistent pattern of movement was detected in carp in South Australian Murray wetlands in December 2012 (Ye *et al.* 2015). In the Edward-Wakool, carp displayed increased movement in response to increasing temperature and flow during spring and early summer of 2012-13, however evidence showed more than 90% of the small juvenile common carp recorded moving were derived from spawning events that occurred prior to the delivery of the environmental flow pulse (Ye *et al.* 2015).

Waterbirds

Basin-wide environmental outcomes were based on annual aerial colonial waterbird monitoring across 13.5% of the Murray-Darling Basin over a 33 year period since 1983. Site-specific outcomes for colonial waterbird abundance, diversity and breeding were based on ground-based surveys conducted or commissioned by government agencies. Site-specific waterbird responses were recorded in 12 valleys receiving environmental water across the Basin in the three year period after the Basin Plan (2012 – 2015). These included the Warrego River, Lower Darling, intersecting streams, Gwydir River, Macquarie River, Lachlan River, Murrumbidgee River, Victorian Murray, NSW Murray, SA Murray, Broken River and Loddon River. Basin-wide monitoring complemented on-ground surveys in helping to understand and contextualise the relative magnitude of localised outcomes.

Colonial waterbird outcomes are summarised below:

- Waterbird abundance and breeding was in overall decline across the Basin, with no indication this long-term trend has slowed even after the wet period from 2010-12.
- Waterbirds were highly responsive to natural and environmental flows, as seen by Basin-wide variability in abundance and breeding related to water availability over the past decade.
- The influence of post-Basin Plan environmental watering on waterbird outcomes at a Basin scale is not yet clear.
- At site scale, environmental watering has supported outcomes for waterbirds with evidence of localised improvements in abundance and diversity.
- Most improvements were related to increases in wetland area and floodplain inundation.
- Environmental flows were critical for the completion of waterbird nesting, breeding and fledging events. In very few cases environmental flows alone triggered a breeding event. Most events were triggered by natural or unregulated flows in conjunction with environmental flows.
- Waterbirds preferred different habitat during wet and dry periods. In wet periods, waterbirds exploited lakes and floodplains for breeding opportunities and food availability, while in dry periods they preferred river channels and lakes for refugia.
- There was evidence that water management decisions take into account water availability and work in concert with natural cues to achieve hydrological objectives.

- The overall magnitude of site-specific responses was difficult to ascertain as most studies reported presence/absence of species rather than quantitative measures in relation to a target or expected outcomes.
- Threatened species were recorded at many sites where environmental watering occurred, but there is no indication of their overall status in relation to obligations under international migratory bird agreements (JAMBA, CAMBA and ROKAMBA).

Abundance and diversity

Environmental flows in 2012-13 were sufficient to support a diversity of shorebirds and waterbirds observed across surveyed wetlands, including the endangered Australian Painted Snipe in the Macquarie Marshes (CEWO 2013; OEH 2014a) and several species listed on migratory bird agreements in the Murrumbidgee (OEH 2014a; Wassens *et al.* 2013). Waterbirds were concentrated in particular wetlands including the Gingham and Lower Gwydir where over 10,000 waterbirds were sighted including juvenile ibis, egret and heron species from the 2011-12 breeding season. Waterbird responses to environmental flows in 2013-14 reflected a continued decrease in water availability. Natural flows in northern valleys of the Basin were insufficient to trigger environmental flow releases for colonial waterbird breeding, so environmental flows were delivered mainly for waterbird abundance and diversity outcomes. Environmental water provided habitat for up to 44 waterbird species in the Gwydir, including threatened species listed under Commonwealth and NSW legislation (OEH 2014b), 20 species in the Lachlan (DOE 2014), 52 species in the Murrumbidgee (CEWO 2014; OEH 2014b; Wassens *et al.* 2014) and a moderate number of waterbirds in the Macquarie River, including limited numbers of threatened species including marsh sandpipers, sharp-tailed sandpipers and Latham's snipe (OEH 2014b). Overall waterbird abundance remained low in the Basin in 2014-15, reflecting smaller inundation extents compared to previous years. Environmental flows in conjunction with unregulated events, created localised waterbird responses in specific wetlands. Increased abundance and diversity of waterbirds was reported in the Gwydir River, Murrumbidgee (Wassens *et al.* 2016), Central Victorian Murray (Stewardson *et al.* 2014), and the Warrego (Southwell *et al.* 2015b) in association with environmental water management. However, for some sites there were reduced abundances of waterbirds in the Macquarie Marshes compared to previous years despite presence of environmental flows. A number of threatened species were observed in these systems. While most monitoring focused on waterbirds, monitoring of bush birds in 2014–15 showed they were significantly more common in areas that had been inundated (MDBA 2015a).

Breeding

Environmental water delivered to wetlands in 2012-13 alleviated some impacts of the transition from wet to dry conditions following the peak breeding events from 2010 to 2012. Minor breeding events were triggered in some locations receiving environmental water in 2012-13 including the Macquarie Marshes (CEWO 2013; OEH 2014a), Nimmie-Caira (OEH 2014a; Wassens *et al.* 2013) and the Barmah forest (DOE 2014). Environmental flows also played an important role in supporting the completion of a previous years' breeding event in the Murrumbidgee, resulting in fledging of royal spoonbills, cormorants, nankeen night herons, and straw-necked and glossy ibis (OEH 2014a; Wassens *et al.* 2013). Nevertheless, environmental flows were insufficient in volume to trigger new large scale breeding events in the Basin, or to sustain a nesting event in Booligal Station on the Lachlan valley where the result was abandonment of most nests prior to laying of eggs (DOE 2014). Environmental water in concert with unregulated flows supported breeding events in a number sites in the southern connected system the following year, including Edward-Wakool, Barmah-Millewa Forest and the Gunbower Forest (DOE 2014). Environmental flows were used after an unregulated flow event in the Edward-Wakool system to maintain water heights at rookeries over the summer and most hatchlings reached the fledgling stage (OEH 2014b). Environmental flows triggered or assisted a small number of breeding events in 2014-15, in the Gwydir River (CEWO 2015; Ye *et al.* 2015), Yanga National Park in the Murrumbidgee River (CEWO 2015; DOE 2015; MDBA 2015a; OEH 2016), Hattah Lakes (Stewardson *et al.* 2014) and Barmah forest (MDBA 2016a). Environmental watering in Yanga National Park resulted in breeding of eastern great egrets, listed under several international and bilateral treaties, for the first time since 2011 (MDBA 2016a).

Frogs

Large-scale response of frogs to environmental flows across the Basin is not well understood and is difficult to monitor (Watts *et al.* 2013). Intervention monitoring is currently undertaken at the site scale to assess the condition, abundance, diversity and breeding of frogs. Monitoring has been undertaken in 9 valleys in the Basin: Gwydir River, intersecting streams, Lachlan River, Loddon River, Macquarie River, Murrumbidgee River, NSW Murray River, SA Murray River and the Warrego River.

Outcomes for frogs are summarised below:

- Reductions in the extent, duration and frequency of wetlands flooded between 2012 and 2015 negatively impacted on frog species.
- There was evidence in some valleys of increases in frog species diversity in response to flows.
- Low response of frogs to environmental watering actions in some valleys was due to low availability of slackwater, inundated habitat and poor timing of watering events.
- The Southern Bell Frog, listed as vulnerable under the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999, was observed or heard calling at multiple sites, and Southern Bell Frog tadpoles were observed in eight wetlands.
- Breeding responses were observed in the Murrumbidgee and Gwydir valleys as a result of environmental flows.

Condition

Recent data on the condition of frog species is not available at the Basin-scale, however there is a general consensus that reductions in flooding and increased drought periods, negatively impact on frog species. Frog species that are highly dependent on seasonal inundation are at greater risk of decline due to reductions in flooding than other species that respond to rainfall and temperature (Gonzalez *et al.* 2011).

Abundance and diversity

Twelve of the 53 species of frogs in the Basin were recorded in wetlands receiving environmental flows between 2012 and 2015. It is not known how many were observed in sites which did not receive environmental water. There were six species recorded at sites in the Lachlan in 2012-13 and 2014-15 (OEH 2014a), six species in the Gwydir in 2013-14 (CEWO 2014; Southwell *et al.* 2015c), five species in Lake Yando on the Loddon river in 2014-15 (Stewardson *et al.* 2014) and four species in the Murrumbidgee in 2013-14 (Wassens *et al.* 2014). Diversity of the frog community increased on the Western Floodplain of the Warrego in response to flows in 2014-15 (Southwell *et al.* 2015b). Species reported during the three year period were Peron's tree frog, broad-palmed frog, desert tree frog, barking marsh frog, eastern sign-bearing froglet, spotted marsh frog, wrinkled toadlet, inland banjo frog, eastern banjo frog, plains froglet, southern bell frog and salmon-striped frog.

Frog responses to environmental flows were mixed at some sites in the Basin, mainly due to failure to achieve the necessary hydrological objective. There was little response of frogs to environmental watering actions in Colligen and Yallakool Creeks in the Edward Wakool in 2012-13 possibly due to low availability of slackwater and inundated habitat (Watts *et al.* 2013). Low frog abundance and activity during and after the water events in the Macquarie floodplain in 2014-15 was because the timing of these events was later than optimal for some species (OEH 2016). In the South Australian Murray, frog calling and species richness declined during a period of environmental watering in summer of 2012-13, probably because of the recent spike in frog activity and diversity caused by an unregulated flow event (Ye *et al.* 2015).

The Southern Bell Frog, listed as vulnerable under the Commonwealth Environment Protection Biodiversity Conservation Act 1999, was observed or heard calling at some surveyed sites in the Basin: South Australian gorge and riverland areas in 2012-13 (Ye *et al.* 2015); Lachlan in 2013-14 (OEH 2014b); NSW mid-Murray in

2014-15 (OEH 2016) and the Murrumbidgee in 2012-13 (Wassens *et al.* 2013) including Nimmie-Caira in 2013-14 (Wassens *et al.* 2014). This was only the second recording of this frog within the Lachlan catchment since 1978, and the first recording in the mid-Murray since the 1990s. Southern Bell Frog tadpoles were observed in eight wetlands at a range of metamorphic stages. Their age structure suggested that individuals spawned as a result of the flow peak in 2012-13 in the South Australian Murray (Ye *et al.* 2015).

Breeding and recruitment

Breeding responses were observed in the Murrumbidgee and Gwydir valleys. Five species were recorded breeding in the Murrumbidgee: the barking marsh frog, spotted marsh frog, inland banjo frog and plains froglet in 2012-13 (Wassens *et al.* 2013); and the southern bell frog and the inland banjo frog in 2014-15 (Wassens *et al.* 2016). Breeding activity was significantly greater in wetlands receiving natural overbank inundation (Lowbidgee) or environmental water (Western Lakes) compared to the mid-Murrumbidgee wetlands which did not receive inflows in 2012-13 (Wassens *et al.* 2013). There was an increase in tadpole abundance at surveyed wetlands receiving environmental water in the Murrumbidgee in 2014-15 (Wassens *et al.* 2016) compared with previous surveys, potentially because of reduced predation by carp due to pumping of water in some areas. Another substantial frog breeding event was observed in November 2013 in the Mallowa Wetlands of the Gwydir for four native species: salmon-striped frog, long-thumbed frog, broad-palmed frog and eastern sign-bearing froglet, likely as a response to environmental water in 2013-14 (Southwell *et al.* 2015c). By contrast, environmental watering in the Yallakool Creek and Colligen Creek of the Edward Wakool (2013-14) did not result in egg masses, tadpoles or metaphorphs despite the frog activity (Watts *et al.* 2014).

Invertebrates

Invertebrates are important to the Murray-Darling Basin ecosystem both as consumers and as food resource. The *Sustainable Rivers Macroinvertebrate Index* measured the condition of communities from 2004 to 2007 (SRA1) and from 2008 to 2010 (SRA2) across the Basin. Long term surveys of macroinvertebrates also occurred in the Murray and Mitta Mitta Rivers (34 and 16 years respectively) to assess the effects of physical and chemical changes in water quality on freshwater biota (Cook and Hawking 2014; MDBA 2014a). More recent surveys of microinvertebrates, macroinvertebrates and zooplankton densities were conducted on the Murrumbidgee and Gwydir floodplains between 2012 and 2015 in response to environmental watering, with observations also recorded for the Goulburn, intersecting streams, South Australian Murray and the Warrego.

Key outcomes for invertebrates are described below:

- Recovery in invertebrate abundance and diversity was apparent in some sites following the long term decline in condition due to the Millennium drought.
- Surveys during periods of environmental watering showed positive results for microinvertebrate densities but less clear trends for macroinvertebrates densities.

Prior to the Basin Plan, invertebrate communities experienced a long term decline in condition in the River Murray from the mid-1990s to the late 2000s, with major changes to dominant species within macroinvertebrate communities (Cook and Hawking 2014). The condition of macroinvertebrates was moderate to poor in most valleys in the Basin during and after the Millennium drought and prior to introduction of the Basin Plan (Davies *et al.* 2012). Invertebrate communities showed signs of recovery after the Millennium drought, with some macroinvertebrate indicators returning to improved state (Cook and Hawking 2014; MDBA 2014a). Surveys during periods of environmental watering under the Basin Plan showed positive results for microinvertebrates but less clear trends for macroinvertebrates. Densities of microinvertebrates increased in response to environmental flows in the Lowbidgee floodplain in 2013-14 (Wassens *et al.* 2014), the Nimmie-Caira, Redbank, mid-Murrumbidgee and Murrumbidgee River in 2012-13 (Wassens *et al.* 2013) and 2014-15 (Wassens *et al.* 2016) and the Carole and Mehi channels of the Gwydir in 2013-14 (Southwell *et al.* 2015c), although abundance fluctuated in the Gingham watercourse and the Lower

Gwydir River in 2013-14 (Southwell *et al.* 2015c). Macroinvertebrate abundance temporarily reduced at the onset of environmental watering in the Goulburn in 2012-13 (Stewardson *et al.* 2014), possibly because flows diluted macroinvertebrate concentrations and reduced slackwater habitat. Macroinvertebrate abundances recovered within weeks as flows receded due to increased breeding and lower flows concentrating individuals. Macroinvertebrates in the Goulburn River in 2014-15 did not show a positive response to environmental flows nor any significant negative impact (Webb *et al.* 2015a).

Higher-order ecological outcomes

Monitoring of higher level objectives relating to resilience (BP S8.07), ecosystem functioning (BP S8.06) and biodiversity and representativeness (BP S8.05) is not yet available, although the Basin Plan evaluation framework identifies potential indicators and data sources for measuring some of these outcomes. The first of a series of LTIM reports reported primarily on site-specific, short-term ecological responses to environmental flows, but ongoing monitoring as part of the LTIM project, combined with modelling and statistical analyses (e.g. see modelling undertaken by Ye *et al.* 2016), is expected to reveal the contribution of successive environmental watering events to higher-level outcomes such as representativeness, resilience and ecosystem function.

Representativeness & diversity

Reinstating environmental flows for a representative range of ecological communities is critical for maintaining diversity across the Basin (Wassens *et al.* 2016). There is a need to ensure environmental watering outcomes are representative, especially because of the spatial variation in biota (González-Orozco *et al.* 2015) and their condition (e.g. Figure 8). However very few environmental watering reports documented the representativeness and diversity of ecological communities that received environmental watering. Exceptions were the Gwydir where environmental water influenced all 10 ecosystem types monitored in the Gwydir (Southwell *et al.* 2015a) and the junction of the Warrego and Darling environmental water influenced six of the 10 ecosystem types monitored, including lowland stream, floodplain lake, lignum, shrubland, floodplain and temporary lake ecosystem types (Southwell *et al.* 2015b).

The Basin Plan focuses on protecting river flows to ecosystems rather than protecting rivers and wetlands themselves. However, protection of these areas is important and can help ensure freshwater ecosystems have the greatest potential for conservation and restoration under the Basin Plan. Protected areas such as National Parks, nationally important wetlands and Ramsar wetlands can help to mitigate impacts of habitat destruction, wildlife harvesting and grazing pressures. However only 10.3% of wetlands in the Murray-Darling Basin are recognised in Australia’s protected area system, the lowest of all drainage basins in Australia (Bino *et al.* 2016). This proportion varies depending on the type of wetland: estuarine wetlands are well protected (99.9%), while lacustrine (15.4%), palustrine (9.3%) and riverine (13.2%) wetlands are not well protected (Bino *et al.* 2016). There are gaps in the representativeness of the reserve system, both spatially and in the spectrum of species and habitats that are protected (Chessman 2013). Assessment of the adequacy of the existing protected area system, management of these reserves, and implications for the Basin Plan is an important step towards restoring ecosystems in the Murray-Darling Basin.

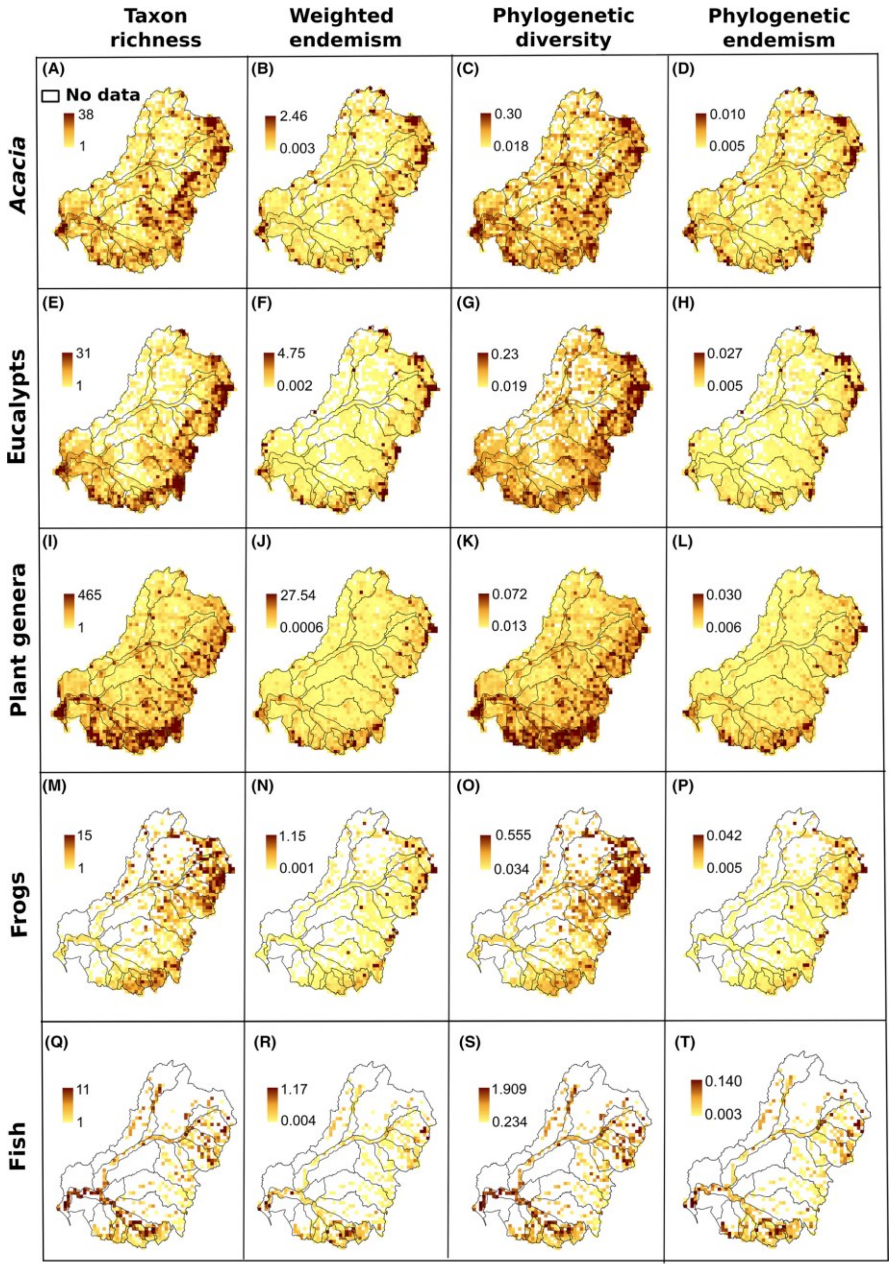

Figure 8. Diversity and endemism for fish, frogs, plant genera, Eucalyptus and Acacia in the Murray-Darling Basin (from González-Orozco et al. 2015)

Resilience

There were some examples of where environmental watering had improved resilience, but there was no overall evaluation of the status and changes in resilience due to environmental watering in the Basin. Among the examples of positive outcomes for resilience was in the Lower Gwydir wetlands where a bushfire burned 1600 hectares of wetland vegetation including stands of endangered marsh club-rush (OEH 2016). Sites that had received water in January and February 2015 had recovered well from the fire and were in good to intermediate condition, while areas that had not been watered had not sufficiently recovered, with approximately 30 per cent bare ground recorded by the monitoring team at these sites. In the Warrego and Darling valleys, environmental water promoted the survival and condition of individuals through dry periods by providing pools as drought refuges (Southwell *et al.* 2015b). In the Goulburn valley, flow-tolerant species located lower down on river banks were likely to be more resistant to erosion and more resilient to disturbance (Webb *et al.* 2015b). Improved condition, abundance and recruitment of species were also recognised as important elements of resilient communities (Southwell *et al.* 2015a).

Water quality outcomes

The River Murray water quality program has been carried out in the southern Basin for over 35 years (MDBA 2015a). The current program is delivered in partnership with NSW, Victoria, South Australia and the Authority. Water quality monitoring consists of weekly sampling at 18 sites in the River Murray and monthly sampling at 10 sites in the major tributaries. Water quality was also recorded in 11 valleys receiving environmental flows across the Basin between 2012 and 2015: Campaspe, NSW Murray, SA Murray, Murrumbidgee, Broken, Goulburn, Gwydir, Victorian Murray, Lachlan and the Warrego. Measurements included dissolved oxygen, salinity, sediment, nutrients and organic matter, water temperature, phytoplankton, zooplankton and biomass, and stream metabolism.

Water quality monitoring was mostly within acceptable limits for aquatic biota at sites receiving environmental water including the Gwydir in 2013-14 and 2014-15 (CEWO 2014; Southwell *et al.* 2015c; Ye *et al.* 2015), NSW Murray in 2013-14 (OEH 2014b), Darling River near the Warrego in 2014-15 (Southwell *et al.* 2015b) and the Edward Wakool on the NSW Murray in 2012-13 (CEWO 2014; Watts *et al.* 2013). Exceptions were attributed to warm temperatures and low water availability (CEWO 2014; Southwell *et al.* 2015c; Ye *et al.* 2015) and large unregulated flows (Watts *et al.* 2013). Environmental water influenced water quality, with different outcomes depending on the location, type and seasonality of flows. We used environmental watering reports to document influences of environmental flows on water quality. Below is a summary of results for each indicator:

- **Dissolved oxygen**: Environmental water helped to maintain acceptable levels of dissolved oxygen in weir pools and some channels in the Basin, but they were not always sufficient to prevent temporary periods of low dissolved oxygen levels. There were no known reported fish kills due to dissolved oxygen from 2013-15.
- **Sediment, nutrients and organic matter:** Environmental flows were associated with increased concentrations of dissolved organic carbon, total nitrogen and total phosphorus in some locations where environmental flows connected channels and floodplains. In others areas, environmental water decreased nutrient concentrations due to insufficient connectivity with the floodplain, low levels of organic matter on floodplains possibly due to successive environmental watering events. There was an overall reduction in the concentration of nutrients, salt and organic matter at Morgan in South Australia, indicating improved water quality towards the end of the system (MDBA 2014a).
- **Salinity:** Salinity targets in the Basin Plan were met in three out of five locations for the most recent reporting period (2010-15). Targets were not met at the end of the Darling River (Burtundy) due to low flows, and at Milang at Lake Alexandria due to the influence of the Millennium drought on reporting. Environmental flows contributed to the maintenance of salinity levels and increased export of salt from the river system through the Murray Mouth. Salt interception schemes also played an important role in managing salinity levels in the River Murray.
- **pH:** Most surface water acidification events in the Lower Lakes were naturally neutralised following a rise in lake levels in 2010, however low residual pH levels at some surface and groundwater sites remains an ongoing problem. Low pH has also been recorded for return flows from the lower Murray irrigation area however dilution flows have been applied to return water to acceptable pH levels.
- **Water temperature**: Water temperature was more strongly influenced by seasonality than environmental flows, however increases in flow velocity due to environmental watering was linked to the prevention of temperature stratification in river channels.
- **Micro-organisms:** Environmental water releases helped to suppress excess biofilm biomass and support biofilm diversity.
- **Stream metabolism:** Environmental water delivery increased stream metabolism where flows provided exchanges of nutrients between channels and floodplains. Environmental flow delivery had

negligible immediate effects on ecosystem respiration in some systems probably because of dilution, but peaks were observed in weeks following receding flows.

Water quality

Dissolved oxygen

There was evidence that environmental flows helped maintain dissolved oxygen at appropriate concentrations in two weir pools. Modelling of Rices Weir Pool in the Victorian Murray in 2012-14 (DOE 2015) and Broken Creek weir pools in 2012-13 (Stewardson *et al.* 2014) showed that in the absence of environmental water, dissolved oxygen levels would have been dangerously low for extended periods, and well below the Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines for aquatic ecosystems. This positive result for weir pools does not discount the importance of inundation of floodplains and appropriate water exchanges for significant downstream benefits (Ye *et al.* 2016). Environmental water in the Edward Wakool assisted in the maintenance of dissolved oxygen concentrations for floodplain zones over the summer of 2014-15 compared areas which did not receive environmental water, a benefit which persisted beyond the end of the watering action (CEWO 2015; Watts *et al.* 2015).

Environmental flows and other discharges were not always sufficient to maintain acceptable levels of dissolved oxygen. Low dissolved oxygen was experienced intermittently during periods of environmental watering in the Goulburn in 2013-14 and in some reaches of the South Australian Murray in 2014-15 (CEWO 2015; DOE 2015; Ye *et al.* 2016). Low levels of dissolved oxygen from return flows to the South Australian Murray in 2014-15 were associated with increased respiration rates but these were not lethal to biota (CEWO 2015; DOE 2015; Ye *et al.* 2016). Despite low oxygen levels in some locations, there were no blackwater events reported in these surveyed areas. Environmental flows mitigated the impacts of blackwater events in 2012 by mitigating extreme low flow events and in doing so, providing refuge habitats for fish (Watts *et al.* 2013).

Salinity

We were able to clearly assess achievement of salinity targets based on annual reporting of targets since the Basin Plan was implemented. Salinity reports showed varying levels of achievement of Basin Plan targets. Salinity targets were met at three out of five sites for the reporting period (2014-15; Table 5). Salinity targets at the remaining two sites were not achieved due to low flows, and lag effects of the Millennium drought affecting the long term averages. Achievement of salinity targets in the long term is highly dependent on flow availability and effectiveness of the salt interception schemes. Commonwealth government modelling shows salt interception activities can be adequately managed over the next 15 years which is within the course of the 10-year Basin Plan (Australian Government 2014). However, salt load is predicted to rise to up to 304 tonnes per day between the South Australian border and Tailem Bend by 2100 as a result of long history of vegetation clearing (Barnett and Yan 2006). Interception schemes are not configured to mitigate such potentially large projected increases in the century ahead.

Table 5. Salinity at five sites over the 5 year period from 1 July 2009 to 30 June 2014, compared to the target values (refer Basin Plan clause 9.14) (MDBA 2015b).

Reporting site	Target value (EC in µS/cm)	Non-exceedance salinity at 95% of the time (µS/cm)*	% of days above the target value
River Murray at Murray Bridge	830	520	0
River Murray at Morgan	800	494	0
River Murray at Lock 6	580	362	0
Darling River downstream of Menindee Lakes at Burtundy	830	911	12

Lower Lakes at Milang	1000	3482	10

*Daily mean values derived from continuously logged data.

Benefits of environmental flows for salinity were reported for the Coorong and Lower Lakes, where environmental flows contributed to the maintenance of acceptable salinity levels and increased export of salt from the river system through the Murray Mouth between 2012 and 2015 (CEWO 2013; 2014; 2015; DOE 2015; Ye *et al.* 2016; Ye *et al.* 2015). In 2014-15, modelling showed Commonwealth environmental water reduced salinity in the Murray mouth from 34.02PSU to 26.70PSU and helped prevent the import of over 3,000,000 tonnes of salt through the Murray Mouth (Ye *et al.* 2016).

Further upstream at Morgan, salinity was significantly lower due to the combined impact of the Basin Plan, the Basin Salinity Management Strategy (2001-2015) and the Salinity and Drainage Strategy (1988-2000) (Figure 9). Environmental flows reduced salinity concentration in the Edward Wakool System (Jimaringle Creek, Cockran Creek, Gwynnes Creek and Tuppal Creek in 2012-13) (CEWO 2013) and Tuppal Creek in 2014-15 (CEWO 2015; Watts *et al.* 2015). There were no negative salinity outcomes reported in relation to environmental watering events.

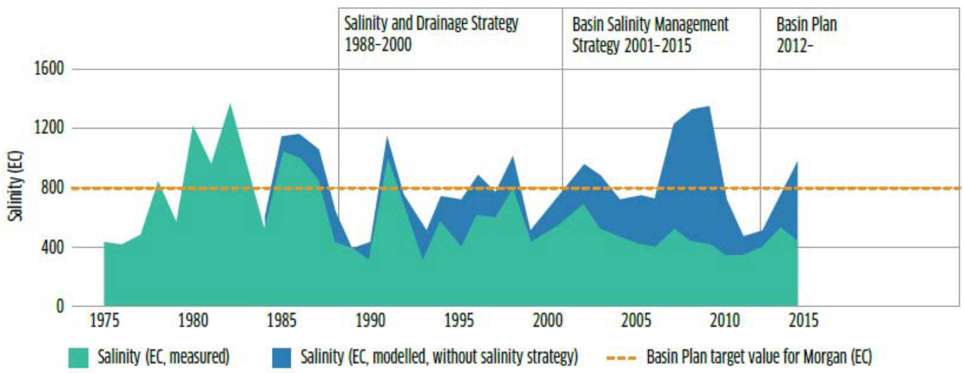

Figure 2.4 River Murray salinity at Morgan and impact of management strategies

Figure 9. Salinity at Morgan on the River Murray from 1975 – 2015 (MDBA 2014a).

Salt interception schemes played an important role in managing salinity at agreed levels in the River Murray. Around 432,000 tonnes of salt were intercepted from the River Murray in 2014–15, the highest recorded since 2010-2011 (Figure 10) (MDBA 2015a).

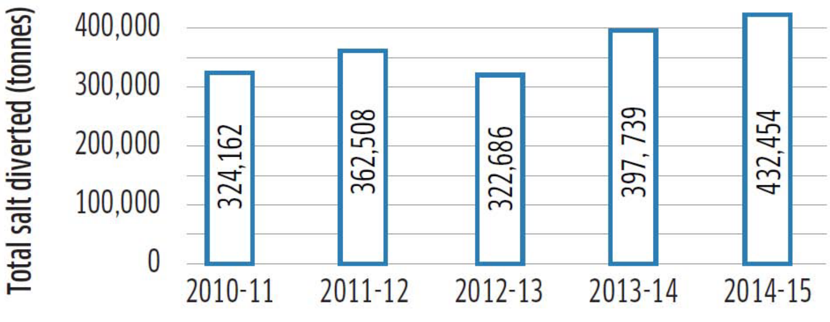

Figure 10. Tonnes of salt diverted from the River Murray from 2010 to 2015 (MDBA 2015a).

pH

Re-wetted acid sulfate soils continued to affect return flows from the lower Murray irrigation (MDBA 2014a). Environmental flow and water management have contributed to mitigating potential impacts of acid drainage in this area through dilution and neutralisation (CEWO 2013; Ye *et al.* 2015). Water quality guidelines were slightly exceeded outside the immediate mixing zone. In the Lower Lakes, ongoing low levels of acidity at some sites have persisted since the Millennium drought (SA EPA 2016). Acidic surface water from the drought percolated through the lake bed causing acidic groundwater (pH 3-5) at some sites between 0.5 to 2m deep (SA EPA 2016).

Sediment, nutrients and organic matter

Environmental water increased the mobilisation of sediments, nutrients and organic material in the Campaspe in 2012-13 (CEWO 2013; Ye *et al.* 2015), Goulburn in 2012 (Stewardson *et al.* 2014) and sites on the mid-Murrumbidgee River in 2012-13 (CEWO 2013; OEH 2014a; Wassens *et al.* 2013). Environmental flows mobilised woody debris within the river channel and increased transport of suspended matter in the Goulburn in 2013-14 (Webb *et al.* 2015b). Environmental flows accounted for approximately 40%, 10% and 20% of exports of particulate nutrients from the Murray River, Lower Lakes and Murray Mouth, respectively, in 2012-13 (CEWO 2013; Ye *et al.* 2015). Exports of nutrients and organic matter from the Murray Mouth was most effective when delivery of environmental water coincided with periods of low oceanic water levels (e.g. summer) (Ye *et al.* 2016).

Environmental watering associated with wetting dry sections of channels and floodplains resulted in increased nutrient concentrations and export. Environmental flow releases contributed to increased levels of carbon, total nitrogen and total phosphorus in channels and refuges of the Mehi River and Carole Creek in the Gwydir valley in 2013-14 (Southwell *et al.* 2015c). Phosphate and dissolved organic carbon concentrations were also higher in some reaches of the Murrumbidgee River receiving environmental flows, and elevated levels were measured up to 3km downstream of the return flows in October but this pattern was not repeated the following February (Wassens *et al.* 2016). Nutrient levels were higher in zones of the Warrego River compared to the Darling, presumably as a result of the inundation of organic matter on previously dry areas. Benefits were realised at the end of the system in 2014-15, where transport of carbon, nutrients and sediment downstream resulted in slightly higher levels of ammonium, silica, and particulate organic nitrogen concentrations in the Murray Mouth as a result of environmental flows (CEWO 2015; DOE 2015; Ye *et al.* 2016).

Conversely, successive years of environmental watering reduced concentrations of nutrients and organic matter. Reductions in carbon and phosphate levels on the Murrumbidgee floodplain lead to an improvement in water quality between 2013-14 and 2014-15 (CEWO 2015; OEH 2016; Wassens *et al.* 2016). Total nitrogen and total phosphorus levels were generally lower in sites on the Edward Wakool receiving environmental water in 2014-15 (CEWO 2015; Watts *et al.* 2015).

No significant differences in dissolved organic carbon and bioavailable nutrients were detected in channels receiving environmental flows in the Edward Wakool in 2012-13 (CEWO 2013; Watts *et al.* 2013), probably because re-wetted areas did not contain sufficient accumulated organic material, and the small in-channel watering actions did not reconnect a sufficient area of upper benches and floodrunners to result in substantial exchange of organic matter and nutrients.

Water temperature

Influence of environmental flows on temperature was reported for only a few valleys. Environmental flows did not exert a strong influence on temperature at surveyed sites, the dominant factor was seasonality (Southwell *et al.* 2015c; Watts *et al.* 2013; Watts *et al.* 2015). However in the lower Broken Creek, environmental water increased flow velocity which prevented significant changes in temperature and stratification of flows (Stewardson *et al.* 2014).

Micro-organisms

Changes in zooplankton assemblages were associated with environmental watering in the Lower Murray River (Ye *et al.* 2015), however increases in zooplankton or phytoplankton abundance were not detected in the Colligen and Yallakool Creeks (CEWO 2013; Watts *et al.* 2013) nor were they clearly related to environmental water in the Gwydir (Southwell *et al.* 2015c). Environmental water released from Chowilla was observed to enhance diversity and transport of zooplankton but the degree of persistence of transported individuals is not known (Ye *et al.* 2016).

Environmental watering helped to scour algae and reduce biofilm biomass in the Murrumbidgee River in 2012-13 (CEWO 2013; OEH 2014a; Wassens *et al.* 2013), the Goulburn River in 2013-14 (Webb *et al.* 2015b) and the Edward Wakool in 2012-13 (CEWO 2013; Watts *et al.* 2013). In the Edward Wakool this was accompanied by higher diversity in biofilms associated with good ecosystem health.

A blue-green algae event along a 900km stretch of river in early 2016 was a symptom of low river flows and prolonged warm weather, although it was not especially unusual given the long history of algal blooms in the Basin (Figure 11). A notable shift in dominant species has yet to be explained.

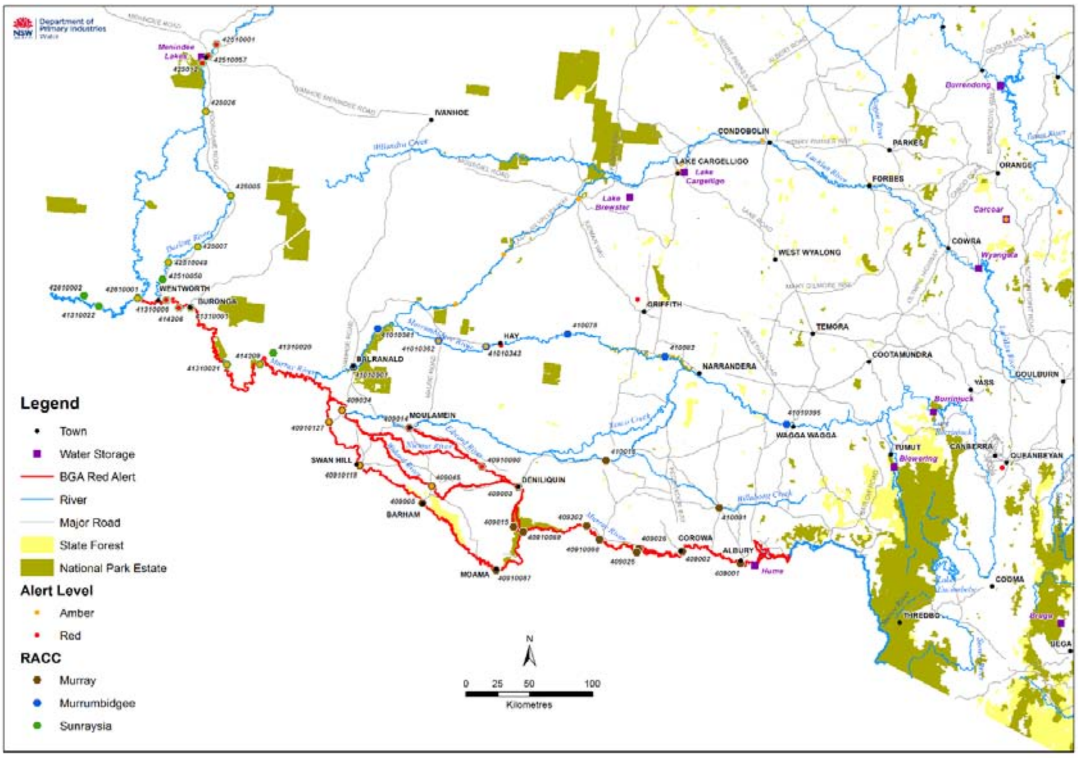

Figure 11. Location of the reach of the Murray River where a blue-green algae red alert was issued in early 2016 (DPI Water 2016).

Stream metabolism

Environmental watering stimulated rates of gross primary production and ecosystem respiration in the Goulburn in 2012-13 and 2013-14 (Stewardson *et al.* 2014; Webb *et al.* 2015b), Hattah Lakes in 2014-15 (Stewardson *et al.* 2014) and the Murrumbidgee in 2013-14 (CEWO 2013; OEH 2014a; Wassens *et al.* 2013) and 2014-15 (CEWO 2015; OEH 2016; Wassens *et al.* 2016), through increased mobilisation of organic matter and nutrients. Enhanced ecosystem respiration rates were associated with return flows from the Chowilla floodplain in mid-November of 2014 indicating increased supplies of organic material to the river (CEWO 2015; DOE 2015; Ye *et al.* 2016).

Conversely, environmental water releases reduced gross primary production and ecosystem respiration in the Lachlan in 2014-15 (Dyer *et al.* 2015), probably because of dilution of phytoplankton and organic matter, and a reduction in light penetration for photosynthesis. However effects were shortlived and gross primary production and ecosystem respiration increased in the low flow period following this environmental watering event (Dyer *et al.* 2015). Similar reductions were observed in the lower Goulburn River in 2014-15 where daily ecosystem respiration rates decreased with discharge due to the dilution effect of the added water (Webb *et al.* 2015a). At one site, ecosystem respiration increased in the weeks following environmental watering, but this increase was not necessarily attributed to flow (Webb *et al.* 2015a). In-channel environmental flows delivered to the lower Goulburn River in 2014-15 had only minor effects upon stream metabolism parameters, although there was a small peak in net primary productivity (Webb *et al.* 2015a)

There were minimal changes to gross primary production and ecosystem respiration in the Edward Wakool system because flows were contained within the stream channel, with little supply of organic matter from inundation of backwater areas or instream benches (Watts *et al.* 2013; Watts *et al.* 2014; Watts *et al.* 2015). There was no clear influence of environmental water on gross primary production in Riverland sites (Ye *et al.* 2016). Ecosystem net production summed to zero indicating a close balance between production and decomposition of organic material i.e. little external food resource supply and all food resources produced in-channel were utilised (Ye *et al.* 2016).

Ecological outcomes at the Basin-scale

Since 2012-13, many early environmental outcomes have been observed at the specific sites where environmental water was directed, however there are many more sites across the Basin which have not received sufficient environmental flow and remain in a poor and degrading condition. Improvements in the condition of the Basin across large scales have not yet been assessed and reported. We are also yet to observe longer lasting improvements in the Basin's environment because, like watering a garden after a drought, it will take consecutive watering events for degraded ecosystems to respond given the lag effects and the trajectory of declining health in past decades. Even when the Basin Plan is implemented in full, recovery of 3,200 GL in full with eight constraints relaxed is expected to achieve only 66% of the 112 target environmental water requirements set by the Murray-Darling Basin Authority in 2012 to deliver a healthy working river.[156]

We also do not have Basin-wide monitoring in place that measures condition of river systems and enables detection of these changes even when they become apparent. No measures of Basin-wide health have been produced since the Sustainable Rivers Audit was discontinued. The Sustainable River Audit was a Basin-wide assessment of river health for the 23 valleys of the Basin for key indicators — vegetation, physical form, macroinvertebrates, fish and hydrology. It was an initiative of Basin governments, coordinated by the Murray–Darling Basin Authority, and overseen by a panel of independent ecologists. Two audits were undertaken for the periods 2004 to 2007 and 2008 to 2010. In 2012, the New South Wales Government cut 60 per cent of its share of funding for the joint management of the Murray-Darling Basin system and as a consequence, state governments decided to cease the audit. Without the ability to track the condition of the Basin it is not possible to understand the ecological changes at a valley and Basin scale.

Native vegetation

The stand condition of woody vegetation (river red gum and black box) was monitored at seven icon sites in the Southern Basin totalling 134,000 ha in area.(MDBA 2016d) This analysis includes areas that have not received environmental water or natural flooding since at least 2009. Between 2009 and 2015, there was an 11% decline in the area of red gum and black box stands classified as good condition, and a 26% increase in the area that was classified as severely degraded (Figure 12).(Hughes *et al.* 2016) Black box stands were generally classified in poorer condition than red gum stands, because black box stands are situated in the upper floodplains which are less frequently flooded.(Hughes *et al.* 2016) Due to the dry conditions there was very little environmental water available on The Living Murray portfolio until 2010-11. The Living Murray works only started to become operational at different icon sites between 2013-14 and 2015-16. Data on recruitment, understorey and other aspects of vegetation condition were not included in the assessment of stand condition.

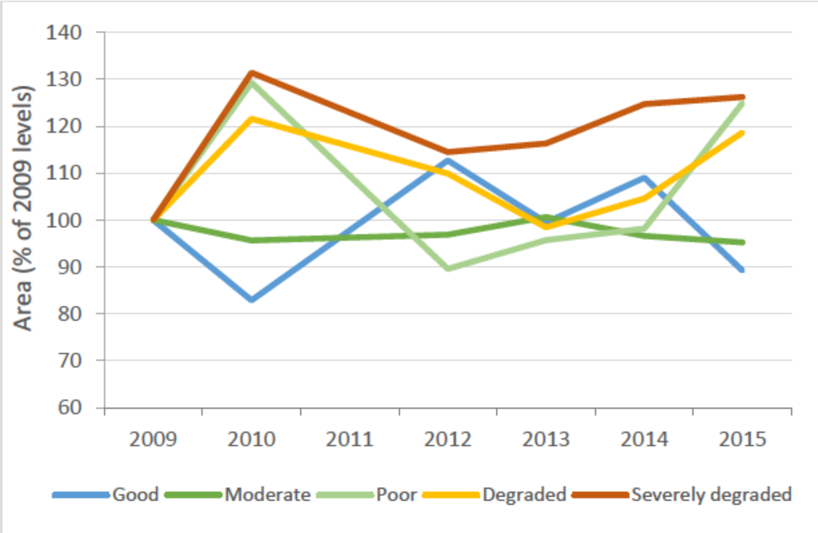

Figure 12. Change in area of floodplain forests and woodlands of different condition across seven Living Murray sites (total of 134,200 ha) relative to 2009 areas. (Source: Compiled from MDBA's stand condition reports; error not quantified).(MDBA 2016d)

Waterbirds

Waterbird abundance for the sample area (13.5% of the Basin) peaked at the beginning of the 33 monitoring period at about 700,000 individuals (1984), then declined through the Millennium drought to a record low of less than 50,000 individuals (2009; Figure 13).(Porter *et al.* 2016) Drought-breaking rains in 2010 and 2011 led to a small recovery in waterbird abundance, reaching about 350,000 individuals (2012). Aerial waterbird surveys across the Murray-Darling Basin showed low populations of waterbirds after 2012, following a small peak in population during the wet period from 2010 to 2012 (Figure 13).(Porter *et al.* 2016)

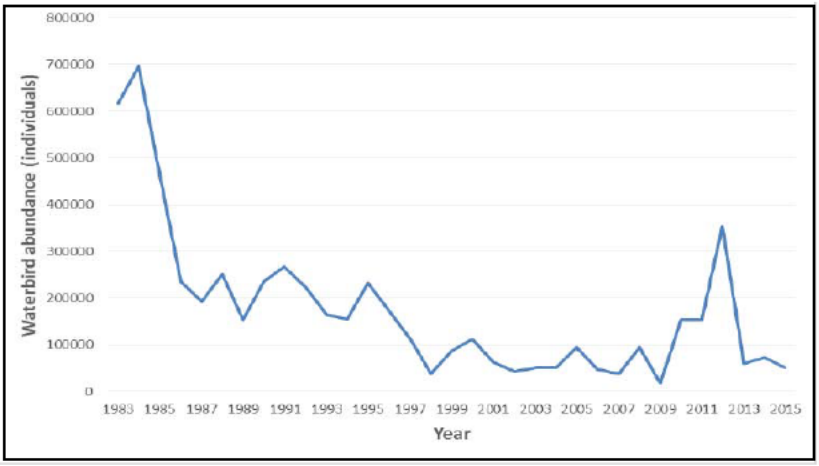

Figure 13. Waterbird abundance across the Murray–Darling Basin 1983–2015 (as estimated during aerial waterbird surveys).(Porter et al. 2016)

The ten most important wetlands for waterbird breeding in the past 33 years have been Lowbidgee, Cuttaburra Channels, Menindee Lakes, Macquarie Marshes, Paroo overflow, Darling River, Corop Wetlands and the Coorong, Lower Lakes and Murray Mouth, Fivebough Swamp and Coolmunda Dam. These wetlands, together with seven additional sites, represented 80% of total abundances of all 52 waterbird species over the 33 year period.(Bino *et al.* 2015) Different wetlands were important for waterbirds in dry years compared to wet years. In dry years, waterbirds preferred 12 riverine and lacustrine habitats for refugia, while in wet years waterbirds preferred 8 lacustrine and palustrine complexes as breeding grounds.

Since implementation of the Basin Plan, declines have continued in total waterbird abundance, wetland area, breeding abundance and breeding species richness,(Porter *et al.* 2016) interrupted by a peak related to the wet period from 2010 to 2012. Waterbird abundance has not exceeded 100,000 individuals in any year since the Basin Plan was implemented.(Porter *et al.* 2016) Declines were related to reduced frequency and magnitude of flows and inundation extent due to changes in climate and impacts of river regulation, given large-scale colonial waterbird breeding generally requires large areas of wetland (>20,000 ha) to be inundated.(Wassens *et al.* 2014)

Native Fish

The abundance and distribution of native fish has declined in the past 50 years (Figure 14) (Banks and Docker 2014). In the southern Basin, native fish populations in the Murray River have declined to about 10% of the pre-European level over the past 100 years.(Ye *et al.* 2015) In the northern Basin, fish communities in most valleys are in extremely poor to poor condition, with the exception of the Border Rivers (moderate), Condamine (moderate) and Paroo (good; Figure 15).(NSW DPI 2015) Low condition scores for the Lower Lachlan were attributed to a number of native species predicted to have historically occurred within the area that were absent (50% of species absent) and because recruitment within the population was observed to be very low.(Dyer *et al.* 2015)

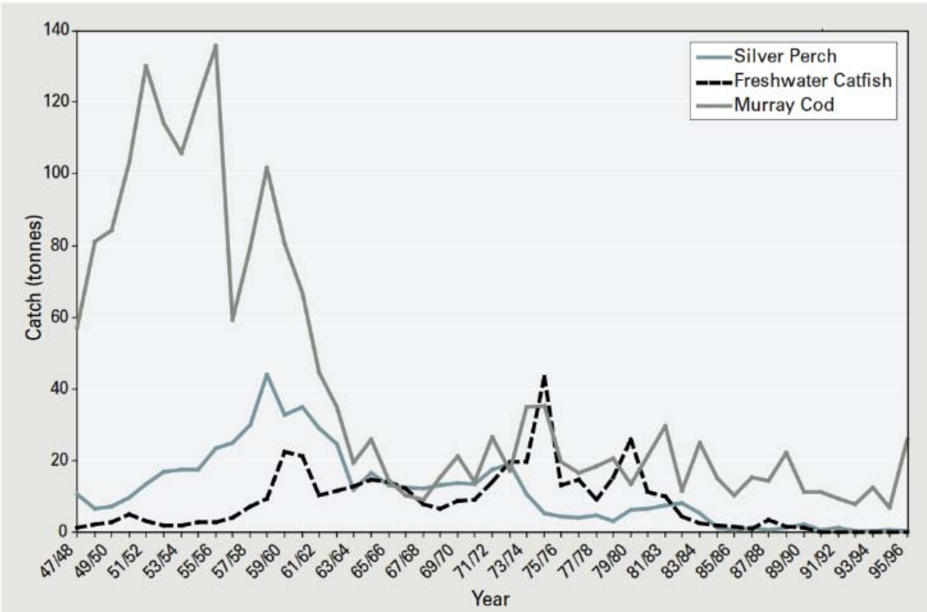

Figure 14. Decline in commercial catches of Murray cod, Freshwater catfish and Silver perch in NSW between 1947 and 1996 (Source: Reid et al. (1997) in Lintermans (2009)).

Despite the localised benefits of environmental water, fish communities in most valleys in the Murray-Darling Basin of New South Wales, particularly in the southern Basin, remained in extremely poor to poor condition in 2015 (Figure 15).(NSW DPI 2015) Results also showed the condition of fish communities changed within valleys, for example in the Macquarie River, where fish condition declined along a downstream gradient from 'poor' below Burrendong Dam to 'extremely poor' in the Macquarie Marshes and downstream to the Barwon River confluence.(Stocks *et al.* 2015) There was a small improvement in trend of the native fish communities in some valleys (e.g. from 'very poor' to 'poor' in the Edward-Wakool.(Watts *et al.* 2014)

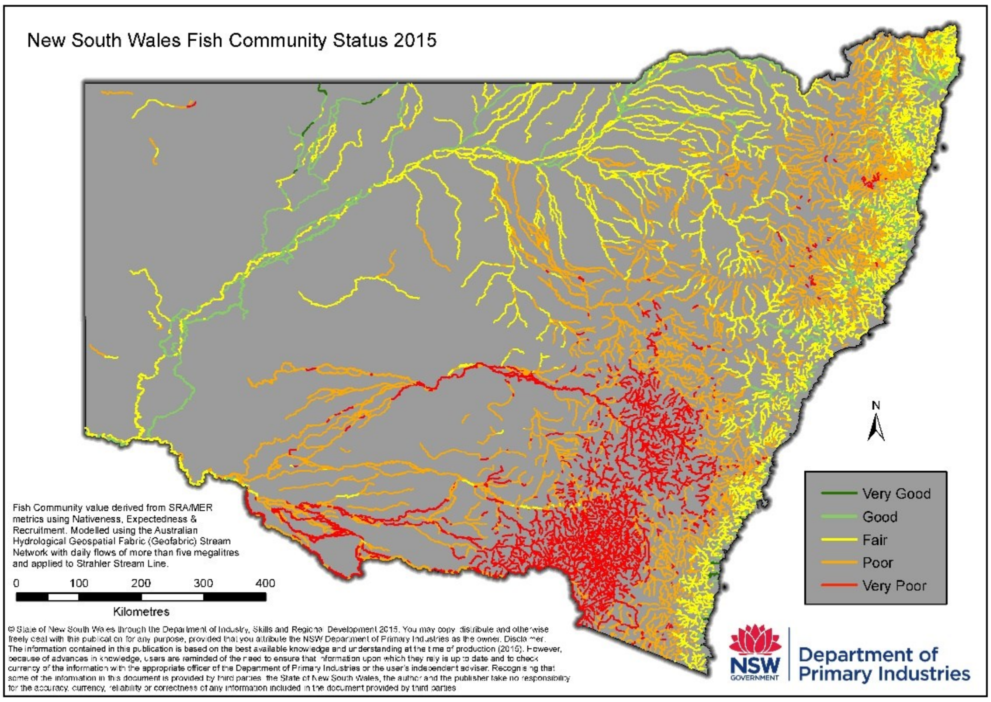

Figure 15. Fish community status in New South Wales.(NSW DPI 2015)

Risks to delivering ecological objectives

We identified key factors reported to have affected or likely to affect the ability to achieve desired environmental objectives at the Basin scale in the Murray Darling Basin Plan:

1. Physical and policy constraints

Constraints were among the most frequently cited challenges affecting the delivery of environmental water under the Basin Plan. Physical and policy constraints were reported to have affected the delivery of flows in a number of valleys including the Murrumbidgee valley, Goulburn valley, Lower Murray and Gwydir valley (Wassens *et al.* 2016; Wassens *et al.* 2014; Webb *et al.* 2015a; Ye *et al.* 2015). Major constraints included operational and channel capacity constraints in the Murrumbidgee (CEWO 2013; OEH 2014a; Wassens *et al.* 2014) and channel capacity constraints at the Barmah Choke in the Lower Murray (VEWH 2016). Constraints ranged from access to irrigation pumps (Papps 2016), crop harvesting (CEWO 2013; Southwell *et al.* 2015a), maintenance work (DOE 2015; OEH 2014a), a water skiing event (VEWH 2016), cod fishing (Papps 2016) and other third party impacts (Watts *et al.* 2014). The Commonwealth has committed $200 million to address physical, institutional and operational constraints over ten years from 2014/15 (COAG 2013), however implementation will not be complete for a number of years and costs could exceed available funding.

2. Environmental factors aside from flow volume

A range of factors besides flow were reported to constrain ecological outcomes, including poor water quality and sub-optimal water temperature (NSW DPI 2015), timing and seasonality of flows which aligned poorly with life history stages (Stocks *et al.* 2015; Ye *et al.* 2016), insufficient inundation of suitable habitat (Watts *et al.* 2013; Ye *et al.* 2015), low availability of food sources for aquatic species (Watts *et al.* 2013), predation by other species (Ye *et al.* 2015), grazing pressure (Dyer *et al.* 2015) and restricted fish passage (NSW DPI 2015). Some of these issues can be addressed through water management, while other issues can be addressed through non-flow related actions which complement environmental watering including riparian revegetation, thermal pollution controls, pest species management, removal of barrages and river obstructions, erosion control and re-snagging of rivers.

3. Flow variability and climate change

Managing environmental flows under variability and uncertainty has been challenging for water managers, and climate change is likely to compound this challenge in the future. Several environmental water events were not triggered due to the absence of unregulated flows (e.g. Gwydir wetlands in 2012-13), while others did not go ahead due to insufficient environmental flow allocations. Addressing climate change impacts in environmental water decision-making should take into account impacts on the availability of environmental water as well as impacts on freshwater ecosystems in the Basin. Gonzalez *et al.* (2011) identified 37 species in South Australia's River Murray that are most vulnerable to climate change impacts due to their narrow water requirements and habitat preferences. Environmental water can help improve the resilience of these species to climate change.

4. Protecting environmental flows

Environmental water is not well protected by existing water management rules and even when the Basin Plan is in place, environmental water may be vulnerable to illegal or harmful downstream extraction, reducing the overall volume of water that is available to achieve environmental outcomes in the Basin.(ANAO 2013) While illegal extraction of environmental water is an obvious threat, there are also many different ways in which environmental water can be taken legally with adverse consequences. Arrangements which ensure flows are protected (e.g. through shepherding, piggy-backing and accreditation of return flows) is essential for protecting and securing environmental flow volumes into the future.

5. Whole-of-ecosystem planning

Environmental water planners faced challenging decisions about the use of environmental water delivered under the Basin Plan, including: weighing the benefits of delivering environmental water against the consequences of adverse impacts for example, stimulating carp and other invasive species through environmental watering (Ye *et al.* 2015); supporting a wide range of outcomes for species and communities rather than single species outcomes; and prioritising competing watering objectives across the Basin with a variable and limited availability of water (Wassens *et al.* 2014). Adaptive management, scientific analysis and modelling, and planning tools will be increasingly important in assisting environmental water planners to navigate such complex decisions into the future.

Conclusion

Commonwealth and state governments have made progress in managing environmental water for ecological benefit since the Basin Plan was enacted in November 2012. Yet achieving the Basin's ecosystem outcomes is much more than simply recovering environmental flows. The challenge is delivering environmental water in a way that will lead to the protection and restoration of freshwater ecosystems in the Murray-Darling Basin. About 9,000GL of environmental flows was delivered under the Basin Plan in the 3 years between July 2012 to June 2015, and most of this water was delivered in line with priorities set by the Authority. There is evidence that freshwater species receiving environmental water have benefitted from these flows, with measurable improvements vegetation, fish and waterbird condition at surveyed sites in the Basin. However there was ongoing decline in health of assets which did not receive environmental flows. It is too early to determine the extent to which these responses will contribute to achievement of ecological objectives in the Basin Plan. This is in part because of the lag effects of these ecosystems, and also because Basin-wide monitoring is in progress and not yet published. Further, many risks could compromise the achievement of ecological objectives in the Basin Plan. Current and future risks include constraints, water variability and scarcity and a range of other physical and institutional factors. Overcoming these challenges will be critical to delivering the Basin Plan's ecological objectives and ensuring the highest return on the multi-billion dollar public investment to restore the health of the Murray-Darling Basin.

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Review of Water Reform in the Murray-Darling Basin
Appendix 3. Socio-economic changes in the Basin

Murray-Darling Basin:
Status and Trends of Key Socio-Economic Indicators and The Economic and Social Effects of Water Reforms

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Abstract
The Murray-Darling Basin (MDB) has been the focus of major water reforms over the past two decades aimed at improving water use efficiency, improving transparency, establishing long-term sustainability, and redressing over-allocation affecting many of the Basin's rivers. These water reforms were expected to have social-economic impacts on the Basin, compounded by the broader changes occurring across the Basin, and indeed Australia, as agriculture adapted to changing market conditions, new technologies and climate conditions. In this paper, we document trends in social-economic indicators in the MDB, as a whole and for selected communities (Deniliquin, Shepparton, Renmark, Griffith and Moree), and identify likely causes for these trends in key indicators. The socio-economic indicators include agricultural production, water use and efficiency, commodity prices, population size and density, labour force and population and employment of indigenous communities. Different towns fared quite differently across the MDB with some communities growing and prospering, while others declined. Drought was a major driver of changes in MDB communities and industries through the 2000s, but water reforms, water prices and other factors also played a role in more recent years. Socio-economic changes are still playing out in the MDB and ongoing assessment at multiple scales will be critical for understanding the nature and drivers of changes experienced by the industries and communities in the MDB.

Key findings

- Agricultural commodity production varied considerably throughout the period examined, with greater fluctuations in production of annual crops including cotton and rice, compared to grapes, a perennial crop which relies on water from higher security entitlements and water trade to sustain permanent plantings.

- The gross value of irrigated and total agricultural production (GVIAP and GVAP; in real terms) has grown in the MDB between 2000-01 and 2010-11 and has been maintained over the five years between 2011-12 and 2015-16, despite being interrupted by several years of decline during the Millennium drought. GVIAP in the MDB reached a record high of $7,135 million in 2013-14 ($5,442 million in 1997-98 price) while GVAP reached a record high of $20,588 million in 2014-15 ($13,634 million in 1997-98 price).

- Drought was probably the major factor driving reductions in GVIAP, but water recovered through buybacks and infrastructure (associated with limits on the quantity of water that can be taken from the Basin's water resources) and consequent pressure on water allocation price also possibly played a role. Drought influenced agricultural production (GVAP) in the MDB to a lesser degree, while effects of water reforms were not significant in our model.

- Total volume used for irrigation declined during the Millennium drought to 3,142GL in 2007-08, but increased to 8,273GL in 2012-13 following a wet period. Pastures and cotton were the highest overall water users, while rice had the highest water application rate (12.6ML/ha on average over the period 2001-2016).

- There was a declining but variable trend in land irrigated, from a high of 1,824,000ha in 2000-01 to 929,000 ha in 2008-09 then rising to 1,560,000ha in 2013-14, then slightly declining to 1,238,000ha in the dry year of 2015-16. Most land irrigated was used for pasture, cereals and cotton. Factors contributing to changes in land irrigated included agricultural commodity producer price index, drought period prior to 2007, water allocation price, and water recovery from buybacks and infrastructure.

- Water use efficiency (measured as the gross value of irrigated agricultural production in the Basin in 1997-98 price per megalitre of water used) increased from $486/ML in 2000-01 to $1,171/ML in 2007-08 during the Millennium drought, but subsequently declined to $704/ML by 2013-14. Significant drivers appear to be water allocation price and water recovery from buybacks and infrastructure.

- Water allocation price appeared to be driven by the volume of water allocation announced and the total water availability. Volumes of water extracted were affected by water allocation, water recovery and water allocation price.

- Increased water recovery was associated with reduced area of land irrigated, GVIAP and GVAP, but was associated with increased water use efficiency. Similar effects occurred with changes in water allocation price.

- Population of the MDB has increased since 1996 to about 2.2 million in 2016, or 9.5% of the population of Australia. However, the rate of population increase in the MDB was lower than the Australian rate. The average age appeared to increase, with an increase in the proportion of population who were 65 years or older in the MDB between 2006 and 2016.

- Indigenous population in the MDB increased from 3.5% of the Basin's population in 2006 to 5.4% in 2016. Between 2006 and 2016, the indigenous population growth rate in the MDB was 41%, nearly four times higher than the overall population growth rate in the MDB (10.1%), and more than double the national rate (18%). Labour force participation of the Indigenous community in 2016 (54%) was less than the MDB average (64%) while the unemployment rate of the Indigenous community (17%) was much higher than the MDB rate (5.6%).

- In 2016, there were almost one million people employed in the MDB, more than half (55%) of the Basin's population aged 15 years and over, similar to the national employment to population ratio (56%). Over the period 1996-2016, the number of employed persons in MDB increased, however, part-time employment increased faster than full-time employment, and the proportion of full time employment decreased from 67.9% to 62.2% over the period.

- In 2016, employment in agriculture in the MDB accounted for 34% of the national employment in agriculture. The decline of 15% in agricultural employment in the MDB between 2006 and 2016 was about twice of the Australia-wide decline in employment in agriculture of 7.4%.

- Between 2005 and 2016, there was a downward trend in the total number of agricultural businesses and the number of irrigating agricultural businesses in the MDB. This is consistent with the national downward trend. We found no evidence of any effect of water reforms on the number of agricultural businesses or irrigating agricultural businesses in the MDB.

- Deniliquin, Moree and Renmark experienced declines in population and economic activity, while Shepparton and Griffith grew strongly. Deniliquin has experienced the greatest decline, with the number of businesses almost halving between 2003 and 2015 with agriculture/forestry/fishing businesses being particularly hard hit with a decline from 498 to 128 over that period. Moree's population declined by 11% between 2000 and 2015 while its agricultural/forestry/fishing labour force dropped by 20% between 1996 and 2011. The Renmark district experienced only a small (6%) decrease in population between 2000 and 2015, although the labour force remained relatively stable.

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1 Introduction

The Murray–Darling Basin (MDB) region covers an area of over 1 million km^2, which is equal to 14% of mainland Australia. This includes 75% of New South Wales, more than 50% of Victoria, large portions of Queensland and South Australia, and all of the Australian Capital Territory. The region is defined by the catchment areas of Australia's two longest rivers: the Darling River (2,740 km) and the Murray River (2,520 km). The region has a population of over 2 million, and irrigated agriculture is a major industry.

The current water reforms in the MDB grew from a Basin-wide approach to water reform that started over 30 years ago, beginning with a development of water market and access to water trading. Water markets, where buyers and sellers can trade the right to receive either an ongoing share of the available water entitlement, or a specified volume of water allocation, are one of the major features of the water reforms.

Trade in water allocations was first allowed in New South Wales and South Australia in 1983 and then later in Victoria in 1987. Trade in water entitlements within an irrigation district was permitted in South Australia in 1983, New South Wales and Queensland in 1989, and Victoria in 1991 (Grafton & Horne 2014). In 1992, the Murray-Darling Basin agreement was established between Basin States to coordinate planning for the equitable, efficient and sustainable use of water, land and other environmental resources. In 1994, the Council of Australian Governments water reform agreement reformed water pricing and facilitated cross-border water trading.

In 1995, a limit on water diversions (called the ‘cap’) was first implemented in the MDB. The Cap was established to limit the total surface water extracted from the Basin’s rivers and streams. In 2004, the National Water Initiative (NWI) was signed by all state governments and sought to establish a nationally consistent water market. Interstate water trade was expanded within the Southern MDB in 2006.

A new stage of institutional and market reforms started in 2007. The Australian Government committed to funding a number of measures to re-balance water between irrigation and environmental needs. In 2007, the Commonwealth government committed $10 billion over ten years under the National Plan for Water Security to facilitate the implementation of the NWI, of which $3.1 billion was committed to water buyback program to purchase water for the environment and $4.4 billion was committed to the investment towards improving the efficiency and productivity of water use and management (Crase et al. 2009; ABARES 2011). The Commonwealth Water Act 2007 established the Murray-Darling Basin Authority with responsibility to develop a Basin Plan that would set enforceable sustainable diversion limits and rules to facilitate water trade. The reforms included critical basin-wide measures to improve competition within the water markets and availability of water information (Connell and Grafton 2011). In 2008, the government committed to a spending of almost $13 billion over ten years in water reforms (Crase et al. 2009; ABARES 2011).

In November 2012, the Murray-Darling Basin Plan was enacted. The central element of the Basin Plan is the introduction of a limit on surface and groundwater diversions. The Basin Plan sets limits on the quantity of water that can be taken from the Basin's water resources. It also includes a requirement for an environmental watering planning as the means to coordinate the delivery of environmental outcomes across the Basin. Water trading rules have also been introduced to further reduce restrictions on trade and improve market transparency and confidence.

As this history shows there have been a number of government-led initiatives – introduction of water trading, a limit on surface water abstractions, buying water entitlements back for environmental use, investments to upgrade irrigation water use efficiencies, and a basin-wide Plan for water resources - to both improve water use efficiency in the MDB and to return water from consumptive uses to the environment to redress over-allocation in some of the Basin's rivers. These water reforms are expected to have social-economic impacts on the basin. In addition, there are wider changes occurring across the Basin, and indeed across Australia, as agriculture adapts to changing market conditions and changes in technology. In this paper we attempt to see if the water reforms have led to significant economic and social changes across the Basin and within selected communities of the Basin.

We base our analysis on publically available data from various sources including data from MDB annual reports, MDBA water audit monitoring reports, agricultural commodity statistics in 2016 from ABARES, Murray Irrigation data, Department of Employment data, and ABS data (surveys on Agricultural Commodities, Gross Value of Irrigated Agricultural Production, Water Use on Australian Farms, Australian Census of Population and Housing 1996, 2001, 2006, 2011 and 2016, National Regional Profile). Depending on the series, the data extracted for the MDB for our analysis are only available between 11 and 16 years over the period 2001-2016. Before 2001, the data for these surveys published by the ABS do not provide information at geographical areas that enable us to extract the data for the MDB.

In Section 2, we report the status and trends of key socio-economic indicators in the MDB. Section 3 analyses the effects of water reforms on key social-economic indicators in the basin. Section 4 presents discussion of the modelling results and Section 5 summarizes key findings.

2 Status and trends of key socio-economic indicators in the MDB

This section reviews the status and trends of key socio-economic indicators in the MDB. The followings are key findings.

- The production of annual, water-dependent crops such as rice, cotton, cereals fell sharply during the drought period 2006-2009 and recovered in 2011 after the dry period. Between 2013 and 2015, the production of these crops experienced downward trends which are associated with a downward trend in natural water availability due to low rainfall levels over those years. Grape production remained stable over the period 2001-2015.
- Gross value of irrigating agricultural production as well as total value of agricultural production in the MDB was severely affected by the drought in 2006-07 and in 2008-10.
- Despite the reduction in severe drought years, the gross value of total agricultural production as well as gross value of irrigated agricultural production in the MDB has risen over the period 2001-2011, and has been maintained over the last five years between 2011-12 and 2015-16, after adjusting for inflation.
- Between 2005 and 2016, there was a downward trend in the total number of agricultural businesses and the number of irrigating agricultural businesses in the MDB. However, there was also a downward trend in these businesses at national level.
- The average water use efficiency in the MDB (measured as the gross value of irrigated agricultural production in 1997-98 price per megalitre of water used overall) increased

during the drought period 2006-2009, and then remained at higher level than before the drought.

- In the MDB, water availability, water allocation announcements and water diversions for consumptive use tended to move together.
- The water allocation price experienced a sharp increase during the period 2006-2009 when water availability dropped to a critically low level due to drought. This price then dropped significantly between 2011 and 2013 when water availability was again at high levels. Between 2013 and 2016, water allocation price experienced an increasing trend, corresponding to a downward trend in water availability over those years.
- Over the period 1996-2016, the MDB population increased by 16%, which is only half of the rate of the increase in national population (32%).
- Population declined in the outer regional and remote locations and increased in inner regional areas and major cities of the MDB between 2001 and 2011.
- The number of employed persons in MDB continued to increase over the period 1996-2016, and the unemployment rate in the MDB was lower than the national unemployment rate.
- Between 2006 and 2016, while the number employed in the MDB increased, the number employed in agriculture decreased by 15.5% in the MDB, and by 7.4% Australian wide.
- The proportion of the MDB community that is indigenous increased over time. The unemployment rate of the Indigenous community was much higher than the average basin unemployment rate. In 2016, it was 17% compared to 5.6% for whole Basin workforce.
- The average incomes from wage and salary in Deniliquin, Griffith, Moree, Shepparton, and Renmark were significantly less than the national average.
- Over the period 2002-2016, the unemployment rate in Deniliquin and Griffith was less than the national level; while the unemployment rates in Moree Plains, Greater Shepparton and Renmark were higher than the national average.

Details of the status and trends of the key socio-economic indicators in the MDB are presented below.

2.1 Agricultural production

The MDB is colloquially known as the nation's ‘food bowl’ because of the volume of agricultural products grown there, collectively generating a gross value of $19.4 billion, or 35% of Australia's total value of agricultural production in 2015-16. Although representing just 14% of Australia's total land area, in 2015-16 the Basin contains 23% of Australia's agricultural land.

A variety of crops and pasture are grown in the MDB for food and fibre for domestic consumption and export. These include: cereals (e.g. wheat, barley, rice, sorghum); cotton; fruit and nuts (e.g. apples, oranges, almonds); grapes; vegetables (e.g. tomatoes, onions); livestock fodder (e.g. pasture for grazing or hay/silage).

Irrigated agriculture is more common in the MDB than elsewhere in Australia. Irrigated agricultural land is a relatively small proportion of total agricultural land throughout Australia (less than 6%). However, in the MDB, 1.5% of agricultural land is irrigated. In 2015-16, the MDB’s irrigation volume accounted for 59% of Australia's irrigation volume (ABS, Water Use on Australian Farms).

The change in agricultural production over time can be influenced by many factors. Climate, specifically rainfall and drought, significantly impacts water availability and farmers' ability to grow crops. Government policies can affect irrigated agricultural production and encourage or discourage the production of particular agricultural commodities (NWC 2008). Changes in commodity prices and input prices influence agricultural production by affecting their revenue and expenditure on farming inputs (such as water, fertiliser, fuels and labour). New technologies can improve productivity and reduce the quantity of inputs (e.g. water, fertiliser) required. These factors affect overall agricultural production in the MDB, and can instigate structural change in the industry, leading farmers to increase production of some commodities and reduce the production of others.

This section reports changes in agricultural activity between 2000–01 and 2015–16 in the MDB, including changes in agricultural commodity production, value of agricultural and irrigated agricultural production, water use on Australian farms, irrigated agricultural area, irrigation application rate, water use efficiency and agricultural commodity prices.

2.1.1 Agricultural commodity production

Cereals: cereals for grain and seeds account for 24% of the gross value of agricultural production in the MDB, most of it is dryland cropping. Nearly half (47%) of all Australian agricultural land dedicated to producing cereals for grain in 2014-15 was located in the MDB, accounting for 45% of all cereals for grain production in Australia (Table 1).

Figure 1 shows the cereals for grains and seed production (excluding rice) in the period 2001-2015 for Australia and the MDB. Cereals production dropped in the years 2006-07 and 2007-08. This reduction could be explained by the impacts of the Millennium Drought (Qureshi et al. 2013). After 2008, cereals production increased and reached a peak in 2010-11. Between 2012 and 2015, there was a downward trend in cereal production in the MDB which is associated with a downward trend in water availability over this period.

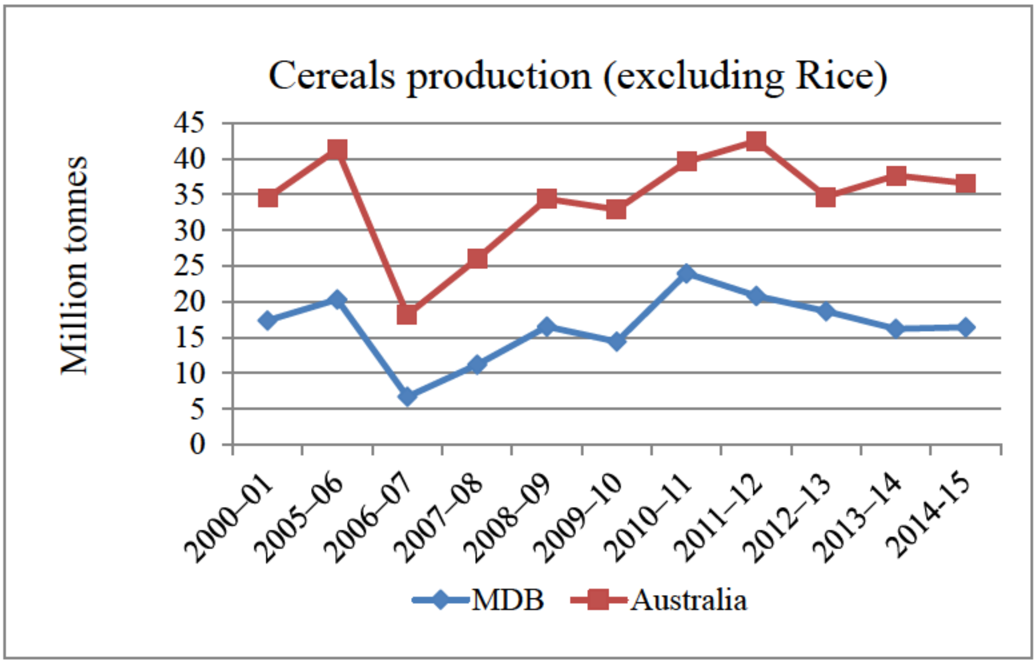
Table 1: Agricultural commodity production in MDB

Year	**MDB (Million tonnes)**				**MDB as proportion of Australia (%)**			
	Cereals (excl. rice)	Rice	Cotton	Grapes	Cereals (excl. rice)	Rice	Cotton	Grapes
2000–01	17.36	1.64	0.60	1.12	50.3	99.7	90.7	72.1
2005–06	20.31	1.00	0.52	1.51	49.2	99.9	92.2	76.1
2006–07	6.69	0.16	0.25	1.00	36.8	99.9	88.3	65.3
2007–08	11.19	0.02	0.11	1.45	43.0	100.0	93.4	73.9
2008–09	16.52	0.06	0.27	1.26	48.0	100.0	90.6	70.1
2009–10	14.41	0.19	0.33	1.22	43.8	99.0	93.6	72.2
2010–11	23.96	0.71	0.67	1.29	60.5	98.6	96.1	75.3
2011–12	20.80	0.92	0.77	1.30	49.0	99.9	94.5	78.5
2012–13	18.64	1.16	0.81	1.40	53.7	100.0	96.5	79.7
2013–14	16.17	0.82	0.81	1.25	42.9	99.8	94.8	80.0
2014-15	16.42	0.69	0.37	1.42	44.9	99.9	92.4	82.4

Source: ABS, Agricultural Commodities, cat. No. 7121.0

Note: Grape production figures are not available for the years 2006-07 and 2008-09: the figures here are calculated as GVIAP/price (source: Kirby et. al. 2012)

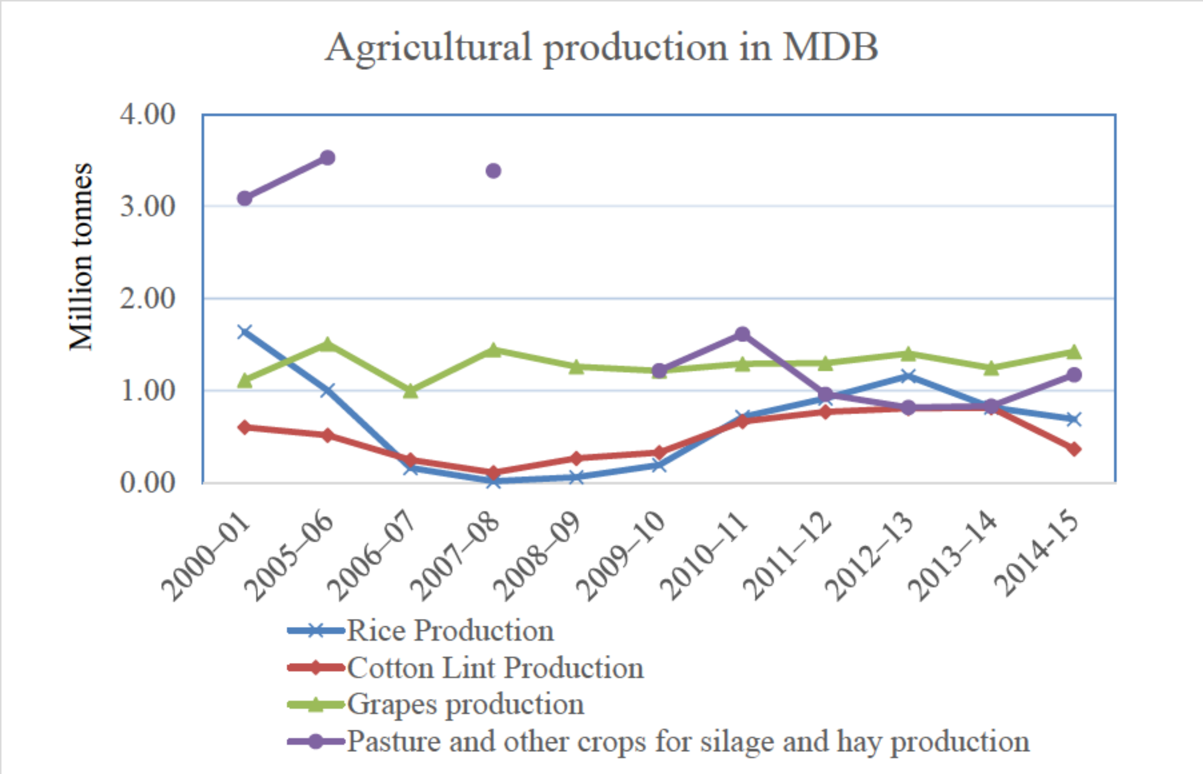
Figure 1: Cereals for grains and seeds production, 2001-2015



Source: ABS, Agricultural Commodities, cat. No. 7121.0

Other selected commodities: Figure 2 shows the production of heavily-water dependent crops including rice, cotton lint, grapes, and pasture and other crops for hay and silage in the MDB for the period 2001-2015. The Figure shows that rice and cotton lint production fell sharply in the Millennium Drought period 2007-2009. Production levels for those commodities recovered in 2009-2010 and showed an increasing trend in the period 2010-2013. However, corresponding to the reduction in water availability between 2013 and 2015, rice production again decreased between 2013 and 2015 and cotton production decreased in 2014-15. Pasture and other crops for hay and silage production fell sharply between 2006 and 2010 and remained at low levels between 2010-2015. Grape production, in terms of volume, remained stable in the period with the level of production being between 1 and 1.5 million tonnes during the period 2001-2015. The stability of grape production might be due to grape being a perennial crop. Because of their relatively fixed water demand, grape farmers tend to hold high-security entitlements. They also bought additional water during droughts. These purchases helped maintain grape production (National Water Commission 2011).

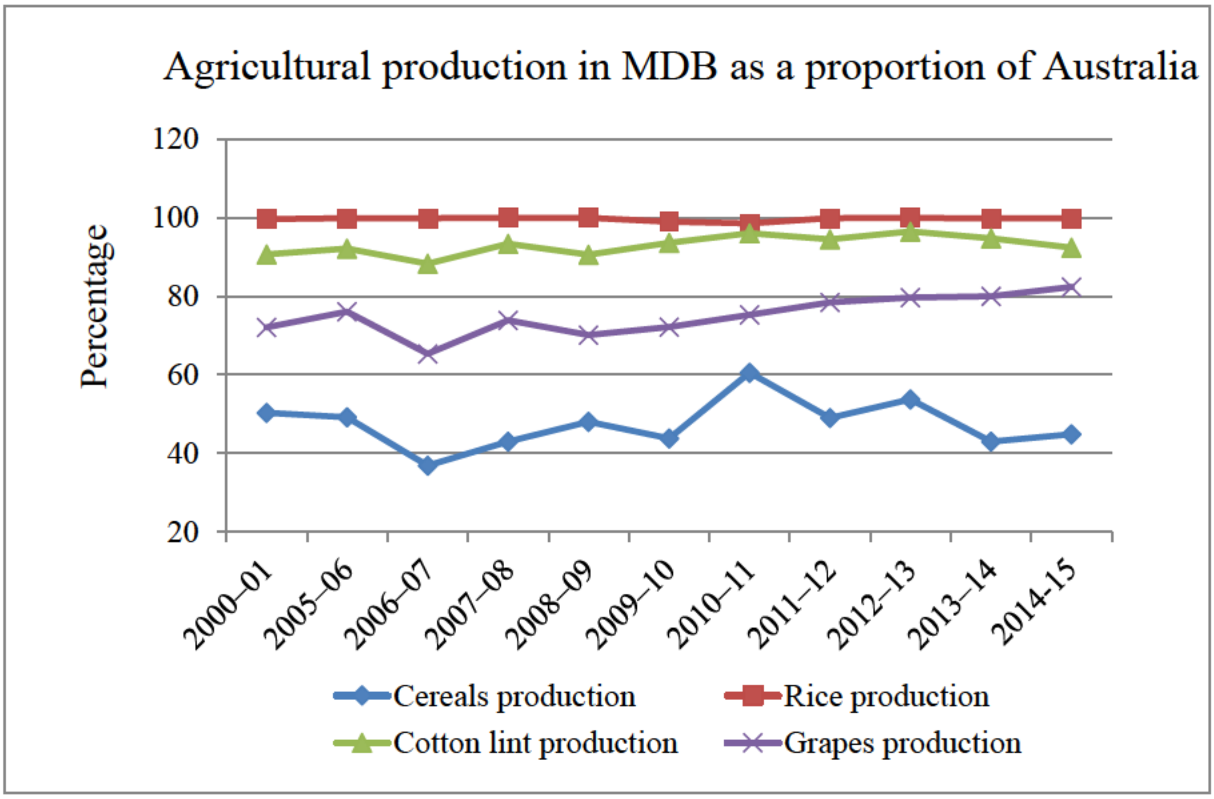
Figure 2: Rice, cotton lint, grapes, and hay and silage production in MDB, 2001-2015



Source: ABS, Agricultural Commodities, cat. No. 7121.0

Figure 3 represents the share of cereals, rice, cotton lint and grapes production in the MDB as the percentage of Australian production. It shows that, over the period 2001-2015, rice production in MDB accounted for almost all of the Australian rice production. The share of cotton lint production remained stable and accounted for more than 90% of Australian cotton lint production. The share of grapes production in the MDB as a proportion of Australia was more than 70% and showed an increasing trend during the period 2007-2015. The share of cereals production is between 40-60% and there is a downward trend in the share of cereals production in MDB between 2011 and 2015.

Figure 3: Agricultural production in MDB as a proportion of Australia, 2001-15



Source: ABS, Agricultural Commodities, cat. No. 7121.0

2.1.2 Gross value of total and irrigated agricultural production

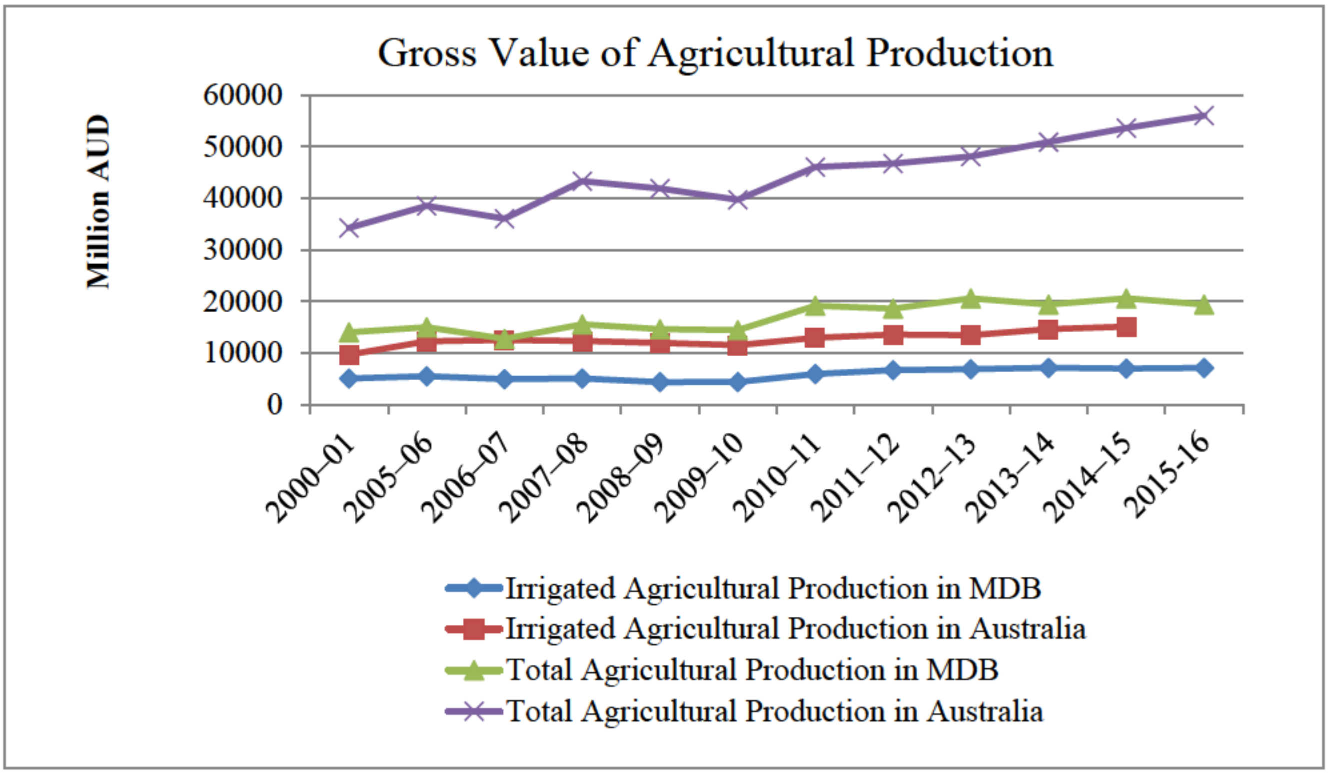
Table 2 shows the gross value of total and irrigated agricultural production in the MDB and Australia for the period 2001-2016. In 2015-16, the gross value of all agricultural production in the MDB was $19.4 billion and represented 36% of Australia's total value of agricultural production. Out of this $19.4 billion, the gross value of irrigated agricultural production (GVIAP) in the MDB was $7.1 billion, representing 37% of the gross value of agricultural production (GVAP) in the MDB. Figure 4 shows a variable, but growing trend in the values of total and irrigated agricultural production in the MDB, as well as in Australia.

Table 2: Gross value of total and irrigated agricultural production in Australia and MDB, 2001-16

Year	Irrigated agricultural production				Total agricultural production		
	Irrigated agricultural production in MDB (million AUD)	Irrigated agricultural production in Australia (million AUD)	MDB as proportion of Australia (%)	Irrigated agricultural production as proportion of total agricultural production in MDB (%)	Total agricultural production in MDB (million AUD)	Total agricultural production in Australia (million AUD)	MDB as proportion of Australia (%)
2000–01	5085	9669	52.6	36.3	14001	34237	40.9
2005–06	5522	12257	45.1	36.8	14991	38527	38.9
2006–07	4922	12488	39.4	38.6	12739	36060	35.3
2007–08	5079	12311	41.3	32.6	15576	43270	36.0
2008–09	4349	11953	36.4	29.7	14637	41849	35.0
2009–10	4386	11485	38.2	30.4	14423	39707	36.3
2010–11	5944	12946	45.9	31.0	19163	46020	41.6
2011–12	6691	13546	49.4	35.9	18620	46687	39.9
2012–13	6837	13431	50.9	33.2	20568	48048	42.8
2013–14	7135	14599	48.9	36.8	19402	50866	38.1
2014–15	6962	15108	46.1	33.8	20588	53625	38.4
2015-16	7100			36.6	19400	55994	35.6

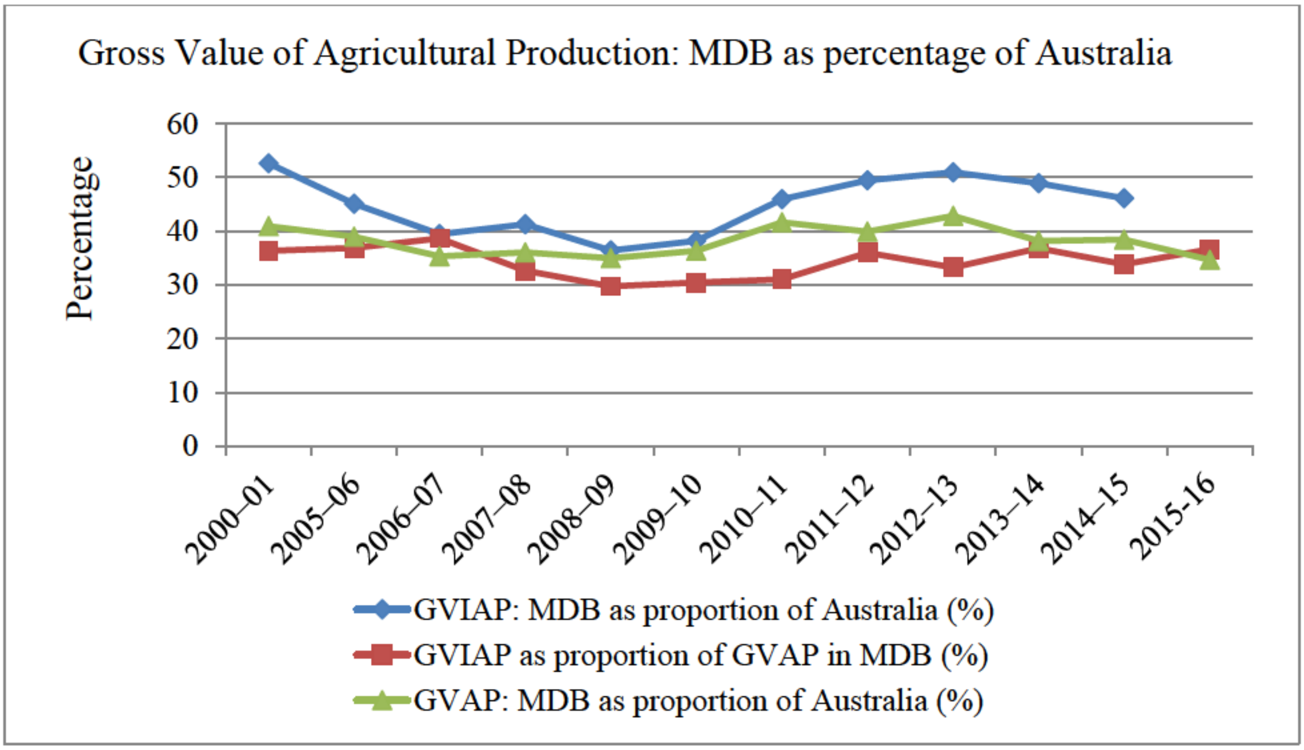
Source: ABS, Gross Value of Irrigated Agricultural Production, cat. No. 4610.0.55.008; MDBA Annual Report 2015-16

Figure 4: Gross value of agricultural production in MDB and Australia (nominal value)



Source: ABS, Gross Value of Irrigated Agricultural Production, cat. No. 4610.0.55.008

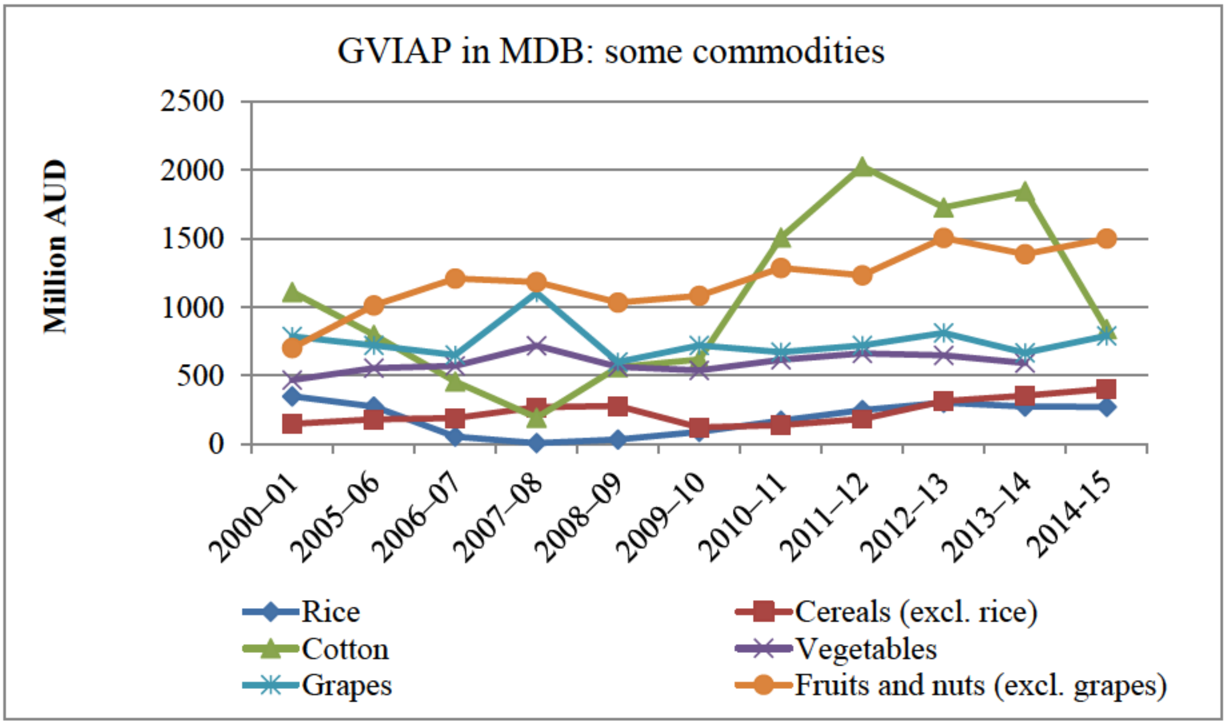
Figure 5: Gross value of agricultural production: MDB as percentage of Australia



Source: ABS, Gross Value of Irrigated Agricultural Production, cat. No. 4610.0.55.008

Figure 5 includes trends in the share of the gross values of total and irrigated agricultural production in MDB as a percentage of the gross values of those in Australia and the share of the gross value of irrigated agricultural production in the MDB as proportion of the gross value of agricultural production in the MDB. It shows that the share of the gross value of irrigated agricultural production to the value of total agricultural production in the MDB declined in the period 2007-2011. This could be partly the result of the Millennium Drought where typically, irrigated crops demand more water than non-irrigated crops, therefore, droughts where there are large reductions in the water available for extraction can have large negative impacts on seasonal irrigated agricultural production. This share of the GVIAP to GVAP in the MDB recovered during the period 2011-14. The share of the GVIAP in the MDB as a percentage of GVIAP in Australia also decreased during the period 2006-2010 and recovered after 2010. The proportion of the GVAP in MDB to GVAP in Australia exhibited no noticeable trend between 2001 and 2016.

Figure 6: GVIAP in MDB: some commodities



Source: ABS, Gross Value of Irrigated Agricultural Production, cat. No. 4610.0.55.008

Figure 6 represents the nominal GVIAP for rice, cereals (excluding rice), cotton, vegetables, grapes, and fruits and nuts (excluding grapes) in the MDB. It shows that GVIAP for rice and cotton both of which depend on irrigation fell sharply during the years 2006-10 and recovered (rice) or increased (cotton) between 2011 and 2015. GVIAP for cereals, vegetables and grapes fluctuated slightly while GVIAP for fruits shows a slightly increasing trend over the period. The fluctuations of the GVIAP for these crops caused by both the changes in production and prices over the period.

2.1.3 Water use on Australian farms

Table 3 and 4 show the water use and water application rate for main crops in the MDB as well as the total irrigation water volume applied and the application rate in the MDB and Australia over the period 2001-2016. The volume of water applied in both the MDB and Australia fell in the period 2006-2011 and recovered back to pre-drought levels during the years 2012-2016 (Figure 7). In 2015-16, the volume of water applied for irrigation in the MDB accounted for 59% of the total water applied for irrigation in Australia. As shown in Table 4, the water application rate is highest for rice production; the next crops that depend heavily on irrigation are cotton and fruits and nuts, while the water application rate is relatively low for other cereals. Generally, over the period 2001-2016, the average water application rate in MDB was higher than the average in Australia. However, average water application rate in MDB was lower than the national average level in 2014-15 (Figure 8). This might be the result of a low water allocation in 2014-15 combined with the government buy-back program in the MDB. With the exception of pasture, there is no discernible reduction in the water application rate over the period. After the drought period, water application rates for cotton and fruits and nuts increased between 2011 and 2016.

Table 3: Irrigation volume for main crops in the MDB

	Irrigation volume (GL)									
Year	Pastures	Rice	Cereals (excl. rice)	Cotton	Grapes	Fruits and nuts (excl. grapes)	Vegetables	MDB	Australia	MDB as % of Australia
2000–01	3227	2418	751	2599	469	372	166	10002		
2001–02	2971	1978	1015	2581	479	389	152	9565		
2002–03	2343	615	1230	1428	492	424	143	6675	10404	0.64
2003–04	2549	814	876	1186	489	382	194	6491	10442	0.62
2004–05	2371	619	844	1743	510	399	152	6640	10085	0.66
2005–06	2571	1252	782	1574	515	413	152	7260	10737	0.68
2006–07	1559	239	690	819	534	417	125	4458	7636	0.58
2007–08	997	27	805	283	434	356	124	3142	6285	0.50
2008–09	842	101	707	793	439	374	121	3492	6501	0.54
2009–10	998	247	469	764	428	450	129	3564	6596	0.54
2010–11	766	755	234	1789	303	379	115	4507	6645	0.68
2011–12	1271	1134	511	1906	365	475	120	5875	8174	0.72
2012–13	2042	1434	701	2735	463	566	114	8273	11060	0.75
2013–14	1941	912	808	2676	415	713	134	7736	10731	0.72
2014-15	2025	876	692	1114	431	502	108	5869	8950	0.66
2015-16	1438	299	535	1294	428	664	149	4938	8381	0.59

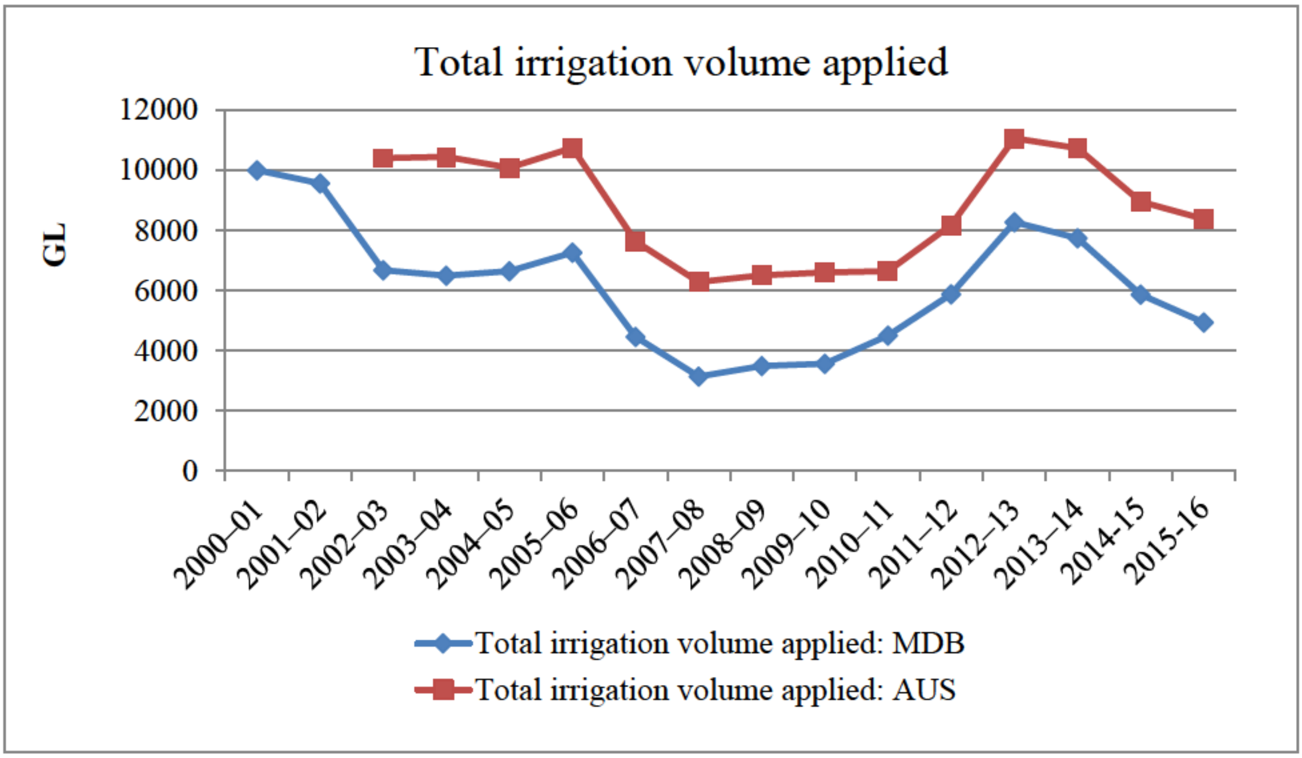
Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

Table 4: Water application rate for main crops in the MDB

Year	Water application rate (ML/ha)								
	Pasture for dairy and other livestock farming	Rice	Cereals (excl. rice)	Cotton	Grapes	Fruits & nuts (excl. grapes)	Vegetables	MDB	Australia
2000–01	4.2	13.6	2.9	6.4	5.6	6.3	4.5	5.5	
2001–02	4.1	13.6	2.9	6.6	5.6	6.3	4.4	5.3	
2002–03	4.2	14.1	3.0	6.5	5.5	5.7	4.6	4.6	4.4
2003–04	3.8	12.4	2.6	6.8	5.6	6.5	4.9	4.5	4.3
2004–05	3.3	12.1	2.6	6.8	5.5	6.3	4.3	4.3	4.2
2005–06	3.5	12.3	2.4	6.4	4.9	5.5	4.7	4.5	4.2
2006–07	3.5	12.2	2.6	6.5	4.8	5.3	4.8	4.1	4.0
2007–08	2.7	12.9	2.8	5.3	4.1	5.0	4.4	3.3	3.4
2008–09	2.8	14.1	2.8	6.2	4.3	5.4	4.8	3.8	3.7
2009–10	2.5	13.0	2.5	5.6	4.5	5.7	5.1	3.7	3.6
2010–11	2.1	10.1	1.7	5.4	3.2	4.7	3.9	3.8	3.4
2011–12	2.6	11.0	2.4	5.2	4.1	6.1	4.2	4.2	3.8
2012–13	3.4	12.6	2.7	7.9	5.3	7.4	4.8	5.2	4.7
2013–14	3.1	12.0	3.0	8.0	5.0	9.0	5.0	5.0	5.0
2014-15	3.0	13.0	2.0	8.0	5.0	8.0	5.0	4.0	4.2
2015-16	2.9	12.3	2.0	6.9	5.4	8.4	4.6	4.0	3.9

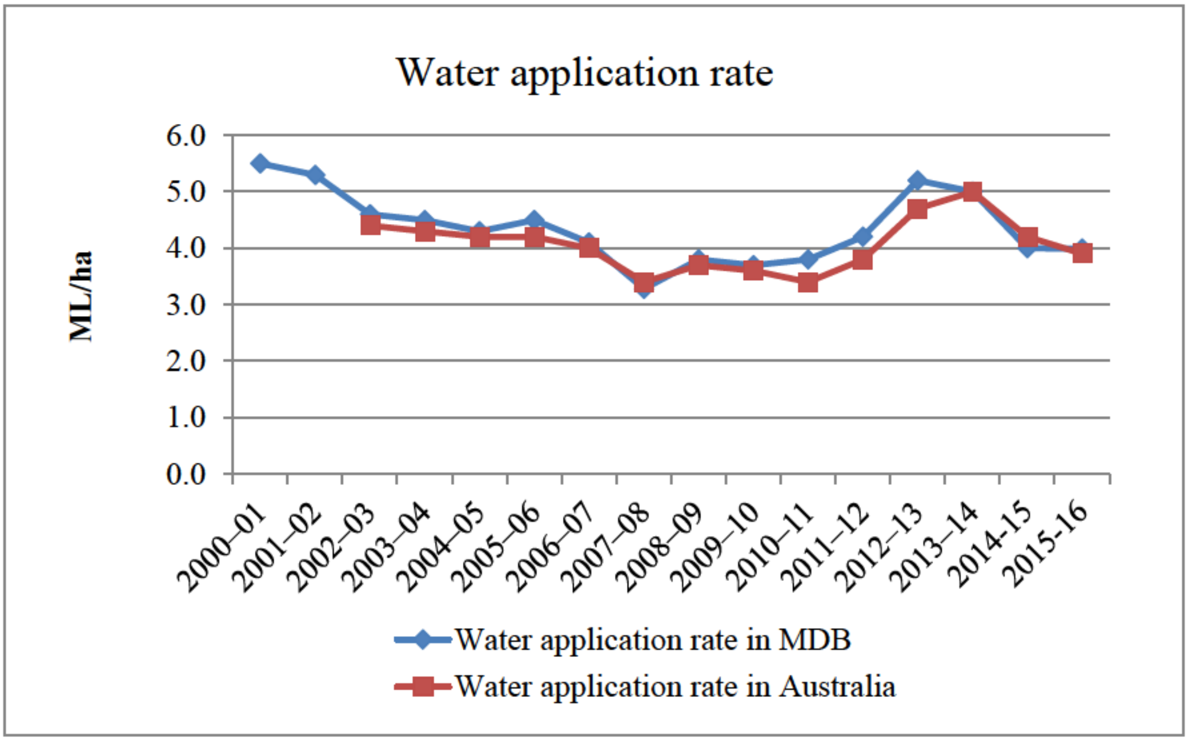
Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

Figure 7: Total irrigation volume applied in MDB and Australia



Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

Figure 8: Water application rate in MDB and Australia



Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

2.1.4 Area irrigated

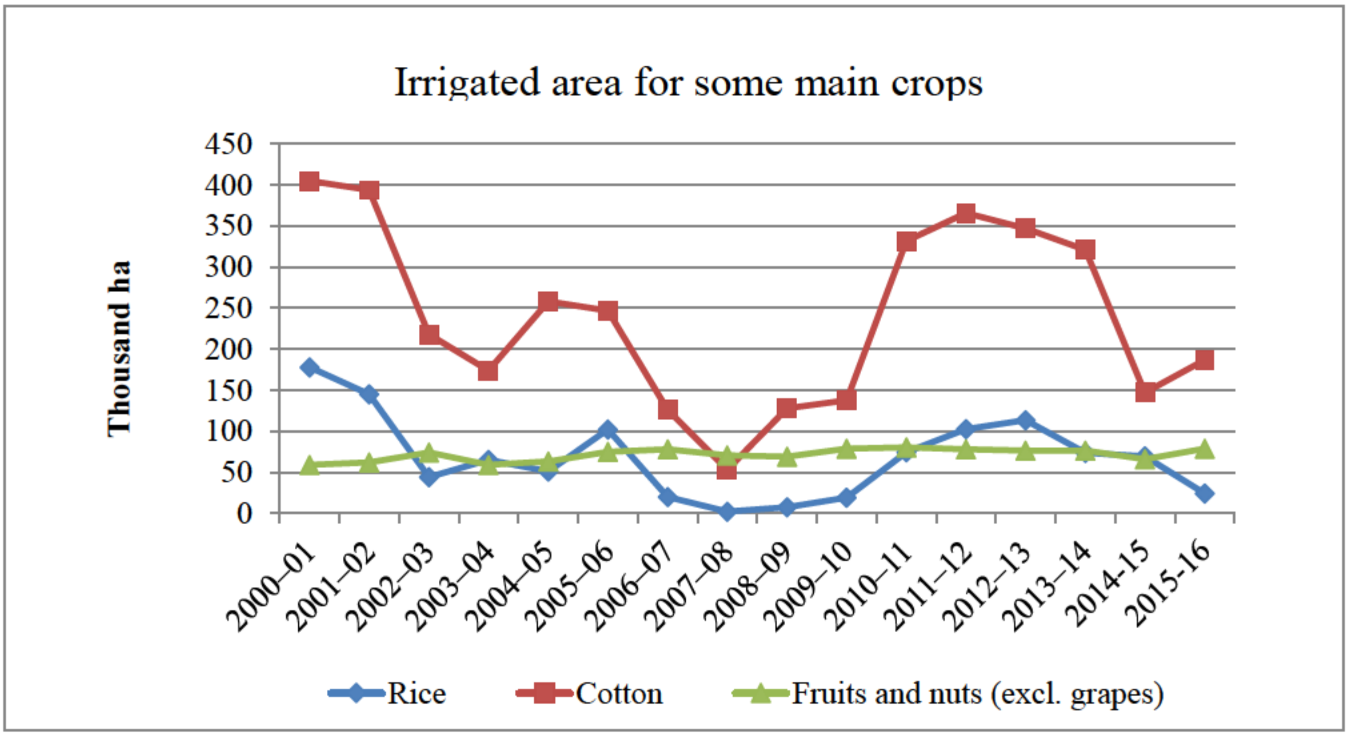
Table 5 and Figure 9 represent the irrigated area for some main crops in the MDB. The irrigated areas for rice and cotton, which are crops that have a high water application rate, fell substantially during the period 2006-2010, but after the Millennium Drought recovered between 2011 and 2015. However, irrigated area for rice in 2014-15 remained significantly below its level in 2001 before the drought, and dropped significantly in 2015-16 compared to its level in 2014-15. Irrigated area for cotton decreased sharply from 321,000 ha in 2013-14 to 147,000 ha in 2014-15 and 187,000 ha in 2015-16 as a result of the persisting drought between 2014-2016. Irrigated areas for cereals (excluding rice) decreased significantly during the period 2007-2011, but had recovered by 2012-13. Irrigated areas for fruits and nuts, grapes and vegetables fluctuated much less than other crops over the period 2001-2016.

Table 5: Irrigated Area in the MDB

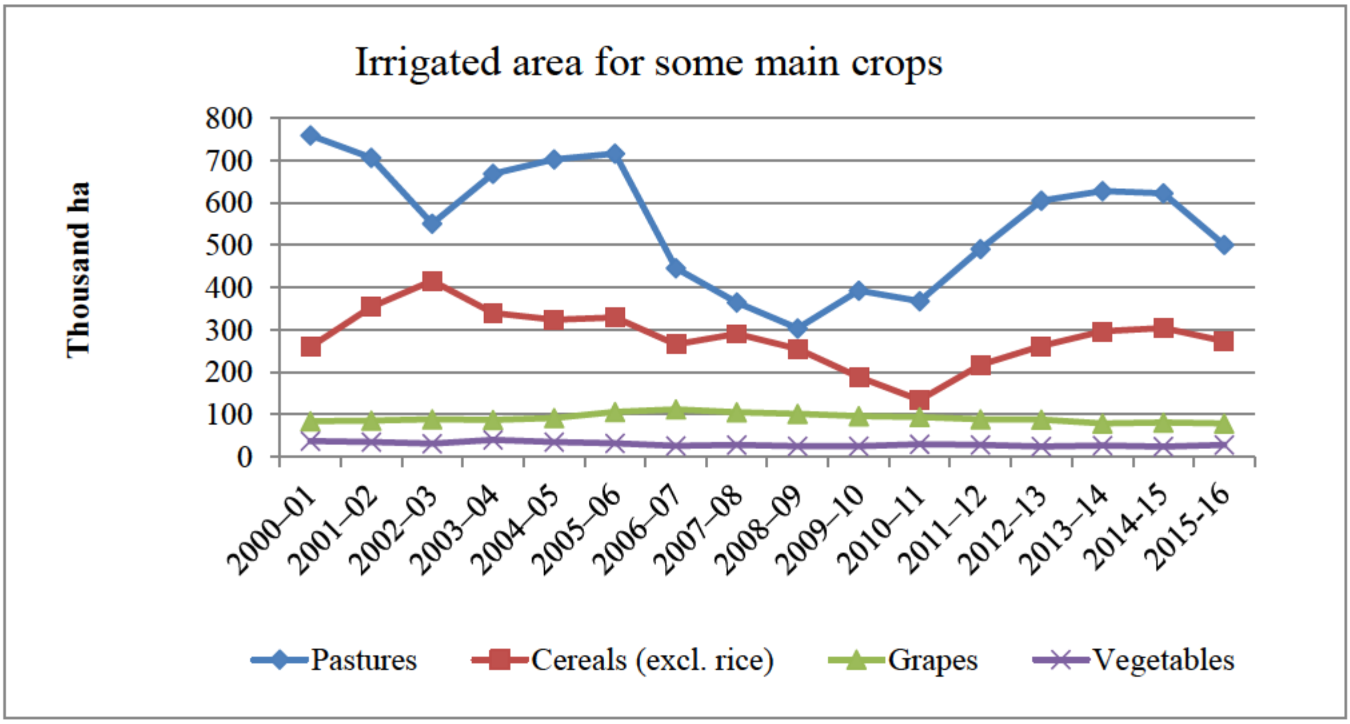
Year	Irrigated Area (thousand ha)							
	Pasture for dairy & other livestocks	Rice	Cereals (excl. rice)	Cotton	Grapes	Fruits & nuts (excl. grapes)	Vegetables	Total agriculture
2000–01	760	178	260	405	84	59	37	1824
2001–02	707	145	354	394	86	62	35	1817
2002–03	551	44	416	218	89	74	31	1466
2003–04	669	65	340	174	87	59	40	1501
2004–05	703	51	324	258	92	63	35	1588
2005–06	717	102	329	247	106	75	32	1654
2006–07	446	20	266	126	112	78	26	1101
2007–08	365	2	291	53	106	71	28	958
2008–09	304	7	255	128	102	69	25	929
2009–10	393	19	189	138	96	79	25	976
2010–11	368	74	134	332	94	80	29	1189
2011–12	491	103	217	366	89	78	28	1412
2012–13	605	113	262	347	88	77	24	1592
2013–14	628	74	296	321	79	76	26	1560
2014-15	623	70	304	147	81	66	24	1367
2015-16	501	24	273	187	79	79	28	1238

Source: ABS, Water Use on Australian Farms, cat. No. 4618.

Figure 9: Irrigated area for some main crops in MDB



(a) *Source: ABS, Water Use on Australian Farms, cat. No. 4618.0*



(b) *Source: ABS, Water Use on Australian Farms, cat. No. 4618.0*

2.1.4 Water use efficiency

As the data for production costs, and therefore data for net returns, of agricultural crops in the MDB are not available over the period, we calculated water use efficiency of agricultural crops using the gross value of agricultural crops. Table 6 and Figure 10 show the water use efficiency (WUE) defined as a ratio of value of production in fixed price of the year 1997-98 (A$; adjusted for inflation) per ML of water used for main crops in the MDB. The water use efficiencies for rice, and cereals have fluctuated, but generally exhibit a growing trend. WUE is lowest in rice production equal to about $228 per ML in 2013-14. The crops with relatively low value of WUE compared to others are cereals and cotton, with the levels $293 and $663 per ML, respectively, in 2013-14. Vegetable has the highest value of WUE, achieving a level of $2,546 per ML in 2013-14. Fruits and nuts are the second highest water efficient crops, achieving a level of $1,224 per ML in 2013-14.

Figure 11 shows that the average water use efficiency in the MDB increased during the period 2000-2008 but showed a decreasing trend between 2008 and 2014, then increased between 2014 and 2016. The value of WUE reached a peak level of $1,171 per ML in 2007-08. The increase in WUE during the drought could arise from one or more of a number of factors: a more efficient use of water in response to water scarcity, a shift from higher irrigation requirement crops to lower irrigation requirement, and water trade that allowed the highest value horticulture to stay in production while crops with lower marginal value and higher demand for water were fallowed crops, as such, water was only being used on crops generating high returns in low water availability years (Kirby et al. 2012). By 2013-14, the average water use efficiency in the MDB had fallen to $704 per ML, although this level of efficiency is still higher than that prior to the drought. WUE increased to $1,117 per ML in 2015-16.

Table 6: Water use efficiency in MDB

Year	Value of WUE (A$/ML) (fixed price year 1997-98)					
	Rice	Cereals (excl. rice)	Cotton	Fruits & nuts (excl. grapes)	Vegetables	MDB
2000–01	174	182	403	1848	2621	486
2005–06	206	237	663	1770	2726	732
2006–07	175	215	676	1573	3233	865
2007–08	170	187	781	2237	3768	1171
2008–09	154	287	732	1861	3037	1039
2009–10	203	239	820	1638	2770	1135
2010–11	243	472	812	1863	3188	1082
2011–12	208	312	959	1429	3425	967
2012–13	208	303	643	1696	3277	637
2013–14	228	293	663	1224	2546	704
2014-15	202	390	721	1751		901
2015-16						1117

Source: ABS, calculated by the author using the GVIAP and producer price index (reference year 1997-98=100)

Figure 10: Water use efficiency in MDB

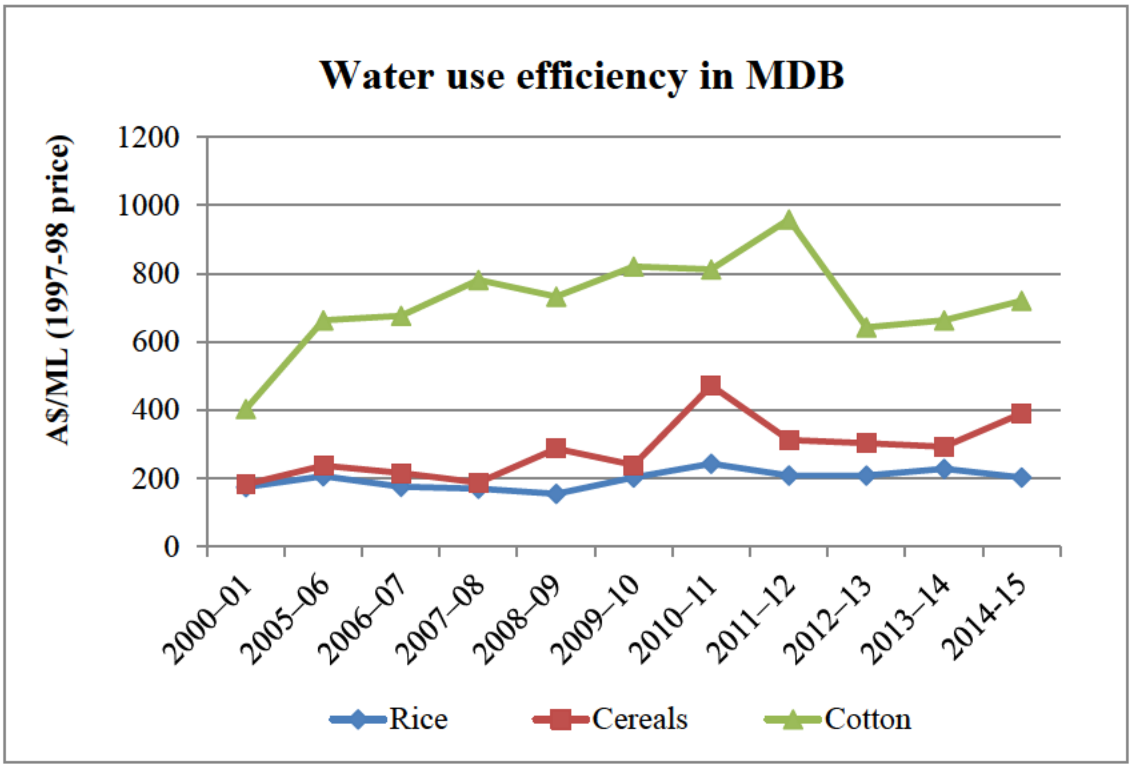
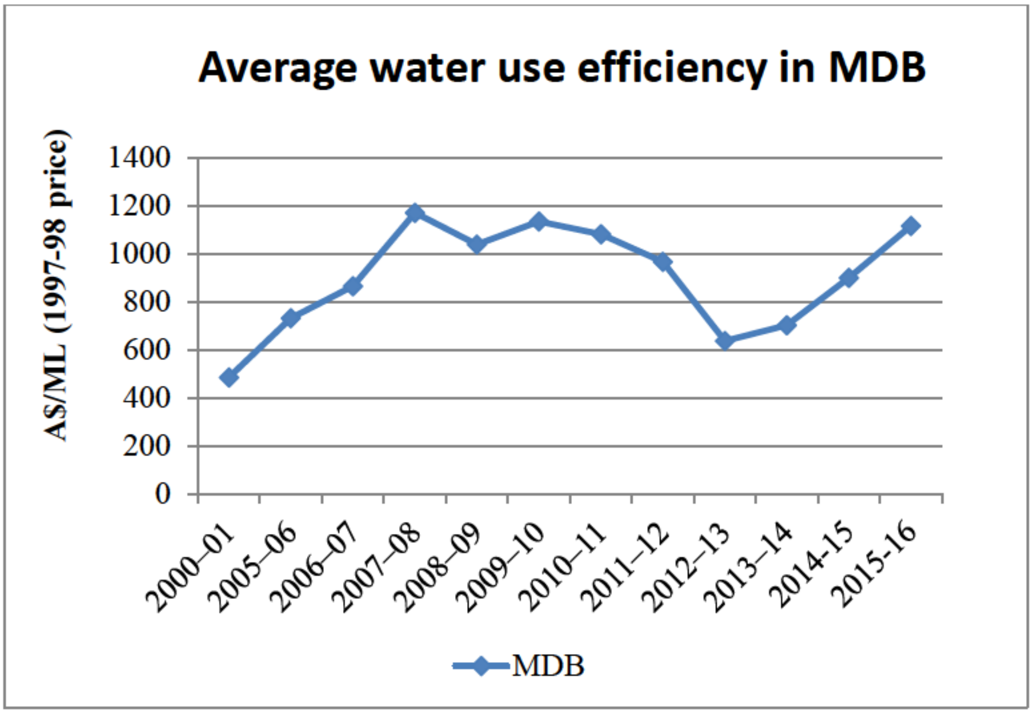


Figure 11: Average water use efficiency in MDB



Source: ABS, calculated by the author

2.1.5 Agricultural commodity prices

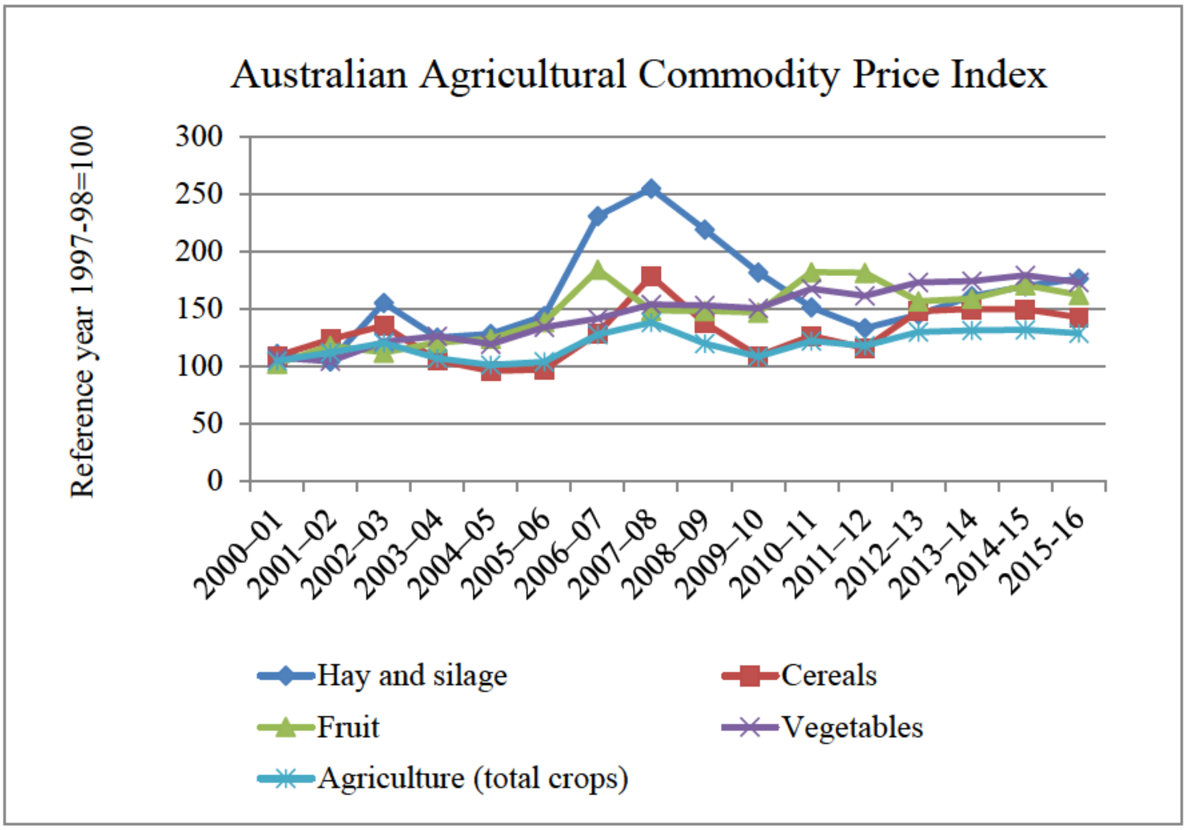
Table 7 and Figures 12 and 13 represent the Australian agricultural commodity price indexes and nominal prices received by farmers for some commodities and the average for Australian crops. Figure 12 shows that there has been an upward trend in the nominal prices of cotton, fruit, cereals, vegetables and the overall average price of Australian crops. Cereals, fruit and average price of Australian crops experienced a significant price spike in 2007-08. This is consistent with the price spike that year in global prices of cereals. Fruit experienced another price spike in 2011. After the price spike in 2007-08, the Australian agricultural commodity prices returned to the 2005-06 level in 2009-10 and showed an increasing trend between 2011 and 2016. Figure 13 shows a big price spike for rice between 2007 and 2010; for grapes in 2007-08; and for cotton in 2010-11.

Table 7: Australian agriculture commodity prices

Year	Australian agriculture commodity price index (97-98=100)					Commodity price		
	Hay and silage	Cereals	Fruits and nuts	Vegetables	Agriculture (total crops)	Rice price ($/tonne)	Raw cotton price (cents/kg)	Grapes price in warm climate ($/tonne)
2000–01	110.7	108.7	102.0	107.5	104.7	213.2	251.5	
2001–02	104.2	123.4	117.8	104.3	111.9	274.2	193.8	
2002–03	155.0	135.2	111.9	121.5	120.2	348.2	225.5	560.3
2003–04	125.0	105.2	120.6	126.0	107.0	325.1	225.9	536.2
2004–05	128.0	95.8	123.9	119.1	101.1	296.8	167.3	473.6
2005–06	143.7	97.2	138.3	133.8	103.9	272.9	177.8	379.3
2006–07	230.7	128.5	184.0	141.3	127.6	337.4	176.9	389.0
2007–08	254.6	178.3	148.4	153.7	138.0	415.0	190.8	546.0
2008–09	219.0	137.5	148.2	152.9	119.8	566.0	193.3	369.0
2009–10	181.5	108.9	146.6	150.3	108.4	457.1	205.1	298.0
2010–11	151.1	126.3	181.8	167.3	121.9	240.0	377.4	285.0
2011–12	133.0	115.7	181.4	161.3	117.8	270.0	225.1	339.0
2012–13	144.9	147.9	156.5	172.8	129.7	260.0	199.5	351.0
2013–14	160.9	149.8	158.8	174.1	131.1	340.0	228.6	300.0
2014-15	169.6	149.6	170.4	179.1	131.7	395.0	199.5	289.0
2015-16	176.4	142.6	162.0	172.9	128.7		226.1	

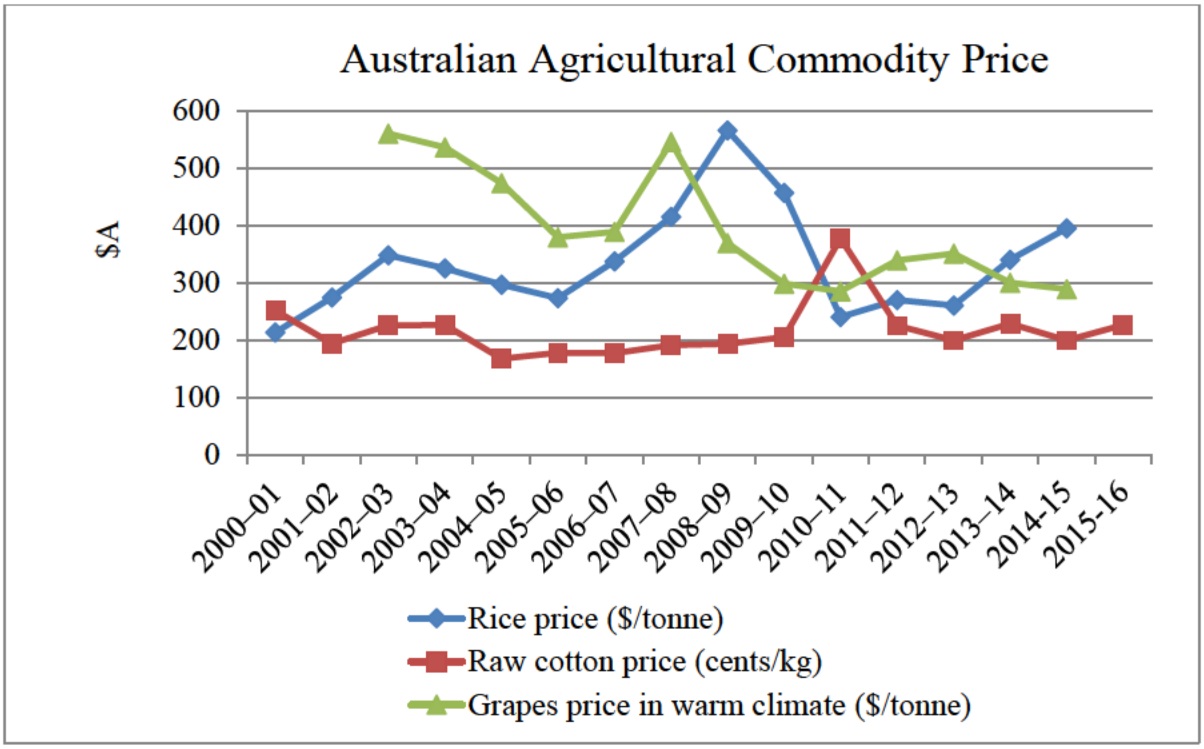
Source: ABARES, 2015, 2016

Figure 12: Australian agricultural commodity price index



Source: ABARES, 2016

Figure 13: Australian Agricultural Commodity Price



Source: ABARES, 2016

2.2 Water availability and extraction

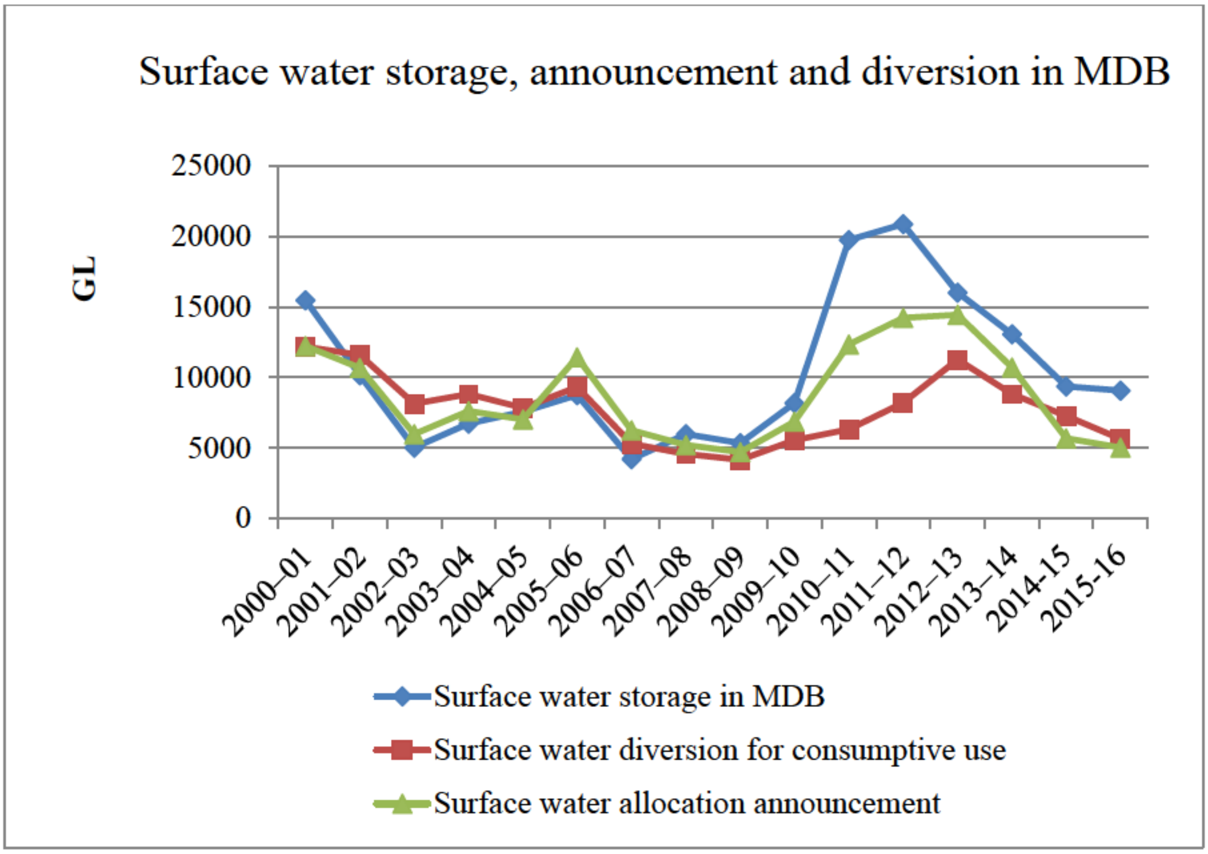
Table 8 and Figure 14 represents the surface water storage, surface water allocation announcement at the beginning of the season that includes net carryover water from the previous year, and surface water diversion for consumptive use in the MDB over the period 2000-2016. The Figure shows that there is a strong association between water storage, allocation and use. Especially, the path of water diversion is closely linked to the path of water allocation over the period. The excess of water storage compared to water allocation and use between 2010 and 2012 results from the significant increase in natural water availability due to high rainfall levels in those years and the cap that places a limit on water allocation and diversion. Water diversions were also significantly less than water allocations in those years. This reflects the effects of factors that affect demand for water such as water price, and area of irrigated land. A comparison between 2001-02 and 2015-16 shows that the water storages in the MDB were similar between those years, however, water allocation and extraction were much less in 2015-16 than in 2001-02.

Table 8: Surface water storage, allocation and extraction in MDB

Year	Surface water storage in MDB (GL)	Surface water diversion for consumptive use (GL)	Surface water allocation announcement (GL)
2000–01	15475	12175	12228
2001–02	10165	11587	10677
2002–03	5023	8136	5986
2003–04	6735	8824	7607
2004–05	7562	7842	7019
2005–06	8753	9327	11427
2006–07	4199	5286	6238
2007–08	5987	4556	5203
2008–09	5342	4154	4701
2009–10	8172	5553	6852
2010–11	19752	6311	12345
2011–12	20881	8214	14222
2012–13	16022	11278	14443
2013–14	13067	8812	10694
2014–15	9365	7281	5670
2015–16	9060	5644	5031

Source: water storage was sourced from MDBA water audit monitoring reports and the National Water Accounts, water diversion and allocation announcement were provided by the MDBA

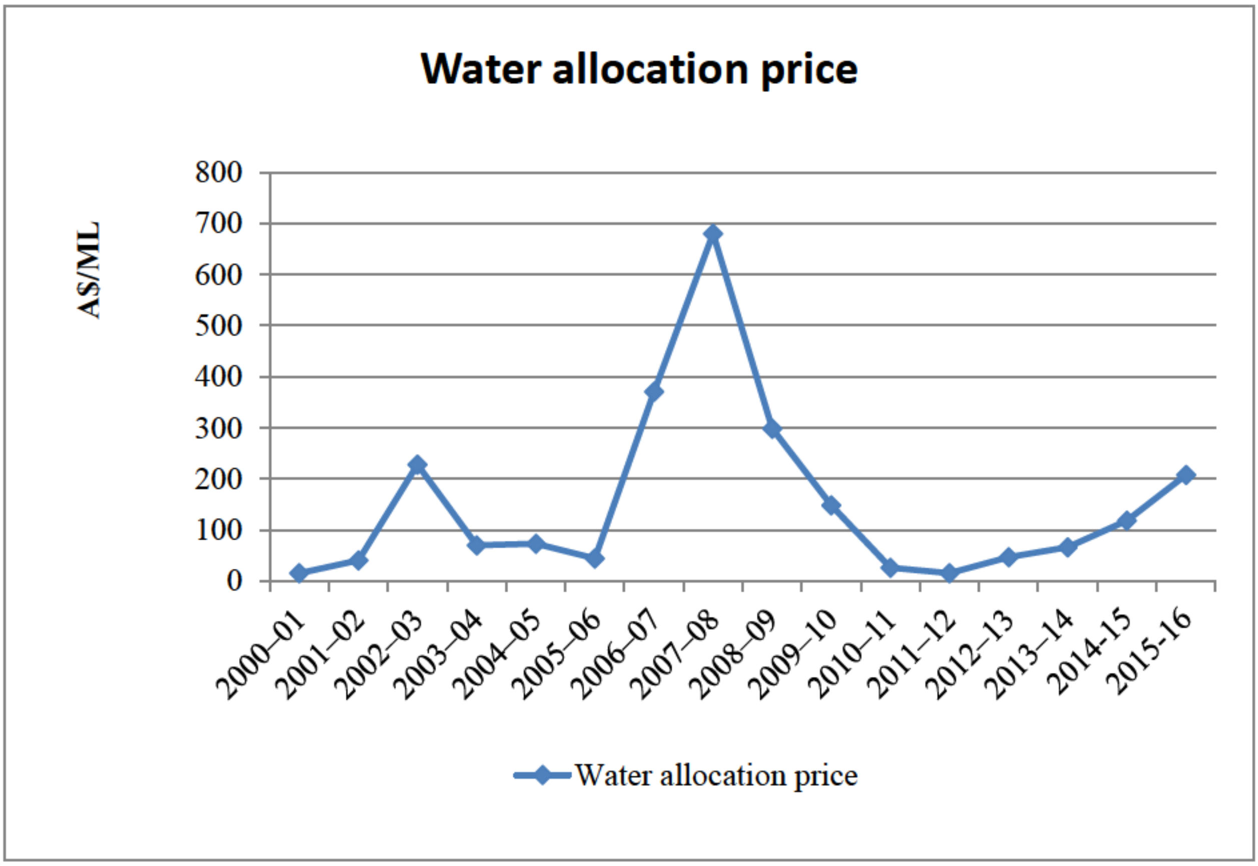
Figure 14: Surface water storage, announcement and diversion in MDB



Source: water storage was sourced from MDBA water audit monitoring reports and the National Water Accounts, water diversion and allocation announcement were provided by the MDBA

As the average water allocation price for the whole MDB is not publicly available, we used average water allocation price extracted from Murray Irrigation. Figure 15 represents water allocation price, which is the average price of temporary trades of water allocation at Murray Irrigation weighted by the amount of water traded at each price, over the period 2000-2016. It shows that water allocation price experienced a sharp increase during the period 2006-2009 when water availability dropped to a critically low level due to drought. This price dropped back to the pre-drought levels by 2010-2011 when water allocations rose again in 2010-2012. As a supply side impact, corresponding to the downward trend in the water availability over the years 2013-2016, water allocation price exhibited an increasing trend over this period.

Figure 15: Water allocation price



Source: Murray Irrigation

2.3 Social and Economic indicators

2.3.1 Population characteristics

Population size and density

In 2016, more than 2.2 million people were living within the MDB, around 9.5% of Australia's population (Census 2016). The largest shares of the Basin's population resided within the states of New South Wales (37%) and Victoria (28%) (Table 9). Over the period 1996-2016, the population increased in the MDB, but at a lower rate than the national population growth rate (Table 10 and Figure 16). Overall, the MDB is sparsely populated with an average density of 2 persons per square kilometre, well below the national rate of 3 persons per square kilometre. The Australian Capital Territory (comprising mainly the city of Canberra) had the highest population density of 169 persons per square kilometre. Besides Victoria (4.8 persons per square kilometre), the population density in the other Basin states were all below the national average.

Table 9: Population density in MDB

			Population	Population density (persons/km2)	Proportion of MDB population (%)
2006	MDB	NSW	777303.8	1.3	38.7
		Vic.	570948.4	4.4	28.7
		Qld	207450.4	0.8	10.8
		SA	110745.6	1.6	5.6
		ACT	322733.4	137.1	16.1
	MDB		2011243	1.9	100
	Australia		19948877	2.6	
2011	MDB	NSW	793769	1.3	37.8
		Vic.	597850	4.6	28.5
		Qld	236431	0.9	11.3
		SA	115897	1.7	5.5
		ACT	356586	151.5	17.0
	MDB		2100533	2.0	100
	Australia		21507719	2.8	
2016	MDB	NSW	823306	1.4	37.2
		Vic.	626975	4.8	28.3
		Qld	241993	0.9	10.9
		SA	126992	1.8	5.7
		ACT	396853	168.6	17.9
	MDB		2216117	2.1	100
	Australia		23401891	3.1	

Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

The distribution of the MDB population by remoteness differs from that of Australia as a whole. In Australia, in 2011, the majority of people were located in the major cities (62% of the total population), while in the MDB the majority of people lived in inner and outer regional areas (78%) (Figure 17).[1]

Analysing population changes between 1996 and 2011 by remoteness area shows population declines in the outer regional (2.1% decrease between 1996 and 2011), and remote (29.6% decrease) locations. There were corresponding population increases in inner regional areas and

[1] The Remoteness Structure is defined by the ABS that includes five categories (major cities, inner regional, outer regional, remote, and very remote area) where the category is based on the distance that people are required to travel to the nearest urban centre

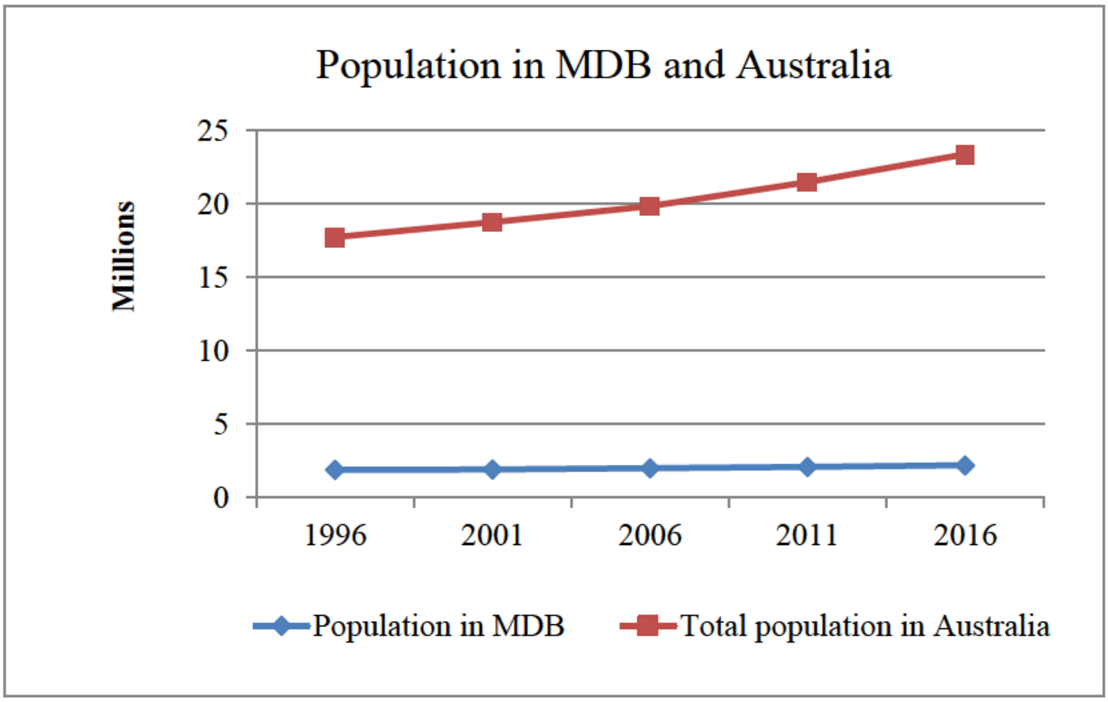
major cities (Table 10). In the very remote areas, population declined by some 43% between 2001 and 2006, but then increased 125% between 2006 and 2011.

Table 10: Population change by remoteness area in MDB, 1996-2016

		Population					Change				
		1996	2001	2006	2011	2016	1996-2001	2001-2006	2006-2011	2011-2016	1996-2016
MDB	Major Cities	324940	349370	358560	394004		7.5	2.6	9.9		
	Inner Regional	958530	975110	1059260	1109537		1.7	8.6	4.7		
	Outer Regional	548060	525180	527880	536486		-4.2	0.5	1.6		
	Remote	60580	58120	50910	42636		-4.1	-12.4	-16.3		
	Very Remote	13500	13890	7950	17869		2.9	-42.8	124.8		
Total: MDB		1905610	1921670	2004560	2100532	2216117	0.8	4.3	4.8	5.5	16.3
Total: Australia		17752830	18769250	19855287	21507719	23401891	5.7	5.8	8.3	8.8	31.8
MDB as proportion of Australia		10.7	10.2	10.1	9.8	9.5					

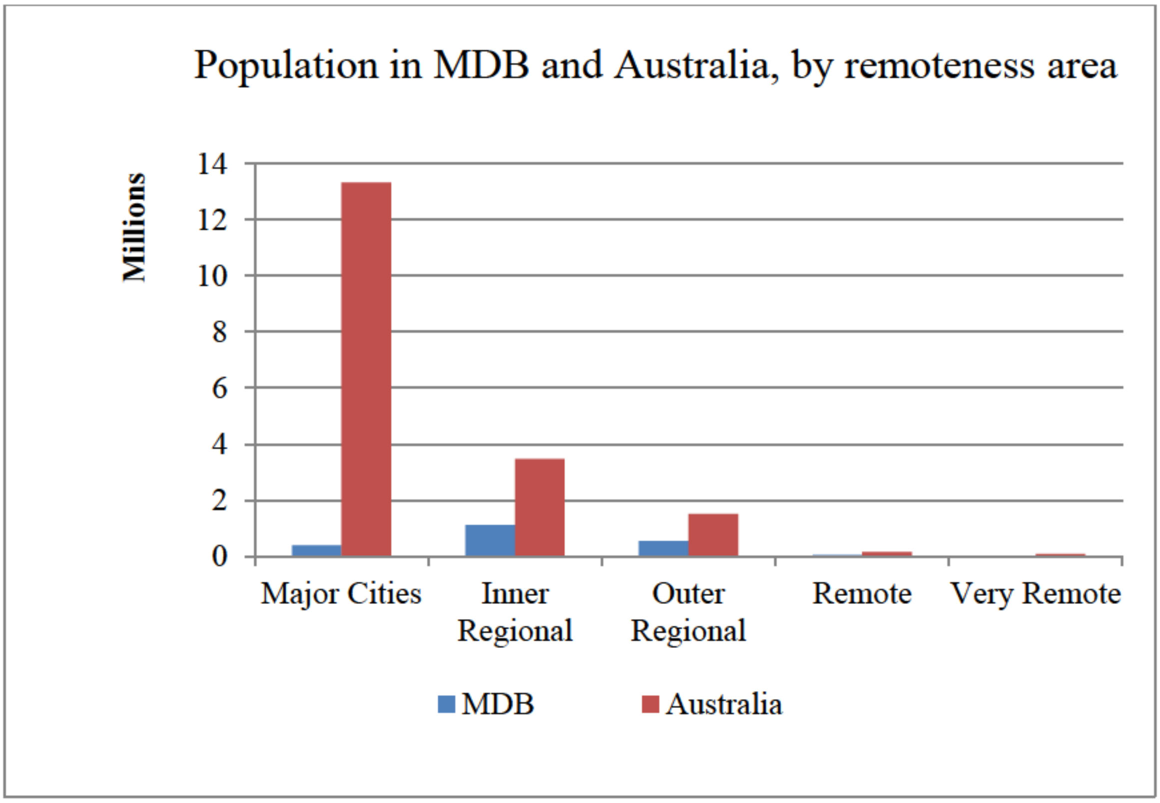
Source: ABS, Australian Census of Population and Housing 1996, 2001, 2006, 2011 and 2016

Figure 16: Population in MDB and Australia



Source: ABS, Australian Census of Population and Housing 1996, 2001, 2006, 2011, 2016

Figure 17: Population in MDB and Australia in 2011, by remoteness area



Source: ABS, Australian Census of Population and Housing 2011

Population by age and sex

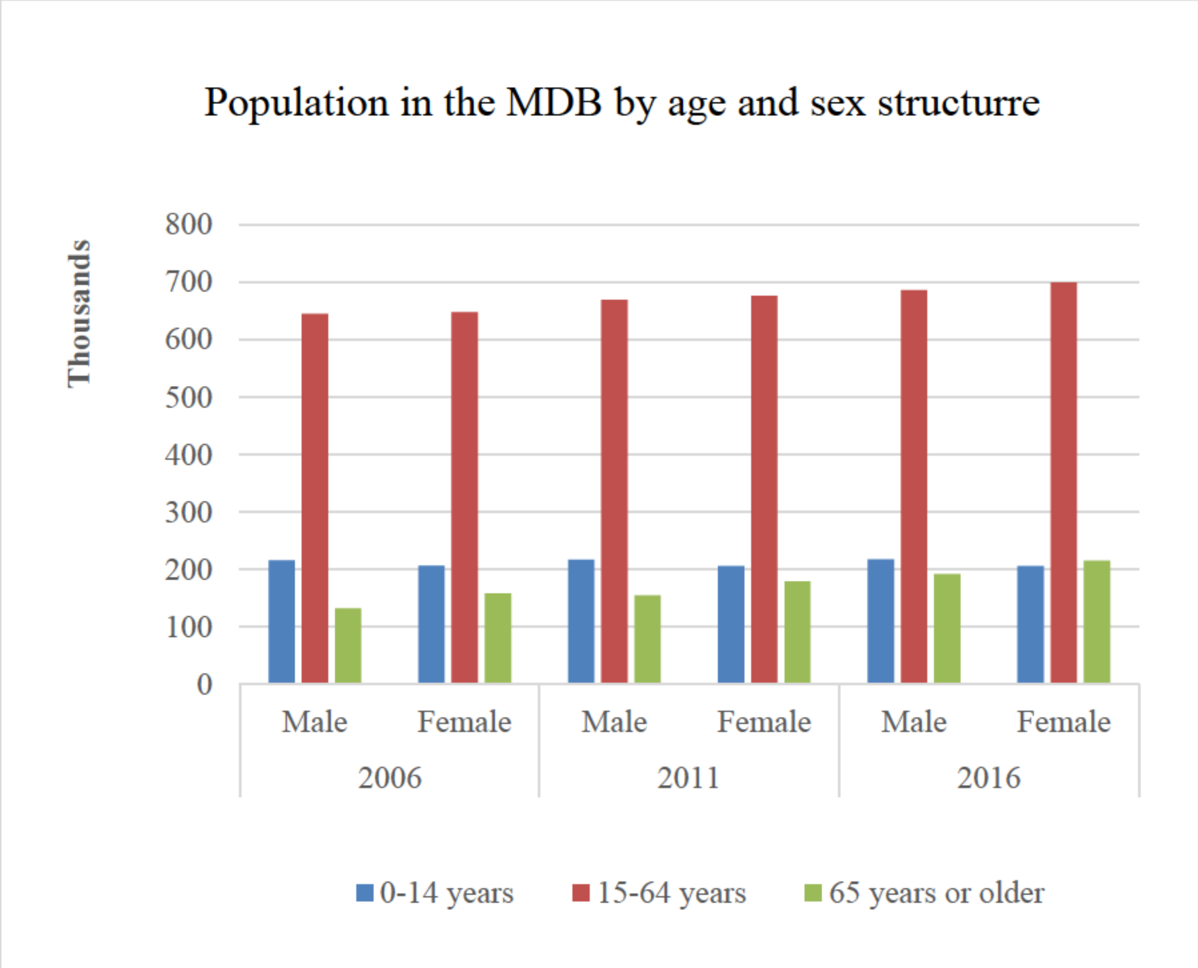
Table 11 and Figure 18 represent the population in the MDB by age and sex structure in 2006, 2011 and 2016. In those years, the female population is larger than the male population. The proportion of population which is 65 years or older increased from 14.5% in 2006 to 18.4% in 2016.

Table 11: Population in MDB, by age and sex

	Age	Male	Female	Total	% of MDB
2006	0-14 years	215488	205684	421172	21.0
	15-64 years	645227	648220	1293447	64.5
	65 years or older	131814	158122	289936	14.5
	Total	**992529**	**1012026**	**2004555**	**100**
2011	0-14 years	216473	205623	422096	20.1
	15-64 years	668950	676346	1345296	64.0
	65 years or older	154660	178480	333140	15.9
	Total	**1040083**	**1060449**	**2100532**	**100**
2016	0-14 years	217084	205643	422721	19.1
	15-64 years	686676	700018	1386688	62.6
	65 years or older	191577	215135	406714	18.4
	Total	**1095337**	**1120782**	**2216117**	**100**

Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

Figure 18: Population in the MDB by age and sex structure



Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

2.3.2 Labour Force

In 2016, there were almost one million people employed in the MDB (as reported in the Census). This represented more than half (55%) of the Basin's population aged 15 years and over, giving an employment to population ratio the same as the national level of 56%.

The number of unemployed people in the MDB decreased from 77,500 in 1996 to 59,021 in 2016, a decrease of 24% (Table 12). Over this period, the unemployment rate in the MDB dropped from 8.7% to 5.6% which is lower than the national figure of 6.9% in 2016. Over the entire period, the unemployment rate in the MDB was lower than the national unemployment rate.

Table 13 shows the employment status of employed persons in the MDB. Over the period 1996-2016, the number of employed persons in MDB increased, however, part-time employment increased faster than full-time employment, and the proportion of full time employment decreased from 67.9% to 62.2% over the period.

2.3.3 Employment by industry

Table 14(a) and (b) reports the number of persons employed by industry of employment for the MDB and for Australia, respectively. In 2016, employment in agriculture in the MDB accounted for 34% of the nation’s employment in agriculture. The proportion of employment in agriculture is much higher in MDB (7.7%) compared to national level (2.1%). The Table shows that although the number of persons employed in the MDB, as well as in Australia, increased between 2006 and 2016, the number of persons employed in agriculture decreased by 15.5% in the MDB, and by 7.4% in Australian wide.

In MDB, between 2006 and 2016, manufacturing industry also experienced a significant contraction (-23.7%); while employment in Health Care and Social Assistance, Education and Training, Public Administration and Defence, and Electricity, Gas, Water and Waste, increased by 31.5%, 19.3%, 14.9% and 14.7% respectively.

Table 12: Labour Force status in MDB and Australia

	MDB					Australia				
	1996	2001	2006	2011	2016	1996	2001	2006	2011	2016
Employed	810760	850900	921297	976272	992901	7636319	8298606	9104187	10058323	10683844
Unemployed	77500		48949	48565	59021	771970	660,709	503803	600133	787454
Labour Force (LF)	888260		970246	1024837	1051924	8,408,289	8,959,315	9607990	10658456	11471295
Not in Labour Force			529719	566179	604078	5174181	5265426	5271110	5729310	6297598
Unemployment rate	8.7		5.0	4.7	5.6	9.2	7.4	5.2	5.6	6.9
LF Participation			64.7	64.4	63.5	61.9	63.0	64.6	65.0	64.6

Source: ABS, Australian Census of Population and Housing 1996, 2001, 2006, 2011 and 2016

Table 13: Employment status in MDB

		Number employed					Change				
		1996	2001	2006	2011	2016	1996-2001	2001-2006	2006-2011	2011-2016	1996-2016
Employed											
	Full-time	550760	552580	590890	619503	617249	0.3	6.9	4.8	-0.4	12.1
	Part-time	239470	272900	268980	292338	315737	14	-1.4	8.7	8.0	31.8
Employed persons		810760	850900	921300	976272	992901	5	8.3	6.0	1.7	22.5
% working full time		67.9	64.9	64.1	63.5	62.2					

Source: ABS, Australian Census of Population and Housing 1996, 2001, 2006, 2011 and 2016

Table 14: Employment by industry in MDB

MDB	2006 No.	2006 % of total employed	2011 No.	2011 % of total employed	2016 No.	2016 % of total employed	Change 2006-2011 (%)	Change 2011-2016 (%)
Agriculture	90840	9.9	80007	8.2	76801	7.7	-11.9	-4.0
Manufacturing	81850	8.9	75219	7.7	62465	6.3	-8.1	-17.0
Electricity, Gas, Water and Waste	9964	1.1	11848	1.2	11428	1.2	18.9	-3.5
Retail Trade	101909	11.1	100953	10.3	93410	9.4	-0.9	-7.5
Public Administration and Defence	105107	11.4	121904	12.5	120730	12.2	16.0	-1.0
Education and Training	73004	7.9	80030	8.2	87081	8.8	9.6	8.8
Health Care and Social Assistance	95133	10.3	112888	11.6	125120	12.6	18.7	10.8
Others	363490	39.5	393423	40.3	415866	41.9	8.2	5.7
Employed persons	**921297**	**100.0**	**976272**	**100.0**	**992901**	**100.0**	**6.0**	**1.7**

Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

Table 15: Employment by industry in Australia

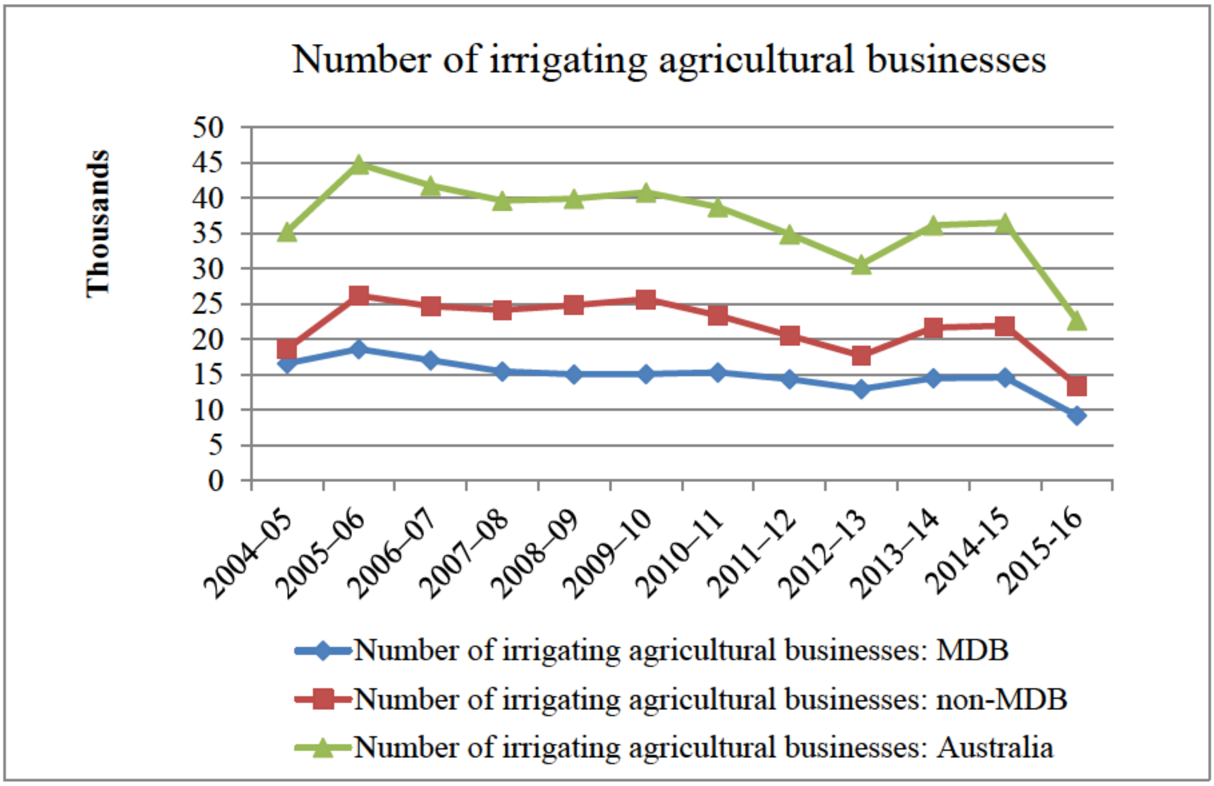
Australia	2006		2011		2016		Change 2006-2011 (%)	Change 2011-2016 (%)
	No.	% of total employed	No.	% of total employed	No.	% of total employed		
Agriculture	246603	2.7	219269	2.2	228372	2.1	-11.1	4.2
Manufacturing	952014	10.5	902830	9.0	683686	6.4	-5.2	-24.3
Electricity, Gas, Water and Waste	89449	1.0	115609	1.1	115753	1.1	29.2	0.1
Retail Trade	1033192	11.3	1057310	10.5	1053815	9.9	2.3	-0.3
Public Administration and Defence	608599	6.7	689929	6.9	713142	6.7	13.4	3.4
Education and Training	697805	7.7	804420	8.0	925890	8.7	15.3	15.1
Health Care and Social Assistance	956147	10.5	1167634	11.6	1351018	12.6	22.1	15.7
Others	4520378	49.7	5101322	50.7	5612168	52.5	12.9	10.0
Employed persons	**9104187**	**100.0**	**10058323**	**100.0**	**10683844**	**100.0**	**10.5**	**6.2**

Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

2.3.4 Trend in agricultural employment

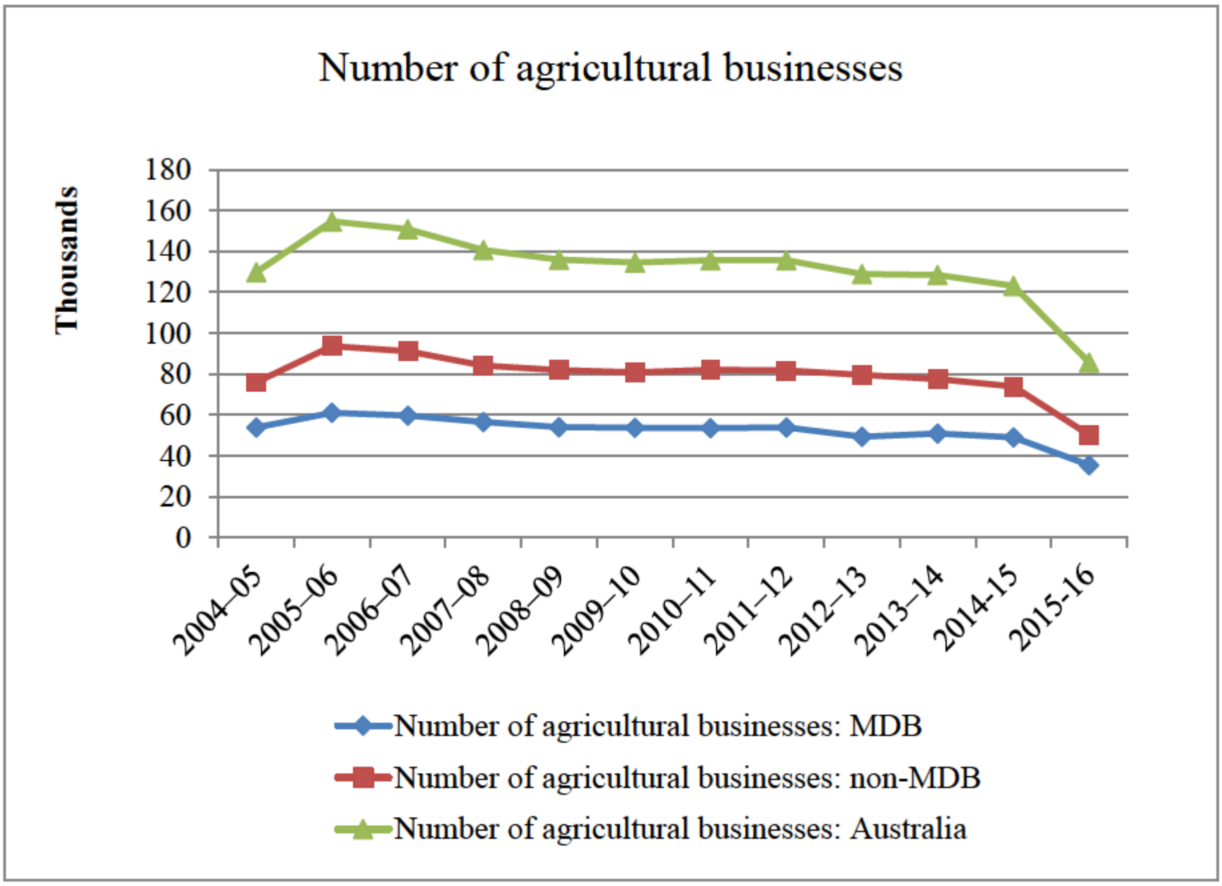
Figures 19 and 20 represent the number of irrigating and total agricultural businesses in the MDB and Australia between 2005 and 2016. In 2015-2016, there were 85,681 agricultural businesses in Australia, of which 35,464 businesses were located in the MDB. The number of irrigating agricultural businesses in MDB, as well as at the national level, peaked in 2005-06, but the number has declined in the 10 year period to 2015-16. In 2004-05, irrigating agricultural businesses in MDB accounted for 47% of the irrigating agricultural businesses in Australia and 32% of the agricultural businesses in MDB. In 2015-16 those numbers were 41% and 26%, respectively.

Figure 19: Number of irrigating agricultural businesses



Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

Figure 20: Number of agricultural businesses



Source: ABS, Water Use on Australian Farms, cat. No. 4618.0

Table 15 reports the changes in employment in agriculture industry in the MDB between 2001 and 2016. Employment decreased in all sub-groups in the agriculture industry, except beef cattle farming and poultry farming which experienced an increase of 6.6% and 22.5% in employment, respectively. There was a large reduction in employment in cotton (-66%); other crops (-45%); horticulture and fruit growing such as grapes (-62%), plant, flower and seed growing (-22%); dairy cattle farming (-41%); sheep-beef cattle farming (-60%). In the MDB, total employment in agriculture decreased by 25.7% between 2001 and 2016.

Table 16: Trend in employment in agriculture in MDB

	Employed persons				Change (%)			
	2001	2006	2011	2016	2001-2006	2006-2011	2011-2016	2001-2016
Horticulture and fruit growing								
Plant, flower, seed growing	1450	1000	693	1126	-31.0	-30.7	62.5	-22.3
Vegetable growing	2540	2220	1959	1978	-12.6	-11.8	1.0	-22.1
Grape growing	7950	5540	3781	3013	-30.3	-31.8	-20.3	-62.1
Apple and pear growing	1180	970	751	596	-17.8	-22.6	-20.6	-49.5
Stone fruit growing	840	670	516	360	-20.2	-23.0	-30.2	-57.1
Other fruit growing	3370	3020	2481	2391	-10.4	-17.8	-3.6	-29.1
Other	1880	1830	1805	2086	-2.7	-1.4	15.6	11.0
Total	**19210**	**15250**	**11986**	**11550**	**-20.6**	**-21.4**	**-3.6**	**-39.9**
Grain, sheep and beef cattle farming								
Grain growing	10720	10680	10442	9824	-0.4	-2.2	-5.9	-8.4
Grain-sheep and grain-beef cattle farming	20120	16150	13726	7409	-19.7	-15.0	-46.0	-63.2
Sheep-beef cattle farming	8410	6170	5331	3374	-26.6	-13.6	-36.7	-59.9
Sheep farming	10690	9710	9130	9032	-9.2	-6.0	-1.1	-15.5
Beef cattle farming	12650	14660	13224	13481	15.9	-9.8	1.9	6.6
Other	1310	400	1028	1351	-69.5	157	31.4	3.1
Total	**63900**	**57770**	**52881**	**44471**	**-9.6**	**-8.5**	**-15.9**	**-30.4**
Dairy cattle farming	8860	6920	5065	5199	-21.9	-26.8	2.6	-41.3
Poultry farming	1690	1440	1558	2070	-14.8	8.2	32.9	22.5
Other livestock farming	3360	3690	3125	3073	9.8	-15.3	-1.7	-8.5
Other crop growing								
Cotton growing	2950	1700	1520	1007	-42.4	-10.6	-33.8	-65.9
Other crop growing	980	1110	575	525	-15.6	-48.2	-8.7	-45.3
Total	**3930**	**2810**	**2095**	**1532**	**-28.5**	**-25.4**	**-26.9**	-61.0

Other	2400	2960	3297	8906	22.8	11.4	170	269
Total Agriculture	**103360**	**90840**	**80007**	**76801**	**-12.4**	**-11.9**	**-4.0**	**-25.7**

Source: ABS, Australian Census of Population and Housing 2001, 2006, 2011 and 2016

2.4 Indigenous community: population and employment

Table 16 reports the status and demographic changes in indigenous community between 2006 and 2016. As a proportion of total population, the share of indigenous community in the MDB increased from 3.5% in 2006 to 4.4% in 2016. Between 2006 and 2016, the population growth rate of the Indigenous community in the MDB was 41%, which is nearly 4 times higher than the overall population growth rate in the MDB (10.6%), and 2.5 times higher than the national population growth rate (18%). Of note, the age structure of the Indigenous community is substantially different to the age structure in the MDB. In 2016, about 36% of the Indigenous population was aged less than 15 years; 59% was aged between 15 and 64, and only 5% of the Indigenous community was aged 65 or older.

Table 17 reports the employment status of the Indigenous community in the MDB. It shows that, in 2016, the labour force participation of the Indigenous community (54%) was less than the average labour force participation in the MDB (64%) while the unemployment rate of the Indigenous community (17.3%) was much higher than the average basin unemployment level (5.6%). While the Indigenous population accounts for 4.4% of the population in the MDB, 10% of the unemployed in the basin are Indigenous people.

Table 17: Indigenous community in MDB

	Indigenous community in MDB				
	Age	**Male**	**Female**	**Total**	**Proportion of indigenous population in MDB**
2006	0-14 years	14071	13597	27668	39.8
	15-64 years	19040	20429	39469	56.8
	65 years or older	1061	1339	2400	3.5
	Total	**34172**	**35365**	**69537**	**100**
	% of MDB	**1.7**	**1.8**	**3.5**	
2011	0-14 years	16015	15645	31660	37.7
	15-64 years	23669	25256	48925	58.2
	65 years or older	1554	1876	3430	4.1
	Total	**41238**	**42777**	**84015**	**100**
	% of MDB	**2.0**	**2.0**	**4.0**	
2016	0-14 years	18078	17016	35090	35.7
	15-64 years	28039	29800	57838	58.9
	65 years or older	2460	2825	5281	5.4
	Total	**48571**	**49638**	**98206**	**100**
	% of MDB	**2.2**	**2.2**	**4.4**	
Growth rate of indigenous community in MDB between 2006-2016					41.2
Population growth rate in MDB between 2006-2016					10.6
Population growth rate in Australia between 2006-2016					17.9

Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

Table 18: Employment status of Indigenous community

	2006			2011			2016		
	Indigenous community	**MDB**	**% of MDB**	**Indigenous community**	**MDB**	**% of MDB**	**Indigenous community**	**MDB**	**% of MDB**
Employed	16851	921297	1.8	21327	976272	2.2	27269	992901	2.7
Unemployed	4182	48949	8.5	4707	48565	9.7	5719	59021	9.7
Labour Force (LF)	21033	970246	2.2	26034	1024837	2.5	32986	1051924	3.1
Not in Labour Force	18651	529719	3.5	24032	566179	4.2	28348	604078	4.7
Unemployment rate	**19.9**	**5.0**		**18.1**	**4.7**		**17.3**	**5.6**	
LF Participation	**53.0**	**64.7**		**52.0**	**64.4**		**53.8**	**63.5**	

Source: ABS, Australian Census of Population and Housing 2006, 2011 and 2016

2.5 Livelihoods and status of key regional towns

2.5.1 Deniliquin

Population

For statistical purposes, Deniliquin covers a land area of about 140km^2 and had a population of 7,429 in 2015. Deniliquin is a service centre for the surrounding agricultural region. The region includes both dryland and irrigated areas. The dryland areas support grazing, in particular beef cattle and wool growing. The irrigated areas produce a range of high yield crops. Rice was a major crop until the recent drought. The largest rice mill in the southern hemisphere is in Deniliquin, producing large packs and bulk rice for export markets. Deniliquin is also the headquarters of Murray Irrigation Limited, an irrigator owned private company and one of the largest privately owned irrigation supply companies in the world.

Table 18 reports the population in Deniliquin between 2000 and 2015. The Table shows that between 2000 and 2015, the Deniliquin population decreased by about 9% from 8,170 to 7,429. Consequently, the population density in Deniliquin decreased from 63 persons/km^2 in 2000 to 52 persons/km^2 in 2015. Over this period, the working age population remained at about 60% of the total Deniliquin population.

Employment

Table 19 reports the employment status in Deniliquin between 2002 and 2011. In 2006, the unemployment rate was 6.1% which is higher than the average MDB level of 5%. However, in 2011, the Deniliquin unemployment rate was 4.6%, close to the average MDB level of 4.7%.

Table 20 shows that the number of businesses in Deniliquin between 2003 and 2015 almost halved from 1,128 in 2003 to 686 in 2015. Industries that experienced a large reduction in the number of businesses include Agriculture, Forestry and Fishing; Manufacturing, and the Retail Trade. The number of businesses in Agriculture, Forestry and Fishing decreased from 489 in 2003 to 128 in 2015.

Table 19: Population in Deniliquin between 2000 and 2015

Year	Population (no.)	Male (no.)	Female (no.)	Working age population (% of total)	Population density (persons/km2)	Indigenous community (%)
2000	8170	4006	4164	61.7	62.9	
2001	8333	4162	4171	61.2	64.1	2.8
2002	8314	4126	4188	60.9	64.0	
2003	8274	4107	4167	60.7	63.7	
2004	8201	3937	4012	60.4	63.2	
2005	7835	3871	3964	60.6	60.3	
2006	7731	3810	3921	60.6	59.4	3
2007	7708	3821	3887	60.7	59.3	
2008	7635	3798	3837	61.0	53.3	
2009	7446	3667	3779	60.9	52.0	
2010	7366	3611	3755	60.9	51.4	
2011	7303	3574	3729	60.4	51.0	3.6
2012	7336	3594	3742	60.2	51.2	
2013	7376	3620	3756	60.3	51.5	
2014	7432	3643	3789	60.4	51.9	
2015	7429	3637	3792	60.0	51.9	

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region

Table 20: Labour force status in Deniliquin

Year	Labour force	Employed	Unemployed	Unemployment rate	Unemployment rate in MDB
2002	4087	3899	188	4.6	
2003	4204	3998	206	4.9	
2004	4250	4063	187	4.4	
2005	4157	3945	212	5.1	
2006	4230	3972	258	6.1	5.0
2007	4450	4272	178	4	
2008	4450	4272	178	4	
2009	3800	3572	228	6	
2010	3895	3673	222	5.7	
2011	3169	3023	146	4.6	4.7

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Table 21: Number of businesses by industry in Deniliquin

Industry	2003	2004	2005	2006	2011	2012	2013	2014	2015
Agriculture, Forestry and Fishing	489	525	516	507	113	120	119	119	128
Manufacturing	45	42	45	45	28	28	27	24	22
Construction	90	81	84	93	87	88	90	86	93
Retail trade	111	117	102	93	63	59	54	47	44
Transport, postal and warehousing	87	72	69	69	59	64	63	67	65
Education and training	9	9	9	9	8	10	7	4	4
Health care and social assistance	24	27	24	27	18	20	22	22	23
Others	273	288	300	312	305	305	295	304	307
Total (no.)	**1128**	**1161**	**1149**	**1155**	**681**	**694**	**677**	**673**	**686**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region

Drivers of population and employment changes in Deniliquin

The population growth of Deniliquin is intrinsically linked to economic conditions of the town. Over the last two decades, the population of Deniliquin declined as the area was in severe drought and due to consolidation of agricultural holdings and concentration of employment in larger towns and cities (Riverina Cities, 2015a). Due to prolonged drought, a number of businesses were shut down, the Deniliquin rice mill was temporarily closed in 2007 and this has had a major effect on Deniliquin's economy. Other reasons contributed to the reduction in agriculture employment and the migration of people out of the town include the mechanization in agriculture sector that substituted labour by machinery; and the ending of a number of government programs in 2001; in 2005, three government agencies for health and communities services were closed down. Between 2006 and 2015, 23 manufacturing companies, 49 retail trade companies and 4 health care and community services were closed down. The most mobile group in the population is young adults. They move out of the town to attend educational institutions, look for work and change a lifestyle. The town retains young family households and older age group people.

Income

Table 21 and Figure 21 show that the average wage and salary income as well as average taxable income[2] in Deniliquin increased steady over the period 2002-2013. In 2010, the average taxable income in Deniliquin was A$ 47,579 and the total taxable income was A$ 125 million. Between 2002 and 2013, average income from wage and salary in Deniliquin increased by 47%, which is significantly lower than the growth rate of 64% in the national average income from wage and salary. The income growth rate in Deniliquin between 2002 and 2013 was also less than that of other communities in the MDB such as Griffith (49%), Moree Plains (50%), Shepparton (52%) and similar to the income growth rate in Renmark Paringa 47%).

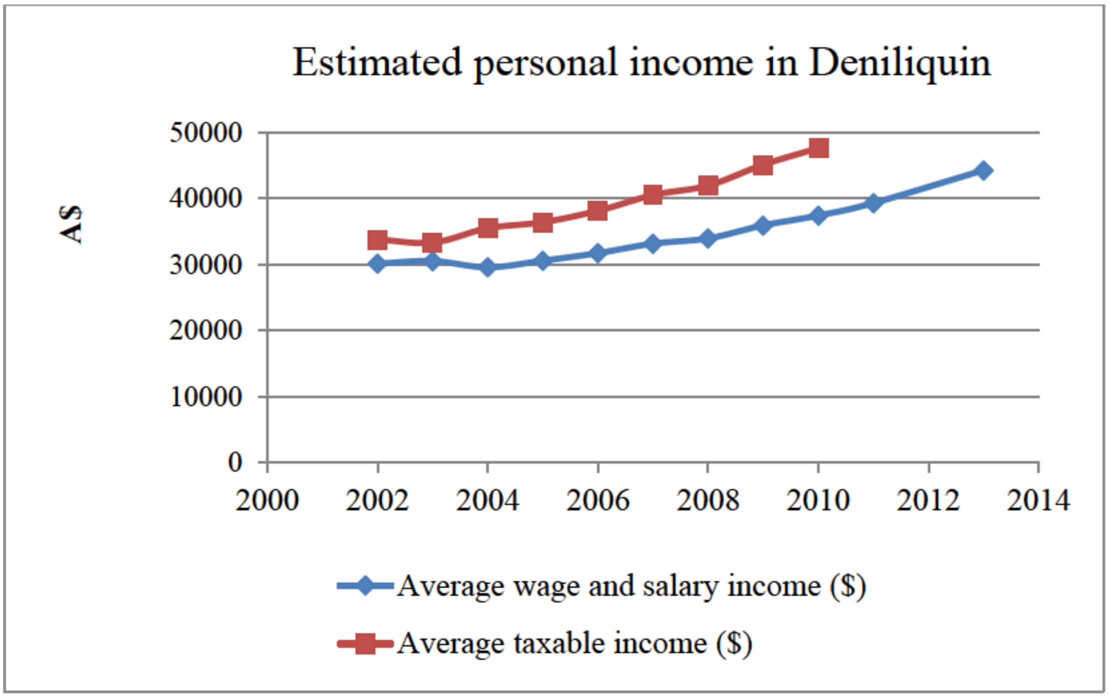
[2] Salary income includes income from salary and wages. Taxable income includes income from salary and wages, and all other taxable incomes such as interest from investment.

Table 22: Estimates of personal income in Deniliquin

Year	Average wage and salary income ($)	Average taxable income ($)	Total taxable income ($m)
2002	30094	33744	107.5
2003	30486	33280	103.9
2004	29542	35442	112
2005	30545	36354	112.7
2006	31682	38083	120.5
2007	33119	40461	122.3
2008	33911	41902	125.7
2009	35873	45 051	121.9
2010	37364	47560	125
2011	39252		
2013	44214		

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 21: Estimates of personal income in Deniliquin



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Agricultural production

Table 22 reports the gross value of agricultural production in Deniliquin in 2001, 2006 and 2011. The Table shows that between 2001 and 2006, value of agricultural production in Deniliquin decreased from $11.2 million in 2001 to $6.1 million in 2006, and the gross value of crops decreased from 6.3 to 2.9 million. The reduction in agriculture production in Deniliquin between 2001 and 2006 was primarily caused by years of severe drought in the MDB which started in 2003. The total value of agricultural production increased to $38.8 million in 2011, of which the gross value of crops increased to $25.1 million. Crops were the major production in the agriculture industry of the region, accounting for 65% of total value of agricultural production in 2011.

Table 23: Gross value of agricultural production in Deniliquin

Gross value of agricultural production ($m)	2001	2006	2011
Gross value of crops	6.3	2.9	25.1
Gross value of livestock slaughtering	2.2	1.3	5.9
Gross value of livestock products	2.7	2	7.8
Total gross value of agricultural production	**11.2**	**6.1**	**38.8**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001, Agriculture Census 2011

2.5.2 Griffith

Population

Griffith city covers an area of 1,640 square kilometres. In 2015, the Griffith population was 25,986. The agricultural industry and value added food and beverage manufacturing/ processing underpins the economy of the region. The area is a major wine grape growing area. The town also hosts other crops and mixed farming such as prune, rice and citrus with emerging industries such as nuts (almonds and walnuts), chicken breeding, growing and processing, cotton, cereals, fruit (melons, pumpkins, onions, cherries, tomatoes, olives) and aquaculture.

Table 23 reports the population in Griffith between 2000 and 2016. The Table shows that the Griffith population increased from 24,036 in 2000 to 26,125 in 2016 (increased by about 8.7%).

Population density in Griffith increased from 14.7 persons/km^2 in 2000 to 15.9 persons/km^2 in 2016. The working age population accounted for about 64% of the Griffith population. The share of the Indigenous community in total population increased from 3.9% in 2001 to 4.7% in 2016.

Table 24: Population in Griffith between 2000 and 2016

Year	Population	Male	Female	Working age population (% of total)	Population density (persons/km2)	Indigenous community (%)
2000	24036	12169	11867	63.9	14.7	
2001	24604	12461	12143	63.8	15.0	3.9
2002	24709	12549	12160	63.9	15.1	
2003	24758	12600	12158	63.6	15.1	
2004	24870	12661	12209	63.6	15.2	
2005	24705	12501	12204	63.7	15.1	
2006	24921	12579	12342	63.8	15.2	4
2007	24907	12585	12322	63.8	15.2	
2008	25107	12725	12382	63.9	15.3	
2009	25100	12748	12352	63.7	15.3	
2010	25264	12835	12429	63.6	15.4	
2011	25395	12875	12520	63.5	15.5	4.1
2012	25493	12999	12494	63.7	15.5	
2013	25417	12973	12444	63.7	15.5	
2014	25795	13193	12602	63.8	15.7	
2015	25986	13330	12656	63.7	15.8	
2016	26125				15.9	4.7

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region; Griffith City: Estimated Resident Population

Employment

Table 24 reports the labour force and unemployment rate in Griffith. Between 2002 and 2008, there was a growing trend in the labour force in Griffith. The overall labour force declined in 2009 and fluctuated between 2009 and 2016. The number of unemployed persons in Griffith fluctuated over the period and there was no obvious trend between 2002 and 2016. The unemployment rate in Griffith is slightly higher than the average unemployment rate of the basin.

Table 25: Labour force status in Griffith

Year	Labour force	Unemployed	Unemployment rate	Unemployment rate in MDB
2002	11978	551	4.6	
2003	13022	599	4.6	
2004	13514	500	3.7	
2005	13256	570	4.3	
2006	13473	741	5.5	5.0
2007	13921	529	3.8	
2008	14378	532	3.7	
2009	12900	645	5	
2010	13273	730	5.5	
2011	13339	981	7.4	4.7
2012	13422	728	5.4	
2013	14070	830	5.9	
2014	15130	814	5.4	
2015	14454	655	4.5	
2016	14234	507	3.6	5.6

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001 for period 2002-2010 Department of Employment: Small Area Labour Markets for period 2011-2016

Table 25 reports the number of employed persons by industry in Griffith between 2001 and 2015. Although employment slightly decreased between 2009 and 2011, there was an increasing trend in the number of persons employed in Griffith over the period 2001-2015 (Figure 22). The total employment in Griffith increased from 11,670 in 2000-01 to 13,700 in 2014-15.

In Griffith, Agriculture, Manufacturing and Health Care and Social Assistance are the main industries in the region. Employment in agriculture declined between 2006 and 2012, but showed a large increase between 2013 and 2015. Manufacturing experienced a growing trend between 2001 and 2013, and then declined in 2014 and 2015. The Health Care and Social Assistance industry experienced a steadily increasing trend between 2001 and 2015 (Figure 23).

Table 26: Employment by industry in Griffith

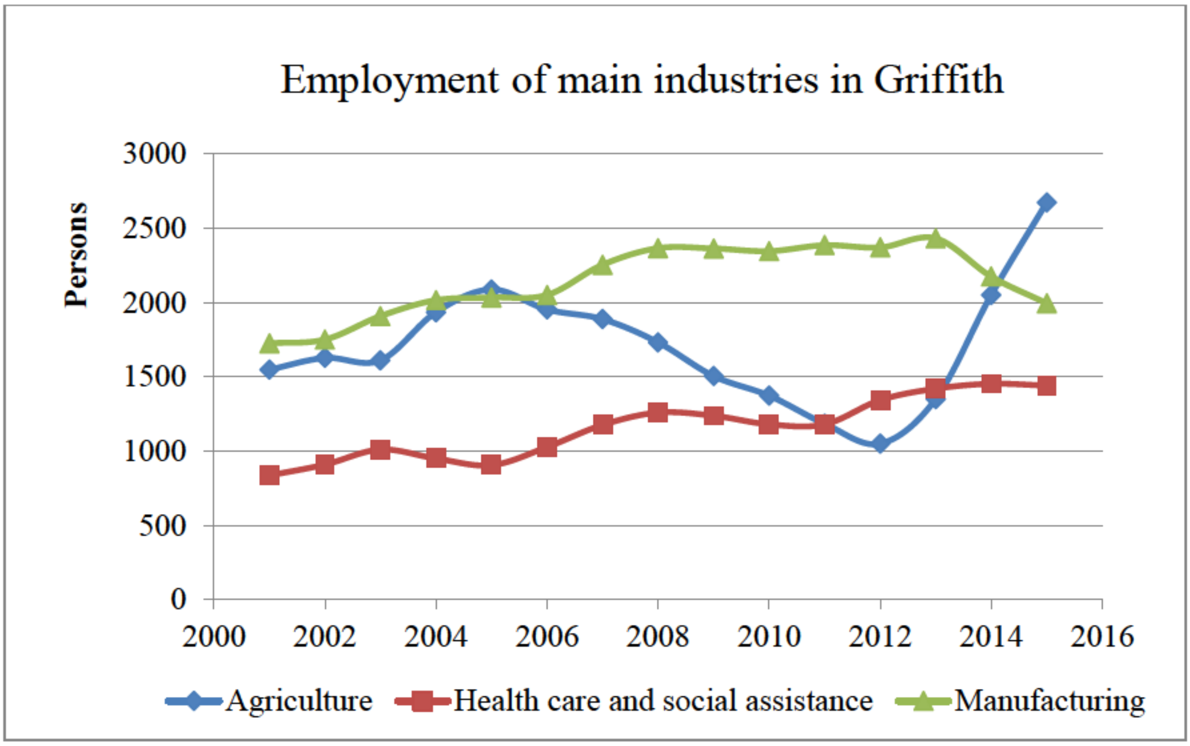
Year	Employment by industry in Griffith									
	Agriculture	Manufacturing	Construction	Accommodation and Food Services	Wholesale and retail trade	Public administration and Safety	Education and training	Health care and social assistance	Others	Total
2001	1547	1725	911	708	2599	408	691	835	2246	11670
2002	1626	1750	882	667	2394	397	868	908	2382	11874
2003	1610	1908	909	677	2315	387	819	1009	2482	12116
2004	1934	2015	939	633	2112	381	792	949	2278	12033
2005	2087	2033	976	639	2035	403	827	904	2154	12058
2006	1952	2050	1047	599	2018	430	852	1026	2284	12258
2007	1887	2253	1121	491	2034	451	768	1175	2441	12621
2008	1731	2365	1088	570	2203	466	707	1258	2434	12822
2009	1504	2363	1063	737	2225	480	694	1237	2355	12658
2010	1372	2345	1120	870	2002	497	696	1179	2476	12557
2011	1183	2385	984	923	2147	513	813	1179	2681	12808
2012	1049	2370	891	833	2415	523	857	1342	2697	12977
2013	1349	2431	829	687	2545	534	762	1419	2584	13140
2014	2050	2174	785	709	2431	546	719	1452	2524	13390
2015	2673	1994	742	711	2268	557	729	1440	2586	13700

Source: Griffith City, Employment Report, 2016

Figure 22: Employment in Griffith

Source: Griffith City, Employment Report, 2016

Figure 23: Employment by industry in Griffith



Source: Griffith City, Employment Report, 2016

Drivers of population and employment changes in Griffith

Over the last two decades, while the Riverina region was in severe drought and the populations of some townships declined, the population and employment of Griffith increased and the economy of the Griffith remained strong and continued to grow. Griffith was one of the main centres that attracted most of the development in the Riverina area. Population and employment growth was driven by the increase in local investment in the town. Younger population is attracted to Griffith due to large employment bases, particularly the Bajada Group which is the Riverina's largest employer, the Riverina Institute of TAFE campuses, and the Regional University Study Centre which was established in 2004 in Griffith. Griffith has also experienced strong commercial growth with new shopping centre developments in recent years (Riverina Cities, 2015b). Between 2001 and 2015, Agriculture and Health Care and Social Assistance are the industries that experienced largest increase in employment. Employment in agriculture industry increased by 73% from about 1,500 in 2000-01 to approximately 2,700 in 2014-15. Number of people employed in Health Care and Social Assistance industry increased by 72% from about 800 in 2000-01 to 1,440 in 2014-15 (Griffith City, 2016). Significant new housing developments on the outskirts of Griffith, providing opportunities for households to relocate from other areas or new households to form locally (such as young people leaving the family home), is also a driver of population growth in the area.

Income

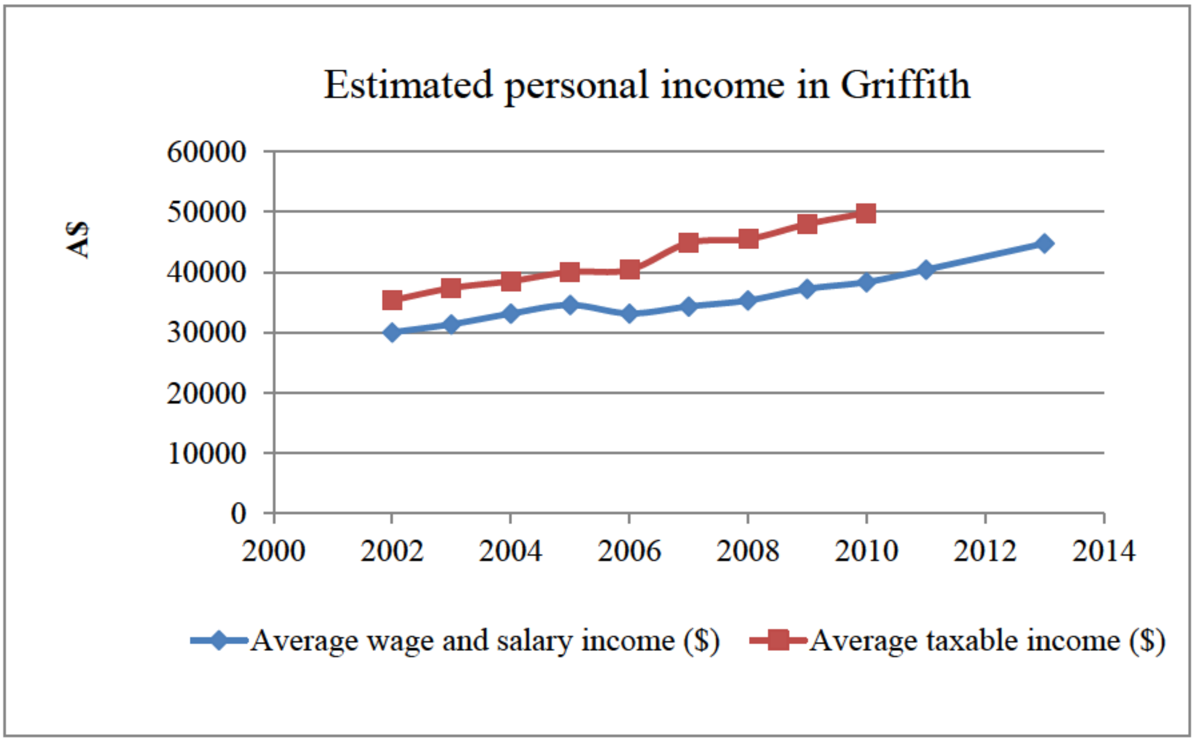
Table 26 and Figure 24 represent the estimates of nominal personal income in Griffith. There is a growing trend in average wage and salary income as well as average taxable income in Griffith over the period 2002-2013. In 2010, the average taxable income in Griffith was $49,831 and the total taxable income was $496.4 million. The average income from wage and salary in Griffith increased by 49% between 2002 and 2013, which was 6 percentage point less than the national average.

Table 27: Estimates of personal income in Griffith

Year	Average wage and salary income ($)	Average taxable income ($)	Total taxable income ($m)
2002	30028	35331	386.1
2003	31362	37365	414
2004	33125	38511	434.3
2005	34555	40045	451.8
2006	33158	40399	464
2007	34316	44850	499.7
2008	35310	45481	520.6
2009	37243	47966	510.8
2010	38359	49831	496.4
2011	40421		
2013	44764		

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 24: Personal income in Griffith



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Agricultural production

Table 27 reports the gross value of agricultural production in Griffith region in 2001, 2006 and 2011. It shows that crops were the main agricultural product which accounted for 91% of total value of agriculture production in 2001, 77% in 2006 and 83% in 2011. Over the period 2001-2011, the value of crops remained stable while the value of livestock slaughtering and livestock products experienced strong volatility. Between 2001 and 2006, the value of agricultural production in Griffith increased from $291 million to $343 million. While the gross value of crops was stable at about $263 million during this period, the value of livestock slaughtering increased from about $4 million to $79 million while the value of livestock products decreased from $22.1 million to $1.2 million. Between 2006 and 2011, the total value of agricultural production decreased from $343 million to $281 million because of a decline in the value of both crops and livestock slaughtering.

Table 28: Gross value of agricultural production in Griffith

Gross value of agricultural production ($m)	2001	2006	2011
Gross value of crops	265.4	263.2	234
Gross value of livestock slaughtering	3.8	78.8	43.3
Gross value of livestock products	22.1	1.2	3.9
Total gross value of agricultural production	**291.3**	**343.3**	**281.2**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001, Agriculture Census 2011

2.5.3 Moree Plains

Population

Moree is a town in Moree Plains Shire in northern New South Wales. The region covers 17,928 km^2 and is a major agricultural centre, noted for its productive agricultural soils. Local crops include cotton, wheat, barley, canola and sunflowers. Permanent crops such as citrus fruit, olives and pecan nuts as well as livestock operations are also part of the mix.

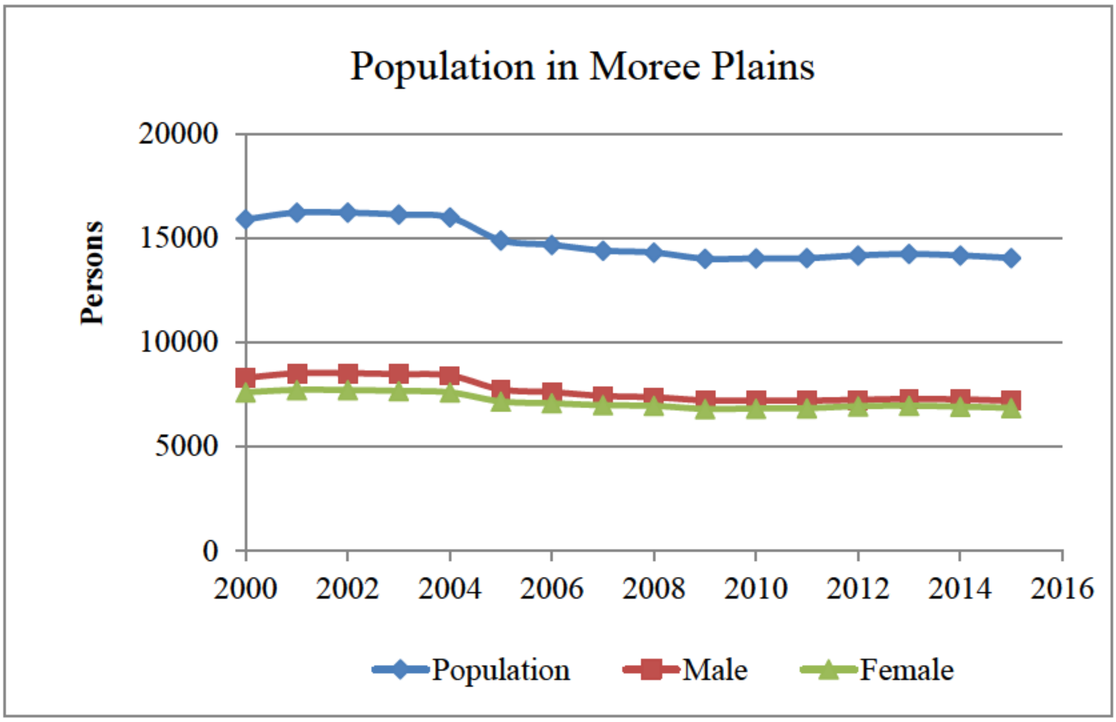
As shown in Table 28 and Figure 25, there is a downward trend in Moree population between 2000 and 2015 and the male population in the region is higher than the number of female population. The region is sparely populated with population density was about 0.8-0.9 persons/km^2 over the period 2000-2015. The indigenous community accounted for a large share of the region population (21% of the region population in 2011).

Table 29: Population in Moree Plains

Year	Population	Male	Female	Working age population (% of total)	Population density (persons/km2)	Indigenous community (%)
2000	15905	8300	7605	66.7	0.9	
2001	16233	8515	7718	66.9	0.9	19.7
2002	16227	8518	7709	66.9	0.9	
2003	16141	8473	7668	66.7	0.9	
2004	16002	8405	7597	66.7	0.9	
2005	14903	7740	7163	65.8	0.8	
2006	14682	7608	7074	65.4	0.8	21.1
2007	14408	7426	6982	65.1	0.8	
2008	14315	7364	6951	65.0	0.8	
2009	14019	7215	6804	64.8	0.8	
2010	14032	7206	6826	64.4	0.8	
2011	14043	7201	6842	64.3	0.8	20.8
2012	14175	7242	6933	64.0	0.8	
2013	14250	7290	6960	64.1	0.8	
2014	14175	7263	6912	63.8	0.8	
2015	14053	7196	6857	63.7	0.8	

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region

Figure 25: Trend in the population in Moree Plains



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Employment

Table 29 and Figure 26 report the labour force status in Moree. Between 2002 and 2008, there was a growing trend in the labour force and the number of persons employed in Moree although both statistics declined between 2009 and 2016. The number of unemployed persons in Moree remained stable over the period 2002-2016, although its unemployment rate was higher than the average unemployment rate of the MDB.

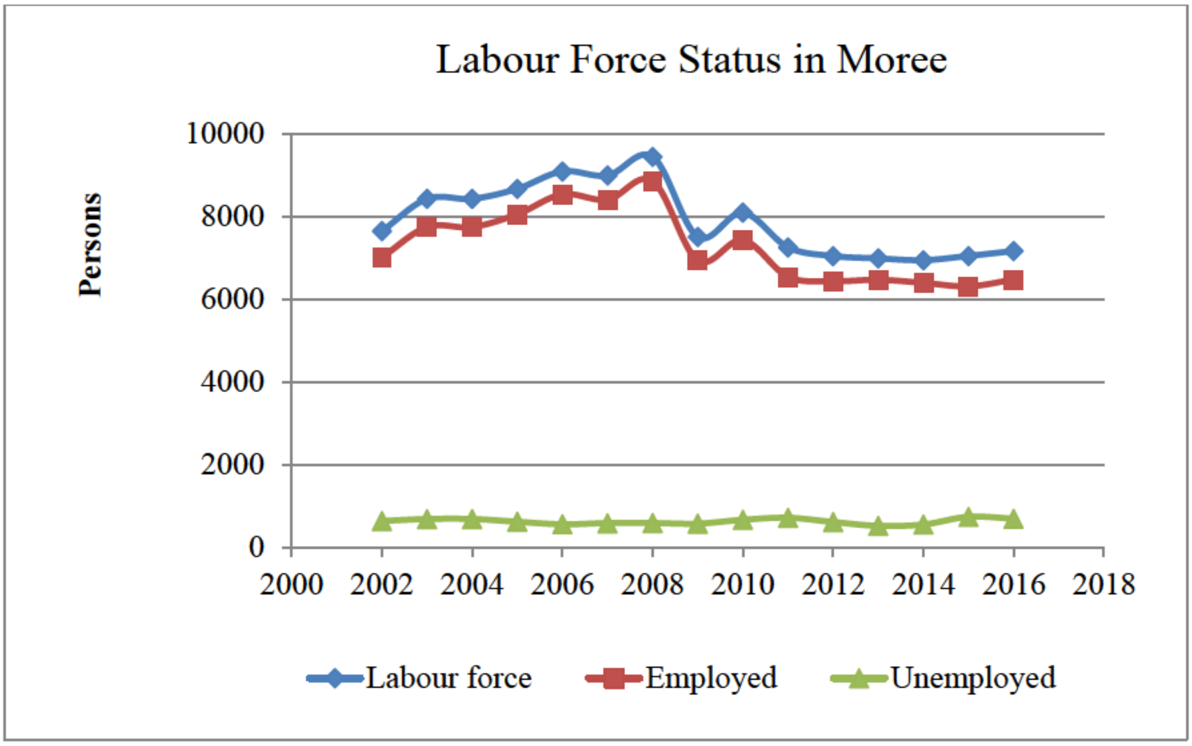
Table 30: Labour Force Status in Moree

Year	Labour force	Employed	Unemployed	Unemployment rate
2002	7639	7005	634	8.3
2003	8420	7738	682	8.1
2004	8420	7738	682	8.1
2005	8662	8047	615	7.1
2006	9082	8528	554	6.1
2007	8985	8401	584	6.5
2008	9435	8850	585	6.2
2009	7500	6930	570	7.6
2010	8085	7422	663	8.2
2011	7248	6536	712	9.8
2012	7038	6429	609	8.6
2013	6980	6463	517	7.4
2014	6938	6389	549	7.9
2015	7040	6305	736	10.5
2016	7158	6468	690	9.6

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001 for period 2002-2010 Department of Employment: Small Area Labour Markets for period 2011-2016

Table 30 shows number of persons employed in main industries in Moree Plains between 1996 and 2011. The Agriculture, Forestry and Fishing, and Wholesale and Retail trade are the main industries in the region. Between 1996 and 2011, employment in these industries decreased. Employment in Education and Training industry experienced a slightly growing trend over the period 1996-2011 (Figure 27). Employment in Heath Care and Social Assistance industry fluctuated and increased slightly between 1996 and 2011.

Figure 26: Trend in the labour force in Moree Plains



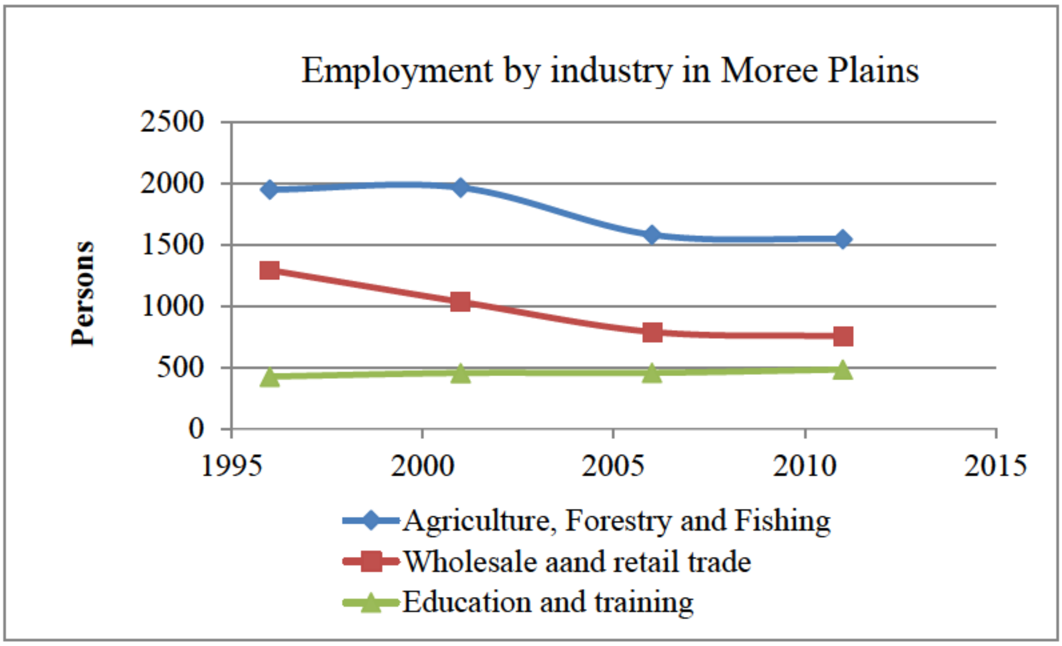
Source: ABS, National Regional Profile, cat. No. 1379.0.55.001 for period 2002-2010 Department of Employment: Small Area Labour Markets for period 2011-2016

Table 31: Number of persons employed by main industry in Moree Plains

Industry	1996	2001	2006	2011
Agriculture, Forestry and Fishing	1946	1962	1579	1544
Manufacturing	268	350	289	282
Construction	286	383	401	347
Wholesale and retail trade	1291	1033	789	754
Accommodation and food services	299	394	319	323
Public administration and safety	374	397	368	377
Education and training	426	455	456	483
Health care and social assistance	473	445	491	486

Source: ABS, Census Community Profiles

Figure 27: Employment by industry in Moree Plains

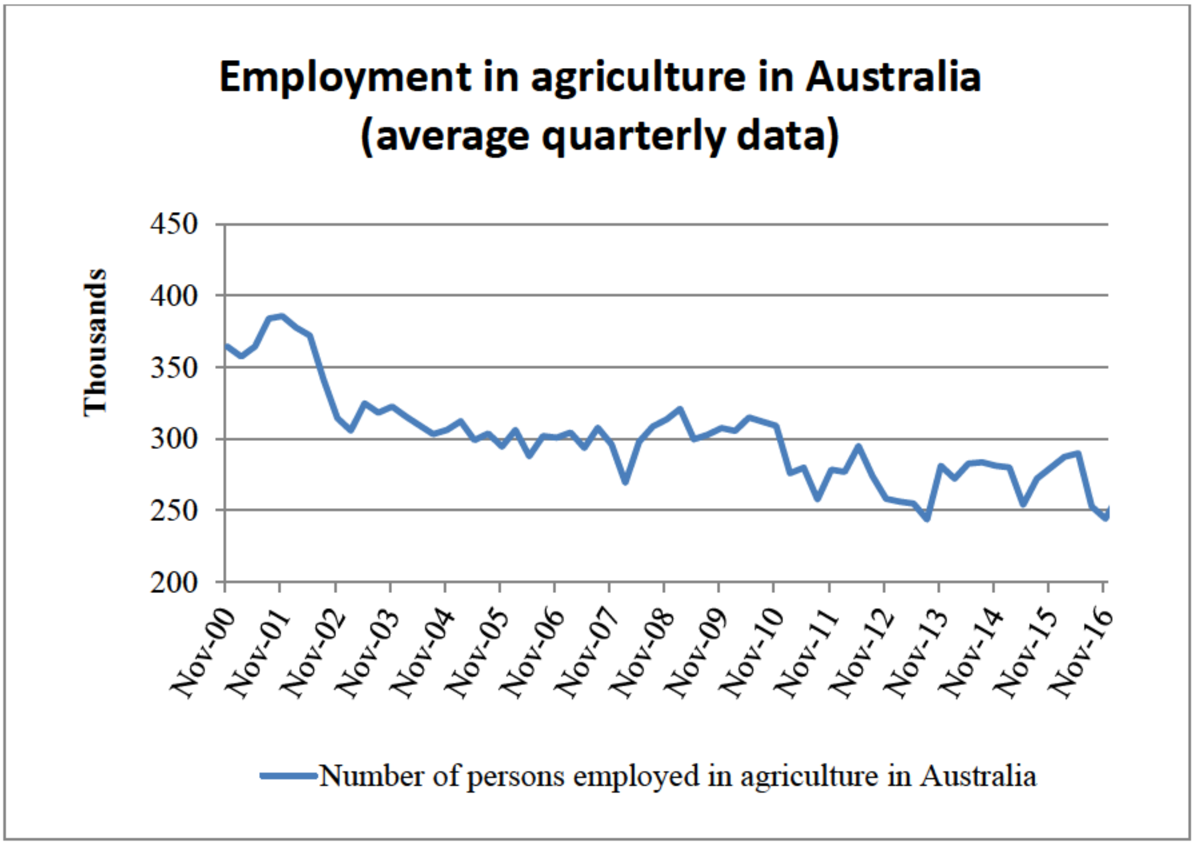


Source: ABS, Census Community Profiles

Drivers of population and employment changes in Moree Plains

Agricultural production is the primary industry of the Moree Plains region. In the last two decades, there was a switch in agricultural production from crops towards sheep and beef farming that requires less labour inputs. This has contributed to a decreasing trend in population and employment in agriculture sector in Moree Plains along with a series of droughts which started in 2003 that has severely affected agriculture industry in the region, and also as the result of mechanization process and a general national downward trend in employment in agriculture (Figure 28). Between 2001 and 2006, Moree Plains was recorded to have the largest population decline of any local government area in inland New South Wales.

Figure 28: National trend in employment in agriculture in Australia



Source: Labour Force, Australia, Detailed, Quarterly, Cat. No. 6291.0.55.003

Income

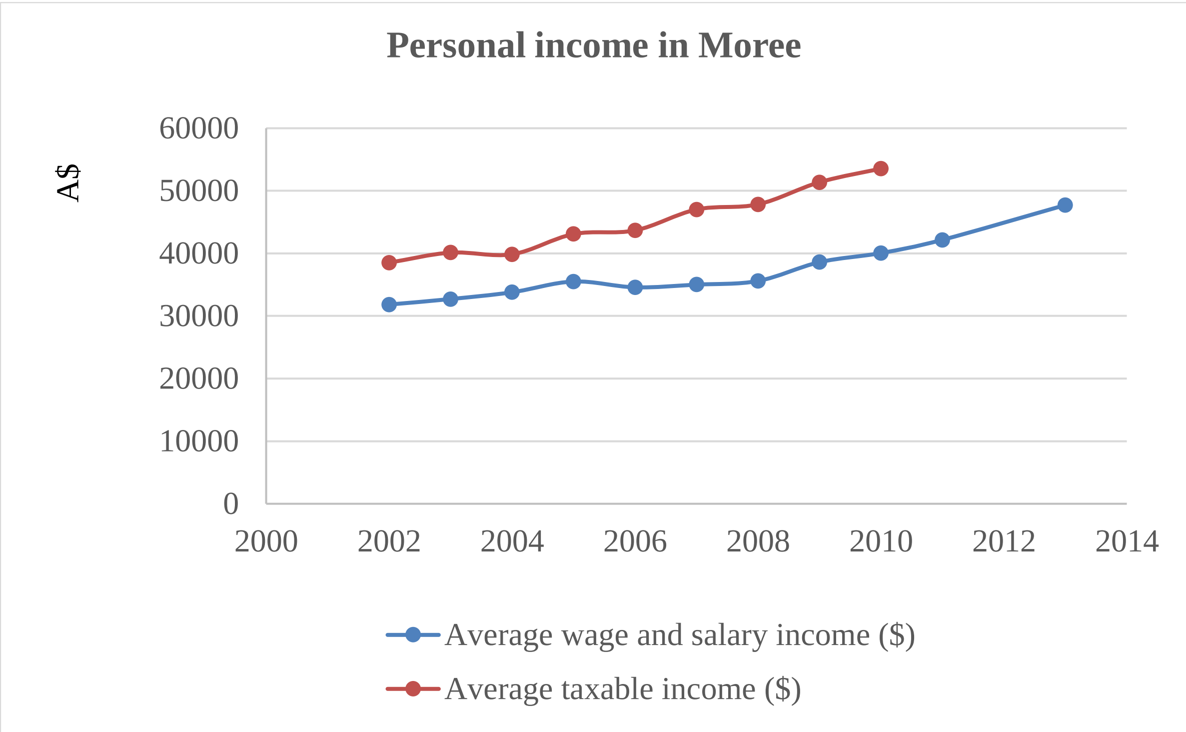
Table 31 and Figure 29 represent the estimates of personal income in Moree. There has been an increasing trend in both average wage and salary income and average taxable income as well as total taxable income in Moree over the period 2002-2013. In 2010, the average taxable income in Moree was $53,536 and the total taxable income was $271.1 million. Between 2002 and 2013, the average income from wage and salary in Moree Plains increased by 50%; while nationally the increase was 65%.

Table 32: Estimates of personal income in Moree Plains

Year	Average wage and salary income ($)	Average taxable income ($)	Total taxable income ($m)
2002	31830	38522	246
2003	32707	40124	`.3235.8
2004	33790	39858	227.5
2005	35509	43090	256
2006	34582	43675	258.6
2007	35011	47017	261.2
2008	35595	47837	261.4
2009	38597	51373	268
2010	40056	53536	271.1
2011	42168		
2013	47720		

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 29: Trend in personal income in Moree



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Agricultural production

As Table 32 shows, crops accounted for about 90% of agricultural production in Moree, with the total value of agricultural production in Moree increasing from $513.5 million in 2001 to $912 million in 2011. The value of crops production increased steadily from $466 million in 2001 to $473 million in 2006 and reached $868 million in 2011; while the value of livestock slaughtering increased between 2001 and 2006, but decreased between 2006 and 2011. Although number of people employed in agriculture in Moree was less in 2006 and 2011 compared to 2001, the value of agricultural production increased over the period as the result of the increase in productivity in agricultural production and also the increase in price of agricultural commodities.

Table 33: Gross value of agricultural production in Moree

Gross value of agricultural production ($m)	2001	2006	2011
Gross value of crops	465.6	473.2	868.4
Gross value of livestock slaughtering	39.9	54.6	36.3
Gross value of livestock products	7.9	4.7	7.3
Total gross value of agricultural production	**513.5**	**532.5**	**912**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001, Agriculture Census 2011

2.5.4 Greater Shepparton

Population

Greater Shepparton is a local government area in the Hume region of Victoria, located in the north-east part of the state. It covers an area of 2,422 square kilometres. In 2015, the population of Shepparton was 63,366. Shepparton's main industries are agriculture and associated manufacturing. Table 33 reports the population in Shepparton between 2000 and 2015. It shows that between 2000 and 2015, Shepparton population increased by about 11% from 57,211 to 63,366. Population density in Shepparton increased from 23.6 persons/km^2 in 2000 to 26,2 persons/km^2 in 2015. Working age group accounted for about 63% of the Shepparton population. The proportion of indigenous community increased from 2.8% in 2001 to 3.5% in 2011.

Table 34: Population in Greater Shepparton between 2000 and 2015

Year	Population	Male	Female	Working age population (% of total)	Population density (persons/km2)	Indigenous community (%)
2000	57211	28502	28709	64.4	23.6	
2001	58150	28952	29198	64.5	24.0	2.8
2002	58830	29305	29525	64.8	24.3	
2003	59517	29649	29868	64.9	24.6	
2004	58687	29255	29432	64.4	24.2	
2005	58829	29323	29506	64.5	24.3	
2006	59427	29640	29787	64.6	24.5	3.3
2007	60162	29962	30200	64.8	24.8	
2008	60383	30166	30217	64.6	24.9	
2009	60758	30406	30352	64.4	25.1	
2010	61443	30768	30675	64.2	25.4	
2011	61744	30986	30758	63.9	25.5	3.5
2012	62379	31281	31098	64.0	25.8	
2013	62784	31480	31304	63.7	25.9	
2014	63131	31565	31566	63.5	26.1	
2015	63366	31649	31717	63.3	26.2	

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region

Employment

Table 34 reports the employment status in Shepparton between 2002 and 2016. In 2006, the unemployment rate was 7.1% which was significantly higher than the average MDB level of 5%. In 2011, Shepparton unemployment rate remained at a high level of 7.7 which was well above the average MDB level of 4.7%. However, the town’s unemployment rate reduced to 5.7% in 2016.

Table 35: Labour force in Greater Shepparton

Year	Labour force	Unemployed	Unemployment rate
2002	28864	1905	6.6
2003	29291	1611	5.5
2004	30250	1694	5.6
2005	30817	1849	6
2006	31338	2225	7.1
2007	31625	1518	4.8
2008	31765	1620	5.1
2009	27125	1519	5.6
2010	30228	2388	7.9
2011	30120	2308	7.7
2012	30531	2355	7.7
2013	30981	1834	5.9
2014	30220	2316	7.7
2015	32322	2398	7.4
2016	33973	1933	5.7

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001 for period 2002-2010 Department of Employment: Small Area Labour Markets for period 2011-2016

Table 35 reports the number of employed persons by industry in Greater Shepparton between 2001 and 2015. Although employment in Shepparton slightly decreased in 2008 and 2009, there was an increasing trend in the number of persons employed over the period 2001-2015 (Figure 30). The total employment in Greater Shepparton increased from 26,743 in 2000-01 to 30,012 in 2014-15.

Table 36: Employment by industry in Shepparton

Year	Employment by industry in Shepparton									
	Agriculture	Manufacturing	Construction	Transport, Postal and warehousing	Wholesale and retail trade	Public administration and Safety	Education and training	Health care and social assistance	Others	Total
2001	3177	3404	1794	1044	5455	747	1592	2963	6567	26743
2002	3243	3469	1936	1114	5387	839	1654	2882	6133	26657
2003	2507	3423	2043	1080	5802	949	1722	3044	6754	27324
2004	2194	3248	2016	1240	5808	1162	2052	3197	7328	28245
2005	2205	3570	2180	1356	5879	1315	2135	3169	7500	29309
2006	2232	4355	2430	1176	5824	1181	1969	3172	7030	29369
2007	2224	4506	2617	1044	5416	1261	2177	3587	6860	29692
2008	2459	4065	2487	1137	4873	1396	2428	4060	6687	29592
2009	2855	3782	2343	1123	4695	1306	2228	4111	6690	29133
2010	2846	3723	2610	1114	4865	1234	2161	4100	6866	29519
2011	2609	4049	2547	1293	5039	1192	2243	4061	7019	30052
2012	2472	4068	2461	1443	4949	1273	2455	4092	7196	30409
2013	2745	3593	2397	1324	4805	1401	2656	4089	7322	30332
2014	2810	3105	2201	1599	5078	1270	2435	4062	7448	30008
2015	2518	3220	2175	1993	5176	1158	2100	4094	7578	30012

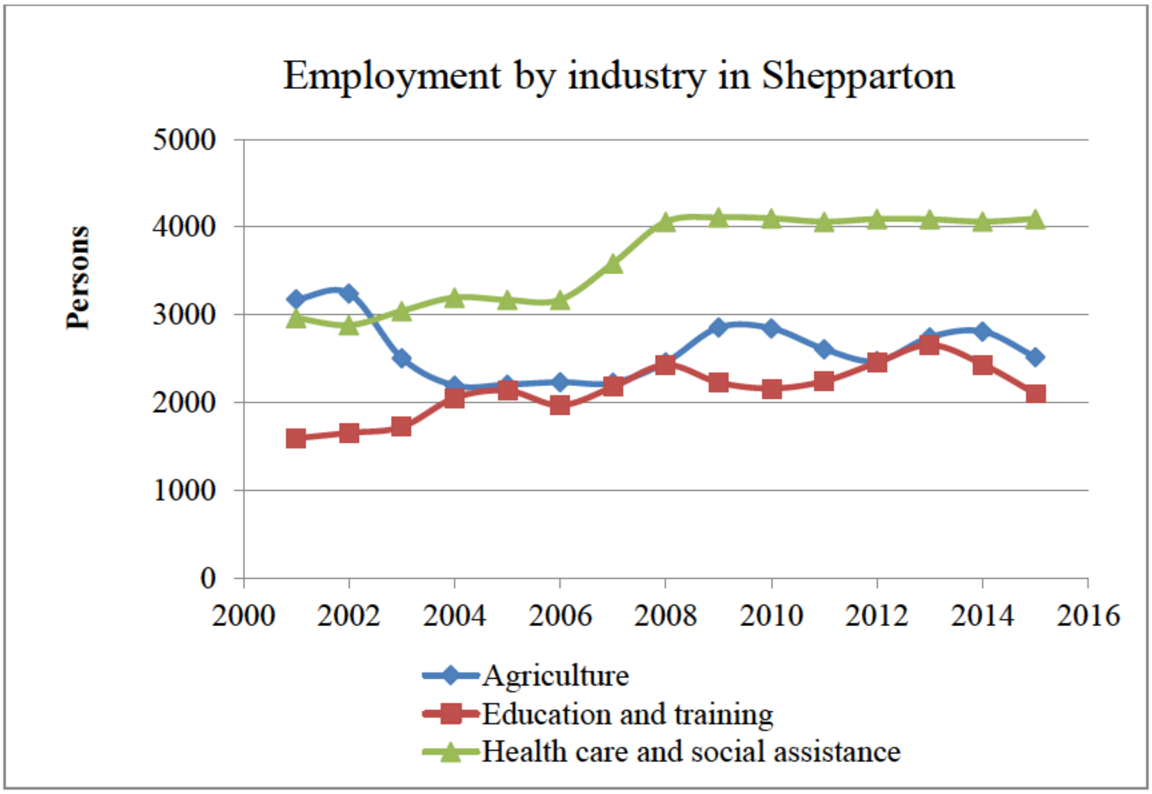
Source: City of Greater Shepparton, Employment Report, 2016

Figure 30: Employment in Greater Shepparton

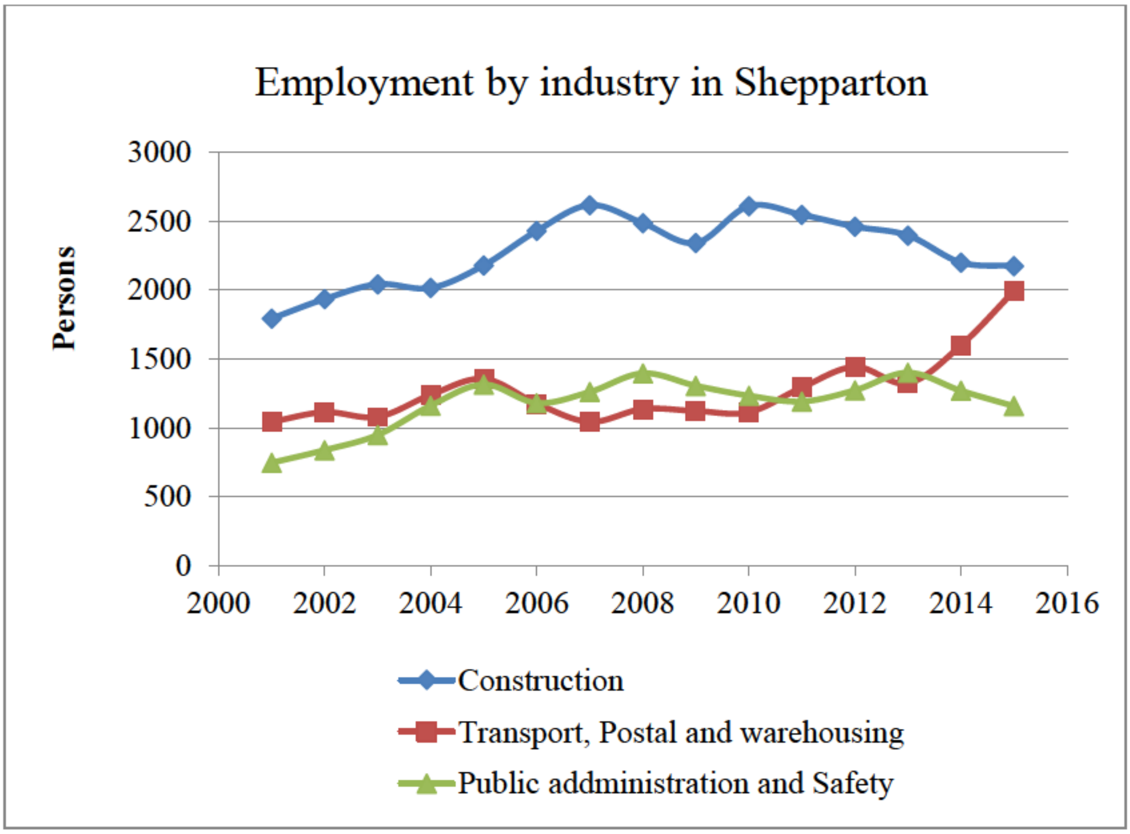
Source: City of Greater Shepparton, Employment Report, 2016

In Shepparton, Agriculture, Manufacturing, Wholesale and Retail trade and Health Care and Social Assistance are the four largest industries. In 2015, these industries accounted for more than 50% of the total employment in the region. Between 2001 and 2015, employment in agriculture and manufacturing industries fluctuated and decreased from about 6,500 in 2001 to 5,700 in 2015; while there was a significant increase in the number of persons employed in Health Care and Social Assistance industry. Other industries experienced a large increase in employment including Education and Training; Construction; Transport, Postal and Warehousing; and Public Administration and Safety (Figure 31).

Figure 31: Employment by industry in Greater Shepparton



(a) Source: City of Greater Shepparton, Employment Report, 2016



(b) Source: City of Greater Shepparton, Employment Report, 2016

Drivers of population and employment changes in Shepparton

The most important industry sectors in Greater Shepparton are: Agriculture; Health Care and Social Assistance; Wholesale and Retail Trade; Manufacturing; Education and Training; Construction; Transport, Postal and Warehousing; and Public Administration and Safety. More than 75% of the employment in the Greater Shepparton is employed in these industries. Increase in the population in the region was mainly associated with employment growth in these industries. Over the period 2001-2015, there was an increase in government investment in public administration and services that increased employment in the public services sector. Between 2006 and 2011 there has also been an increase in retirees moving to the City as a number of new ‘lifestyle villages’ were constructed in the region. Over the period 2003-2013, reduction in the employment in agriculture industry was caused by the consolidation of agriculture industry (City of Greater Shepparton, 2015).

New employment opportunities in the region that would spur population growth in the region include the Shepparton Bypass project, the road-rail interchange at Mooroopna and additional production jobs at Unilever in Tatura. Significant housing development opportunities have been identified in fringe areas in Shepparton that will contribute to Shepparton’s population growth.

Income

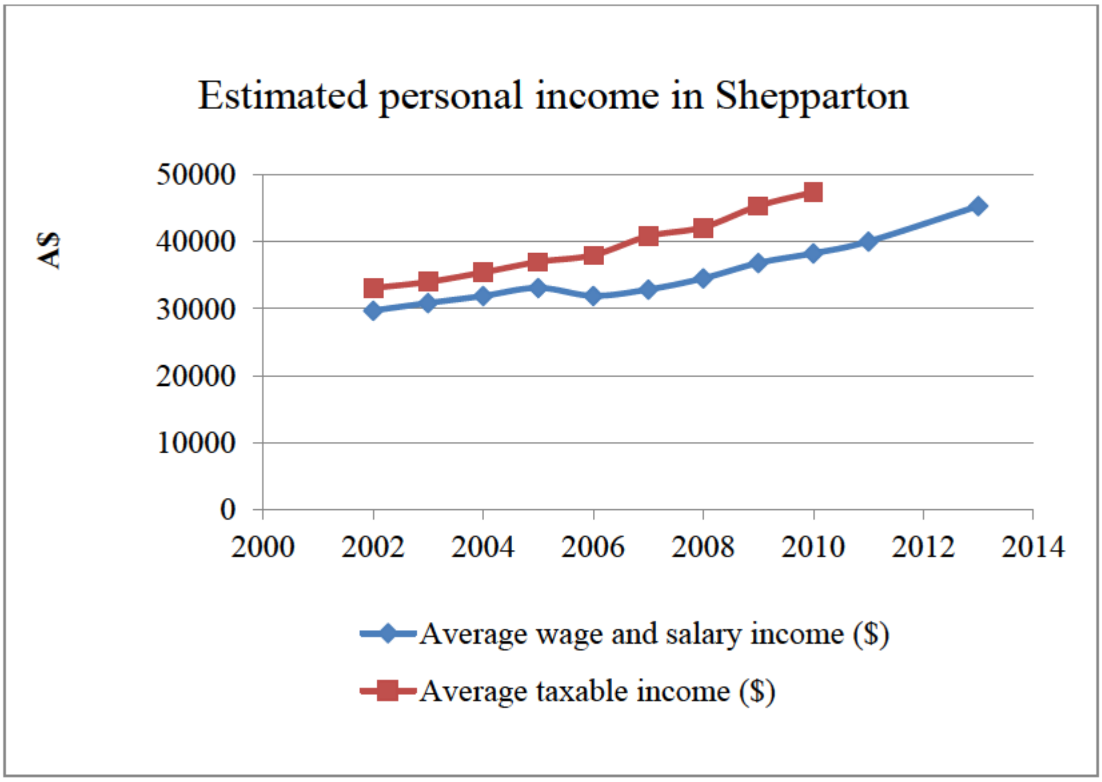
Table 36 and Figure 32 represent the estimates of personal income in Shepparton. Average wage and salary income as well as average taxable income increased steadily over the period 2002-2013. In 2010, the average taxable income in Shepparton was $47,396 and the total taxable income was $1125.6 million. The average income from wage and salary in Shepparton increased by 52% between 2002 and 2013; which was 13 percent less than the national income growth rate.

Table 37: Estimates of personal income in Shepparton

Year	Average wage and salary income ($)	Average taxable income ($)	Total taxable income ($m)
2002	29737	33100	822.1
2003	30858	34005	848.3
2004	31908	35428	896.1
2005	33120	36997	963.8
2006	31937	38010	1018.4
2007	32877	40833	1041.4
2008	34541	42170	1092
2009	36833	45346	1083.4
2010	38281	47396	1125.6
2011	40050		
2013	45334		

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 32: Estimates of personal income in Shepparton



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Agricultural production

Table 37 reports the gross value of agricultural production in Shepparton in 2001, 2006 and 2011. It shows that the value of agricultural production in Shepparton increased from $412 million in 2001 to $620 million in 2011. Crops accounted for 70% of total agricultural production in the region in 2011. The gross value of crops increased from $207 million to $432 million between 2001 and 2011.

Table 38: Gross value of agricultural production in Shepparton

Gross value of agricultural production ($m)	2001	2006	2011
Gross value of crops	207	280.4	432.2
Gross value of livestock slaughtering	57.3	62	60.9
Gross value of livestock products	147.7	144.4	126.7
Total gross value of agricultural production	**411.9**	**486.8**	**619.8**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001, Value of Agricultural Commodities Produce 2010-2011

2.5.5 Renmark Paringa

Population

Renmark Paringa is a local government area in the South Australia's rural Riverland area. It covers an area of land of 915 km^2. The agriculture industry is the largest employer in the area. The region grows about half of South Australia's grapes, and 90% of the citrus and stone fruit. Most major Australian wine companies source a significant amount of bulk wine from the Riverland. The Riverland is also a significant almond growing region.

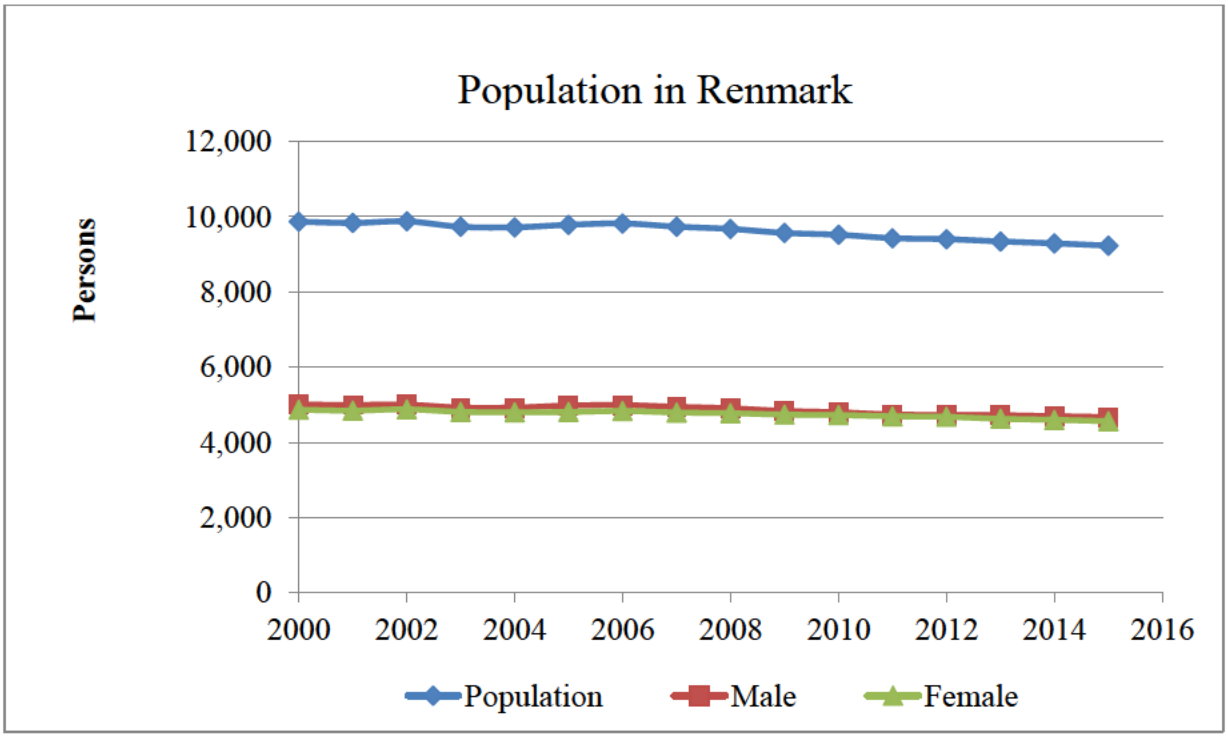
Table 38 and Figure 33 report the population in Renmark between 2000 and 2015. The Figure shows that there was a decreasing trend in Renmark population between 2000 and 2015. Renmark population decreased by 6.4% from 9,866 in 2000 to 9,230 in 2015. Renmark population density decreased from 10.8 persons/km^2 in 2000 to 10.1 persons/km^2 in 2015. During the period 2000-2015, working age population accounted for about 63-64% of the Renmark population. The population share of indigenous community decreased from 2.3% in 2001 to 1.8% in 2011.

Table 39: Population in Renmark

Year	Population	Mal e	Female	Working age population (% of total)	Population density (persons/km2)	Indigenous community (%)
2000	9866	5001	4865	64.3	10.8	
2001	9834	4992	4842	64.4	10.7	2.3
2002	9875	4999	4876	64.4	10.8	
2003	9731	4922	4809	64.1	10.6	
2004	9718	4922	4796	63.6	10.6	
2005	9783	4977	4806	64.1	10.7	
2006	9820	4988	4832	63.6	10.7	2.2
2007	9734	4942	4792	64.0	10.6	
2008	9674	4902	4772	64.5	10.6	
2009	9567	4832	4735	64.8	10.5	
2010	9519	4797	4722	64.6	10.4	
2011	9429	4738	4691	65.0	10.3	1.8
2012	9402	4727	4675	64.3	10.3	
2013	9346	4721	4625	63.9	10.2	
2014	9290	4693	4597	63.4	10.1	
2015	9230	4669	4561	62.9	10.1	

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region

Figure 33: Trend in Renmark population



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Employment

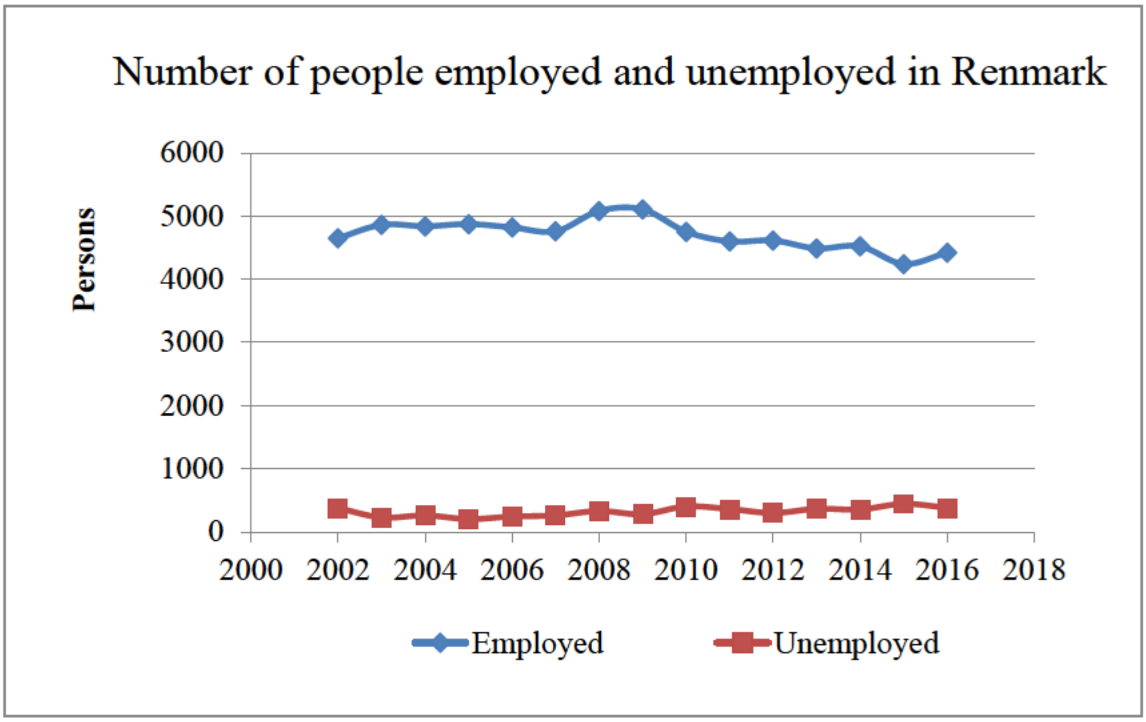
Table 39 and Figure 34 report the labour force status in Renmark. Between 2002 and 2007, the labour force as well as the number of employed and unemployed people remained stable. The number of persons employed decreased between 2010 and 2016 that matched the downward trend in Renmark population. The unemployment rate in Renmark in 2006 was slightly less than the average unemployment rate in the basin, but Renmark unemployment rate in 2011 was higher than the average of MDB unemployment rate.

Table 40: Labour force status in Renmark

Year	Labour force	Employed	Unemployed	Unemployment rate	Unemployment rate in MDB
2002	5027	4650	377	7.5	
2003	5089	4860	229	4.5	
2004	5098	4838	260	5.1	
2005	5075	4872	203	4.0	
2006	5063	4820	243	4.8	5.0
2007	5019	4758	261	5.2	
2008	5410	5080	330	6.1	
2009	5385	5105	280	5.2	
2010	5154	4752	402	7.8	
2011	4961	4599	362	7.3	4.7
2012	4911	4611	300	6.1	
2013	4853	4487	365	7.5	
2014	4875	4520	355	7.3	
2015	4685	4241	444	9.5	
2016	4802	4420	382	8.0	

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 34: Number of people employed and unemployed in Renmark



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Table 40 reports the number of businesses in Renmark between 2003 and 2013. The total number of businesses in Renmark fluctuated with a growing trend between 2003 and 2007. However, the number of businesses in Renmark decreased between 2011 and 2015. Agriculture, Forestry and Fishing is the main industry in the region. There was a downward trend in the number of businesses in this industry over the period. In 2002, Agriculture, Forestry and Fishing accounted for about 58% of the number of businesses; in 2015 this industry accounted for 44% of the number of businesses in the region. Construction and Health Care and Social Assistance are growing industries in the region.

Table 41: Number of businesses in Renmark

Industry	2003	2004	2005	2006	2007	2011	2012	2013	2014	2015
Agriculture, Forestry and Fishing	570	552	558	552	525	455	438	432	423	406
Manufacturing	51	54	48	45	45	34	34	30	29	29
Construction	57	60	81	78	90	104	108	112	95	94
Retail trade	84	93	93	96	99	55	54	52	50	52
Transport, postal and warehousing	45	39	45	36	45	39	38	39	43	44
Education and training	0	0	0	3	3	3	3	3	0	3
Health care and social assistance	15	15	18	15	21	22	24	22	22	19
Others	153	150	180	192	204	295	291	275	268	272
Total (no.)	**975**	**963**	**1023**	**1017**	**1032**	**1007**	**990**	**965**	**930**	**919**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; Data By Region

Drivers of population and employment changes in Renmark Paringa

The agriculture industry accounted for 18% of the total employment in Renmark Paringa in 2011 (Census, 2011). Situated in the Riverland, which produces approximately 60% of the volume of the South Australia's Wine each year, the economy of Renmark Paringa is heavily reliant on irrigated orchards and vineyards. Due to the downturn of the grapes wine market started in 2007-08 with a sharp reduction in grapes price from $546 per tonne in 2007-08 to $369 per tonne in 2008-2009, with the price remaining at low levels thereafter, grapes production in Renmark Paringa experienced a downward trend between 2009 and 2013. The downturn of the grapes market, combined with a period of prolonged drought and the operation of the Small Block Irrigators Exit Grant started in 2008 contributed to the reduction of population and employment in Renmark Paringa. Other factors contributed to the outflow migration of population in Renmark include the contraction in manufacturing and retail trade sectors. There were 25 manufacturing companies and 41 retail trade companies were shut down between 2004 and 2015 in Renmark.

Income

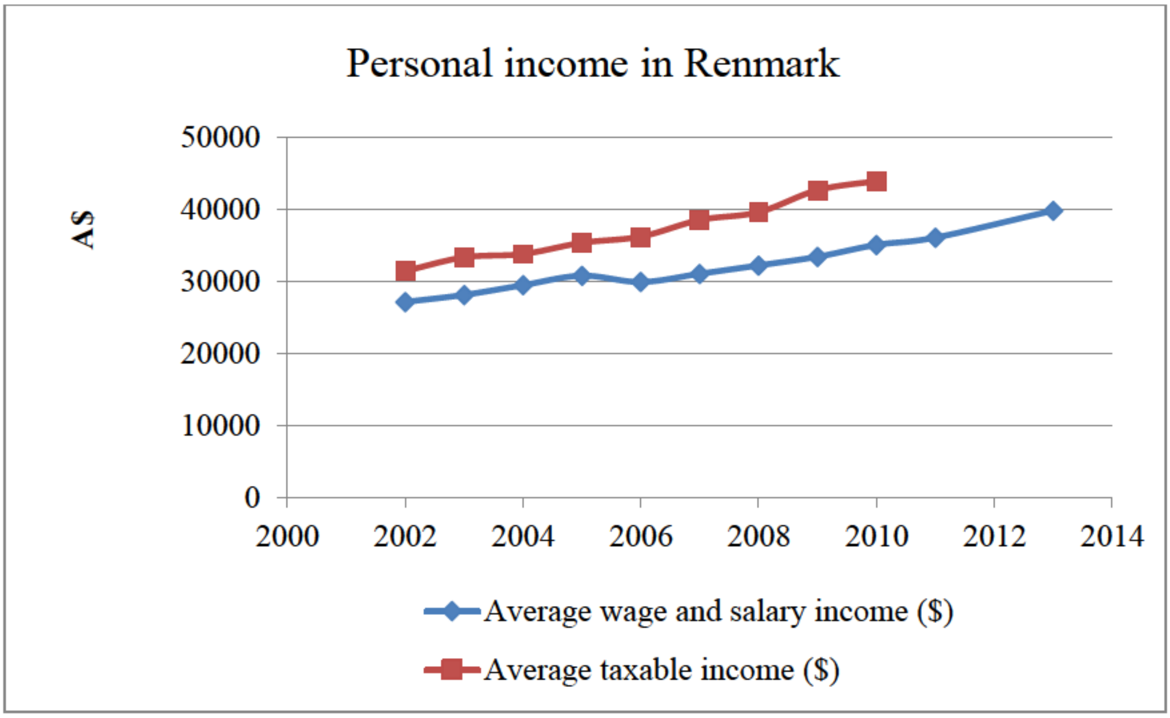
Table 41 and Figure 35 represent the estimates of personal income in Renmark. The average wage and salary income, as well as the average taxable income, increased steadily over the period 2002-2010. However, as the result of the reduction in the number of persons employed, total taxable income decreased in 2010. In 2010, the average taxable income in Renmark was $43,961 and the total taxable income was $158.9 million. The growth rate of wage and salary income in Renmark between 2002 and 2013 (47%) was less than the national growth rate (65%).

Table 42: Personal income in Renmark

Year	Average wage and salary income ($)	Average taxable income ($)	Total taxable income ($m)
2002	27214	31501	131.3
2003	28187	33401	143.4
2004	29538	33868	143.4
2005	30853	35420	152.4
2006	29982	36284	154.7
2007	31121	38585	155.4
2008	32281	39678	161.8
2009	33486	42736	165.3
2010	35133	43961	158.9
2011	36145		
2013	39889		

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 35: Personal income in Renmark



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Agricultural production

Table 42 reports the gross value of agricultural production in Renmark in 2001, 2006 and 2011. Crops accounted for nearly 100% of agricultural production in Renmark. The Table shows that value of agricultural production in Renmark decreased from $206 million in 2001 to $183 million in 2006, and a further reduction to $141 million in 2011.

Table 43: Gross value of agricultural production in Renmark

Gross value of agricultural production ($m)	2001	2006	2011
Gross value of crops	205.3	182.3	138
Gross value of livestock slaughtering	0.2	0.3	1
Gross value of livestock products	0.6	0.6	1
Total gross value of agricultural production	**206.2**	**183.1**	**141**

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

2.5.6 Comparison of incomes and employment between local towns and national level

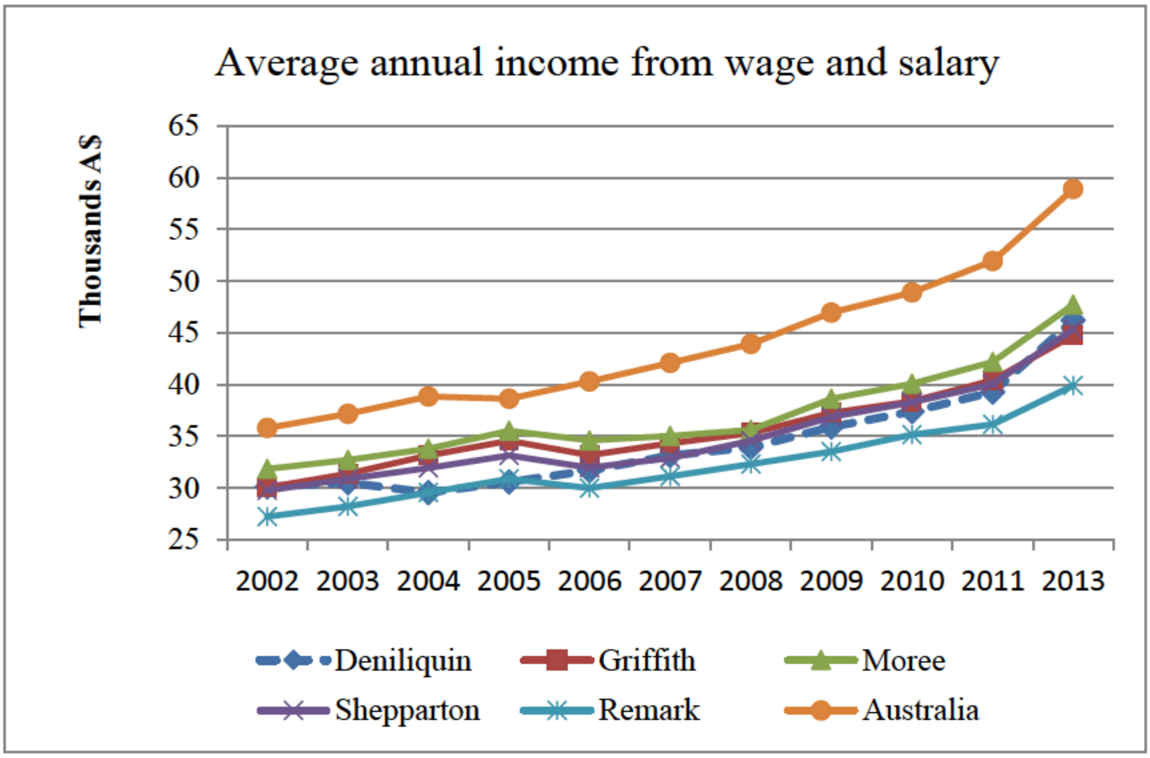
Table 43 and Figure 36 compare the average income from wage and salary for the five local towns examined above to the national level. The average incomes from wage and salary in the five towns are significantly less than the national average level. In 2013, the average income from wage and salary in Deniliquin, Griffith, Moree, and Shepparton was between $44,000 and $48,000; while the national average level was more than $58,000. Average income in Renmark was $40,000 in 2013.

Table 44: Comparison of average income between local towns and national level

Year	Average annual income from wage and salary (A$)					
	Deniliquin	Griffith	Moree	Shepparton	Remark	Australia
2002	30094	30028	31830	29737	27214	35782
2003	30486	31362	32707	30858	28187	37144
2004	29542	33125	33790	31908	29538	38820
2005	30545	34555	35509	33120	30853	38607
2006	31682	33158	34582	31937	29982	40276
2007	33119	34316	35011	32877	31121	42081
2008	33911	35310	35595	34541	32281	43921
2009	35873	37243	38597	36833	33486	46949
2010	37364	38359	40056	38281	35133	48907
2011	39252	40421	42168	40050	36145	51923
2013	46214	44764	47720	45334	39889	58893

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Figure 36: Comparison of average income between local towns and national level



Source: ABS, National Regional Profile, cat. No. 1379.0.55.001

Table 44 compares the unemployment rates of the five local towns to the national level over the period 2002-2016. The unemployment rates in Deniliquin and Griffith appear to be lower than the national level; while for most of the years unemployment rates in Moree, Shepparton and Renmark were higher than the national average.

Table 45: Comparison of unemployment rate between local towns and national level

Year	Unemployment rate					
	Deniliquin	Griffith	Moree	Shepparton	Remark	Australia
2002	4.6	4.6	8.3	6.6	7.5	6.4
2003	4.9	4.6	8.1	5.5	4.5	5.9
2004	4.4	3.7	8.1	5.6	5.1	5.4
2005	5.1	4.3	7.1	6.0	4	5.0
2006	6.1	5.5	6.1	7.1	4.8	4.8
2007	4.0	3.8	6.5	4.8	5.2	4.4
2008	4.0	3.7	6.2	5.1	6.1	4.2
2009	6.0	5	7.6	5.6	5.2	5.6
2010	5.7	5.5	8.2	7.9	7.8	5.2
2011	4.6	7.4	9.8	7.7	7.3	5.1
2012		5.4	8.6	7.7	6.1	5.2
2013		5.9	7.4	5.9	7.5	5.7
2014		5.4	7.9	7.7	7.3	6.1
2015		4.5	10.5	7.4	9.5	6.1
2016		3.6	9.6	5.7	8.0	5.7

Source: ABS, National Regional Profile, cat. No. 1379.0.55.001; World Bank

3 Effects of water reforms on key social-economic indicators in the basin

In this section we analyse the effects of water reforms in the MDB based on the data available as at June 2016 using a series of linear regression models. The dependent variables are:

- gross value of irrigated agricultural production (GVIAP) and gross value of agricultural production (GVAP) in the MDB in fixed price (price prevailed in 1997-98) ($ million);
- total area irrigated in the MDB (000 ha)

- water use efficiency of irrigated agricultural production in the MDB defined as the value of production in fixed price (price prevailed in 1997-98) per ML of water used ($/ML);
- number of irrigating agricultural businesses and total number of agricultural businesses;
- total water extraction for consumptive use in the MDB (GL) and;
- water allocation price (extracted from the Murray Irrigation) ($A/ML).

Explanatory variables grouped into three categories:

- variables related to water reform
  - water entitlements recovered through buybacks and infrastructure investment (GL)
  - Water allocation price (extracted from Murray Irrigation) (A$/ML)
- variables related to commodity prices
  - agricultural commodity producer price indexes (aggregated for all crops and aggregated for all agriculture products with reference year 1997-98 =100)
  - input prices (fertilizer price index, electricity price index, chemical price index, interest rate index, etc.) (reference year 1997-98 =100)
- variables related to water availability
  - dummy variables for the year 2006-07 and 2008-09 to capture the effects of the Millennium Drought in 2006-07 and 2008-09 which are the most severe years of drought
  - water allocation volume in the MDB (GL)
  - water storage at the end of the year in the MDB (GL)

We estimated linear regression models using the Ordinary Least Squares (OSL) method. For every model we undertook a diagnostic test for stationarity of the error terms of the model to check for spurious regressions; i.e. apparent correlations between dependent and explanatory variables that are not causally related to each other. We found that the error terms are stationary. The LM test and the Ljung–Box statistics also find no evidence of autocorrelation in error terms of the model where we test for AR(1) in Ljung–Box and LM tests. These diagnostic results imply that the results are non-spurious.

These results are subject to caveats in terms of the availability and the quality of the data used. We only have 10-15 years of data available so the accuracy of the estimated effects and relevant tests is restricted. While the tests for significance take account of the data limitations, it is still best to treat these results as indicative rather than definite. All results were reported at a basin scale and do not necessarily reflect local trends.

3.1 Factors affecting agricultural production in the MDB

As rainfall level is a crucial factor for agricultural production and rainfalls are unevenly distributed in time and spaces over the MDB, a detailed analysis at local areas and/or seasonal data is ideal. However, due to limitation regarding data availability and time frame of this research, we focused our analysis on aggregated level for annual data over the MDB.

We acknowledge that agricultural production might be affected by a range of factors such as government policies before the Water Act in 2007 and different years of drought over the period 2001-2015. However, with our data limitation where the data is only available between 10 and 15 years, the inclusion of a full set of explanatory variables is impossible. Therefore, we focused on analysing the effects recent policy-relevant factors and the most severe years of drought. We examined the relationship between GVIAP, GVAP and four factors: agricultural commodity producer price indexes (annual average, aggregated for all crops in model of GVIAP and aggregated for all agricultural products in model of GVAP); water allocation price (A$/ML); the amount of water recovery (GL) under the government water buy-back program and the infrastructure water efficiency improvement program as established in the Water Act in 2007. We included a dummy variable for the years 2006-07, 2007-08 and 2008-09 in the model of GVIAP to capture the effects of severe years of the Millennium Drought in 2006-07, 2007-08 and 2008-09. However, this dummy variable is not significant in the model of GVAP, therefore in the model of GVAP we included a dummy variable for only the year 2006-07 which is the most severe year of the Millennium Drought (Table 45). We also tested for the effect of other input prices including fertiliser, electricity, chemicals, wages, and interest rate index. As we did not find significant effects of these latter variables, we dropped these variables from the estimated models.

The results indicate that an increase in agricultural commodity price index of 1 percentage point will increase GVIAP and GVAP in the MDB by 0.8% and 0.6%, respectively. The effects of the Millennium Drought was negative and significant. The drought in period 2006-09 reduced the GVIAP by 23%; while the drought in 2006-07 reduced the GVAP by 18%. The effect of drought was larger for GVIAP than for GVAP. This could be explained by the number of irrigated agricultural businesses that closed after the severe drought in 2006-07 and the continuing dry conditions in the MDB between 2007 and 2009; while non-irrigated agriculture industry might have diversified production to adapt to the dry conditions and rely less on water availability.

The effects of water price on GVIAP and GVAP are negative and significant. An increase in water allocation price of $10 per ML (which is about 8.5% of the water allocation price in 2014-15) will reduce gross value of irrigated agricultural production by 0.6% and reduce gross value of agricultural production by 0.5%. The effect of water recovery was found to be negative and significant in the model of GVIAP; this effect was negative but insignificant in the model of GVAP. An increase of 10 GL in water recovery will reduce GVIAP by 0.4%.

Table 46: Factors affecting GVIAP and GVAP in the MDB

	Log of gross value of irrigated agricultural production (1997-98 $ million)	Log of gross value of agricultural production (1997-98 $ million)
Agricultural commodity Producer price index	0.008*	0.006**
Dummy variable for years 2006-07, 2007-08, 2008-09	-0.23**	
Dummy variable for years 2006-07		-0.18**
Water allocation price ($/ML)	-0.0006*	-0.0005**
Water recovery from buybacks & infrastructure (GL)	-0.0004*	-0.0003
Constant	7.66***	8.78***
N	10	11
Test for overall significant of the model	F=10.3 (p=0.012)	F=13.4 (p=0.004)
Ljung–Box statistics to test for AR(1)	Q=1.51 (p=0.219)	Q=1.37 (0.241)

Note: *,**,*** indicate statistical significance at the 10%, 5%, and 1% significance level respectively.

3.2 Factors affecting area irrigated in the MDB

We examined the effects of five factors on the total area irrigated in the MDB: agricultural commodity producer price indexes (aggregated for all crops); a dummy variable taking value 1 for the period 2007-2015 and taking value 0 for the period 2001-2007 to capture the effect of farmers' adjustment after the serve drought in 2006-07; water allocation price (A$/ML); water allocation announcement (GL); and the amount of water recovery (GL). The results show that all of these five factors have significant effects on the total area irrigated in the MDB. An increase in price of crop products significantly increases the area of land irrigated. As the result of farmers' adjustment to the severe drought in 2006-07 and the continuing dry condition thereafter, on average, total irrigated land was reduced by 365,000 ha per year in the period 2007-2015 compared to the period 2001-2006. Holding other factors in the model unchanged, a $10 increase in water allocation price will reduce the area irrigated by 13,000 ha; an increase of 1 GL in water recovery will reduce the total area irrigated by about 800 ha; while an increase of 1 GL in water allocation announcement will increase the total land irrigated by 20 ha (Table 46). Care must be taken when interpreting these results because the relationship holds only for very small shifts in the explanatory variable (e.g. $1/ML increase in water allocation price, or 1GL increase in water recovery) while holding other variables in the model constant. The actual estimate of the area irrigated would need to include all model variables rather than a single coefficient in isolation.

Table 47: Factors affecting the area irrigated in the MDB

	Total area irrigated in MDB (000 ha)
Agricultural commodity Producer price index	16.2***
Dummy variable for period 2007-2015	-365**
Water allocation price ($/ML)	-1.27***
Water recovery from buybacks & infrastructure (GL)	-0.77*
Water allocation announcement (GL)	0.02*
Constant	201
N	15
Test for overall significant of the model	F=27.1 (p=0.000)
Ljung–Box statistics to test for AR(1)	Q=0.003(p=0.960)

Note: *,**,*** indicate statistical significance at the 10%, 5%, and 1% significance level respectively.

3.3 Effect of water reforms on water use efficiency

We examined how water use efficiency of irrigated agricultural production in the MDB, in terms of the value of irrigated agricultural production in 1997-98 price per ML of water used, changed with water allocation price and the amount of water recovery under the government water buy-backs and the infrastructure water efficiency improvement program as established in the Water Act in 2007. Water allocation price and water recovery have a positive and significant effect on the water use efficiency of irrigated agricultural production (Table 47). An increase in water allocation price by $1 per ML will increase the value of irrigated agriculture production per ML of water used by $0.86. A 1 GL increase in the amount of water recovery will increase the value of irrigated agriculture production per ML of water used by $0.96.

Table 48: Factors affecting water use efficiency in MDB

	Water use efficiency of irrigated agricultural production in the MDB in 1997-98 price ($/ML)
Water allocation price ($/ML)	0.86***
Water recovery from buybacks & infrastructure (GL)	0.96**
Constant	577***
N	10
Test for overall significant of the model	F= 6.19 (p=0.028)
Ljung–Box statistics to test for AR(1)	Q=0.31 (p=0.576)

Note: *,**,*** indicate statistical significance at the 10%, 5%, and 1% significance level respectively.

3.4 Factors affecting the number of agricultural businesses in MDB

We examined the effects of water allocation price and the amount of water recovery under the government water buy-backs and the infrastructure water efficiency improvement program on the number of irrigating agricultural businesses and on the total number of agricultural businesses in the MDB. The results show that there is a decreasing trend in the number of irrigating agricultural businesses and number of total agricultural businesses in the MDB over the period 2001-2015. Effects of water allocation price and water recovery are not significant in both models of irrigating as well as total agricultural businesses (Table 48).

Table 49: Effect of water price on the number of agricultural businesses in MDB

	Number of irrigating agricultural businesses	**Number of agricultural businesses**
Time trend	-399***	-872**
Water allocation price ($/ML)	-1.12	1.96
Water recovery from buybacks & infrastructure (GL)	-0.11	-0.25
Constant	19591***	62595***
N	11	11
Test for overall significant of the model	F=4.76 (p=0.041)	F=4.51 (p=0.046)
Ljung–Box statistics to test for AR(1)	Q=0.011 (p=0.918)	Q =0.740 (p=0.390)

Note: *,**,*** indicate statistical significance at the 10%, 5%, and 1% significance level respectively.

3.5 Factors that affect water allocation price

We examined the effects of water allocation announcement at the beginning of the season that includes net carryover water from the previous year, and water availability measured as the volume of water storage at the end of the year in the MDB, on water allocation price. The results show that effects of water allocation and water availability on water allocation price are significant. An increase in water allocation by 100 GL will reduce water allocation price by about 4$ per ML; while an increase in water availability by 100 GL will reduce water allocation price by $2 per ML (Table 49).

Table 50: Effect of water allocation and availability on water allocation price

	Water allocation price ($/ML)	
	Regression 1	Regression 2
Water allocation announced (GL)	-0.04***	
Water storage in MDB (GL)		-0.02**
Constant	475***	361***
N	15	15
Test for overall significance	F = 10.7 (p=0.006)	F =7.23 (p=0.019)
Ljung–Box statistics to test AR(1)	Q=0.172 (p=0.189)	Q=2.14 (p=0.143)

Note: *,**,*** indicate statistical significance at the 10%, 5%, and 1% significance level respectively.

3.6 Effect of water reform on volume of water extraction in MDB

We analysed the effects of water allocation price, water allocation announcement, and water recovery (GL) under the government water buy-back program and the infrastructure water efficiency improvement program as established in the Water Act in 2007, on volume of water extraction for consumptive uses in the MDB using data for the period 2001-2015. The results show that an increase of $1 per ML in water allocation price will reduce the total water extraction by about 7 GL. An increase of 1 GL in water allocation announcement will increase water extraction by about 0.4 GL; while an increase of 1 GL in water recovery will reduce the total water extraction by about 8 GL (Table 50).

Table 51: Effect of water price, allocation and recovery on water extraction in MDB

	Water extraction for consumptive uses (GL)
Water allocation price ($/ML)	-6.58**
Water allocation announced (GL)	0.36**
Water recovery from buybacks & infrastructure (GL)	-7.95***
Constant	6735***
N	15
Test for overall significance of the model	F = 12.8 (p=0.001)
Ljung–Box statistics to test for AR(1)	Q=2.92 (p=0.1)

Note: *,**,*** indicate statistical significance at the 10%, 5%, and 1% significance level respectively.

4 Discussion

Our study examined the changing nature of industries and communities in the Murray-Darling Basin in the past two decades and the possible drivers of these changes. We measured changes in a number of key variables related to agricultural production, water use, population and employment. It is clear from our analysis that there were significant changes in the economic and social structure of the Basin as a whole in recent years. These changes were not uniform across the Basin, with some communities growing and prospering, while others were in decline.

Multiple factors influenced the Basin's socio-economic structure, including rainfall and consequent water availability, local and international commodity prices, changes in agricultural technology, improved transport and internet communications, as well as the structural changes being brought about by reforms in water management. The latter comprise a suite of interventions that have now been operating for over 20 years including transfer of responsibility for irrigation areas from government to irrigator owned corporations, increases in water prices to better reflect operating and capital costs, introduction of water markets for water entitlements and water allocations, improvements in water use efficiencies both on-farm and off-farm, and the return of water from the consumptive pool to the environment. Some of these factors, such as changes in agricultural technology, were national in scope; some, such as the Millennium drought and many water reform programs, were regional or Basin-wide; while others were local. Some factors operated over the short-term (e.g. changes in rainfall and water availability, changes in commodity prices) and their effects were detected almost immediately in production and economic data. However, most operated over the long term. Given this complexity, it is difficult to disentangle the effect of any particular influence on the Basin's production and society from the multitude of concurrent influences without careful systematic analysis. In this study, we used multiple regression models to find the likely causes of social and economic changes across the Basin.

Linear regressions are a useful approach to assess whether changes in these variables could be explained by variables related to water reform, commodity prices and water availability. However our study examined only a subset of drivers and socio-economic indicators, and they do not necessarily represent the full suite of indicators that are important to communities and industries in the Basin. Even when relationships were found they need to be treated with caution given that only 10-15 years of data were available and we did not model interaction effects. Despite these data limitations, these results provide important evidence of the effect of water reforms and other drivers on socio-economic indicators in the Basin.

Some changes and their probable causes were apparent from this analysis. The production of water-dependent annual crops such as rice, cotton, cereals fell sharply between 2006 and 2009 and then recovered in 2011 although not to pre-2006 levels in the case of rice. While a number of factors may have been in play, the Millennium drought was very likely to have been the main driver. Between 2013 and 2015, the production of these crops again declined and this was most probably associated with reduced water availability over those years. In contrast, grape production remained comparatively stable over the period 2001-2015. Grapes are a perennial crop, and their production was sustained through this period with water sourced from rainfall, allocations from high security entitlements, and temporary trade from rice growers, mixed farmers and dairy farmers who had more flexible production systems (NWC 2011).

The gross value of agricultural production (both GVIAP and GVAP) declined gradually through the drought period, reaching a low in 2008-09, but then grew steadily to record levels in 2013-14 and 2014-15, respectively. Trends in irrigated agricultural production in the MDB reflected national trends. Not surprisingly, our analysis showed that drought was a significant factor in explaining the decline in agricultural production across the Basin, probably because of reduced water allocations, and closure of irrigating agricultural businesses (1,985 fewer businesses between 2006-07 and 2008-09). Model results showed that drought impacts on the irrigated agriculture industry probably persisted until at least 2008-09 with the arrival of the drought-breaking rains, while drought impacts on the agriculture industry as a whole were short-lived through 2006-07, suggesting the industry may have adjusted to the continuing dry conditions.

Water allocation prices were also found to have significantly affected agricultural production in the Basin. The rising water allocation price explained some of the decline in agricultural production during the drought, reflecting the reduced demand for water as allocation price increased. This was consistent with research by Burdack et al. (2011) who found that an increase in water allocation price would reduce the production of irrigated crops; the more the industry is dependent on irrigation, the more it is affected by an increase in water price.

The influence of water recovery appeared to be significant for irrigated agricultural production but not for total agricultural production. Effects were relatively small (a 10GL increase in recovery reduced GVIAP by 0.4% over the range of water recovery examined here), compared to effects of drought and water prices. Water recovery commenced in the mid-2000s as part of a number of initiatives including The Living Murray and the Basin Plan. Water recovery during this period was linked to reduced irrigated agricultural productivity in the Basin, as water entitlements were moved from agricultural production to environmental benefits. Similar effects were shown in an ABARES (2011) which found that reducing irrigation diversions by 26% could reduce the GVIAP in the basin by 10-15%.

Declines in value of agricultural production were significantly less than the declines in volumes of production, implying that there were mechanisms operating to cushion the effects of the drought and water recovery. While this analysis is unable to fully unravel these compensating mechanisms, the ability to trade water (part of the water reforms) was likely to have been a significant factor (NWC 2014).

Area of irrigated land in the MDB was reduced to about 365,000 ha in 2006-07 primarily because of the severe drought. The area under irrigation fluctuated considerably for rice, cotton, pastures, cereals but remained relatively stable for grapes and vegetables. The regression models imply that the total area irrigated was affected significantly by changes in water prices and water recovery, with increases in crop prices leading to an increase in the area under irrigation, and an increase of 1GL in the water allocation announcement leading to an increase of 20ha in irrigated land. Conversely, 1GL of water recovery led to a reduction in irrigated area of about 800ha.

Water allocation price appeared to be driven by the volume of water allocation announced and water availability in the MDB. A decrease in water allocation by 100 GL was found to increase water allocation price by about $4 per ML. This was consistent with a recent report that found that total volume of water allocation was an important driver of water allocation price because it placed a constraint on the total supply of water available for consumption (Aither 2016).

Water use efficiency, averaged across all irrigated crops, improved significantly over the 2000-2008 period from A$486/ML to A$1171/ML although it then declined to A$700/ML in 2013-14. Water use efficiency reached a near-record high of A$1117/ML in the dry year 2015-16. The high WUE during the time of the Millennium drought could be caused by a number of factors: more efficient use of water in response to water scarcity, a shift from higher to lower irrigation requirement crops, and water trade that allowed the highest value horticulture to stay in production while crops with lower marginal value and higher demand for water were fallowed. The WUEs of the major water using crops – rice, cotton, grapes, vegetables - all fluctuated but generally increased during the period.

While the number of both agricultural businesses and irrigation businesses declined in the MDB between 2005 and 2016, this largely reflected a national decline in these businesses implying that there were no specific MDB factors at play here. Nor was there evidence that this trend was associated with water prices or the water recovery program. Despite this decline in the number of agricultural businesses, the number of employed persons in MDB continued to increase over the period 1996-2011, and the unemployment rate in the MDB was lower than the national unemployment rate. However this increase in overall employment masked some significant shifts in the structure of the Basin's workforce. There was a distinct shift away from agricultural and manufacturing employment towards services such as health care, public administration and utilities. The decline in the agricultural workforce (12%) was not specific to the Basin – it was virtually the same as the 11% decline in the agricultural workforce, nationwide.

The MDB has also changed socially. Over the period 1996-2016, the population increased in the MDB but at a lower rate than the national population growth rate. However, the Basin's population growth was not evenly distributed, with the outer regional and remote parts of the Basin declining in absolute population, while the inner regional areas and major cities of the MDB increased between 2001 and 2011.[3] There was a small decline in the proportion of young people in the Basin (0-14 years) between the 2006 and 2016 censuses and a corresponding small increase in the proportion of older people (65+).

While these results show how the Basin as a whole fared, different Basin towns fared quite differently. Five towns – Deniliquin, Shepparton, Renmark, Griffith, and Moree – were examined. Three of these towns, Deniliquin, Moree and Renmark, experienced declines in population and economic activity, while the other two grew strongly. Deniliquin experienced the greatest decline, with the number of businesses almost halving between 2003 and 2015 with agriculture/forestry/fishing businesses being particularly hard hit with a decline from 498 to 128 over that period. Moree’s population declined by 12% between 2000 and 2015 while its agricultural/forestry/fishing labour force dropped by 20% between 1996 and 2011. The Renmark district experienced only a small (6%) decrease in population between 2000 and 2015, although the labour force remained relatively stable. However, the number of agricultural/forestry/fishing businesses declined by 29% between 2003 and 2015, while other sectors (notably construction) increased, so that, overall, there was no significant change in the number of businesses.

While some towns experienced a decline in key indicators, Griffith and Shepparton showed growth in population and employment during the reporting period. Population increased by 8% in Griffith and 11% in Shepparton between 2000 and 2015, and the proportion of indigenous community also increased in both regions. There was an increasing trend in total employment in Griffith (17%) and Shepparton (12%) during the reporting period (2000-01 to 2014-15). In Griffith, there was a strong boost in employment in agriculture between 2012 and 2015 following a 7-year decline. By 2015, Griffith’s agriculture sector had fully recovered and agriculture employed the highest number of people of all reported sectors. Strong growth in

[3] Outer regional and remote parts of the Basin were areas where geographic distance imposed a moderate to high restriction upon accessibility to goods, services and opportunities for social interaction, while inner regional areas and major cities were areas where geographic distance imposed minimal to some restrictions (ABS 2001).

total employment in Shepparton from 2002 to 2007 reflected growth in services sectors including health care, construction and education, despite a decline in agricultural employment. Ongoing growth in employment from 2007 to 2015 was mainly due to growth in services sectors (transport, postal and warehousing) and to a lesser extent in health and agriculture.

The decline in agricultural employment in Shepparton (20%, 2001-2015), Moree (20%, 1996-2011) and Renmark (25%, 2003-2013) was similar to that occurring nationally (20% decline) over that period, showing that this decline was not specific to the Basin. However, Deniliquin's drop in agricultural employment (75%) between 2003 and 2013 was far greater than the national reduction. Only Griffith showed an increase (42%, 2001-2015) in agricultural employment over the full period of record.

In spite of the decline in agricultural businesses and employment, all towns in our assessment, except Griffith and Renmark, showed increases in the values of agricultural production. In spite of the decline in the agricultural workforce in the Moree district, the gross value of agricultural production rose substantially between 2001 and 2011 from $513m to $912m, while the Deniliquin district, in spite of the population and business decline, saw the gross value of agriculture increase significantly between 2001 and 2011 from $11.2 million to $38.8 million following a drop to $6.1 million in 2006 during the Millennium drought. In the Shepparton district, the gross value of agricultural production increased by 50% during the 2001-2011 period, with most of the growth occurring in cropping. The value of agricultural production was relatively stable in the Griffith district during the 2001-2011 period, at about $290m. Renmark, whose economy is heavily dependent on irrigated orchards and vineyards, was the exception. Due to the sharp reduction in grape price from $546 per tonne in 2007-08 to a new floor of about $369 per tonne from 2008-2009, grapes production in Renmark experienced a downward trend between 2009 and 2013. Overall, the value of agricultural production dropped from $206m in 2001 to $141m in 2011.

There are a number of reasons for the different trajectories of these MDB towns and their associated districts. The 2007-08 drought seriously affected Deniliquin's rice industry, and this downturn exacerbated other pressures on the district including increased mechanisation of agriculture, and the closing of government agency offices in 2005. On the other hand, Griffith's population and employment increased over the same period, partly driven by the increase in local investment in the town. A younger population is attracted to Griffith due to large employment bases, particularly the Bajada Group which is the Riverina's largest employer, the Riverina Institute of TAFE campuses, and the Regional University Study Centre which was established in 2004 in Griffith. Griffith has also experienced strong commercial growth with new shopping centre developments in recent years (Riverina Cities, 2015).

Shepparton, like Griffith, showed an increase in population and employment during the last 15 years. While the size of the agricultural workforce has fluctuated over the period it has remain relatively steady at about 2600 for the last 8 years. However, employment in health care and social assistance has increased significantly (over 30%) during the same period so that it is now notably larger than agricultural employment. There has also been a growth in government investment in public administration and services, while there are new employment opportunities in the district outside of the agricultural sector, such as the Shepparton Bypass project, the road-rail interchange at Mooroopna and additional production jobs at Unilever in Tatura.

The Renmark district has been severely affected by drop in grape prices and this impact has been exacerbated by prolonged drought and the operation of the Small Block Irrigators Exit Grant. Unlike Griffith and Shepparton, Renmark has not experienced a compensating increase in activity in non-agricultural sectors. Instead there has been a contraction in manufacturing and retail trade sectors.

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Appendix: List of variables

Agricultural commodity Producer price indexes: are the agricultural commodity prices indexes (aggregated for all crops and aggregated for all agriculture products with reference year 1997-98 =100)

Dummy variable for year 2006-07: is a dummy variable that takes value 1 for year 2006-07 and takes value 0 otherwise

Dummy variable for years 2006-07, 2007-08, 2008-09: is a dummy variable that takes value 1 for years 2006-07, 2007-08, 2008-09 and takes value 0 otherwise

Dummy variable for period 2007-2015: is a dummy variable that takes value 2 for the period 2007-2015 and takes value 0 for the period 2001-2006.

Water allocation price: is price per ML of water allocation ($/ML)

Water recovery from buybacks & infrastructure (GL): is the amount of water recovery under the government water buy-back program and the infrastructure water efficiency improvement program as established in the Water Act in 2007

Log of gross value of irrigated agricultural production: is the natural logarithm of the gross value of irrigated agricultural production in the MDB in 1997-98 price ($ million)

Log of gross value of agricultural production: is the natural logarithm of the gross value of total agricultural production in the MDB in 1997-98 price ($ million)

Water use efficiency of irrigated agricultural production in the MDB: defined as the gross value of irrigated agricultural production in the MDB in 1997-98 price divided by the amount of water used for irrigation in the MDB (A$/ML)

Water use efficiency of rice production: defined as the value of rice production in the MDB divided by the amount of water used for rice production in the MDB (A$/ML)

Water use efficiency of cotton production: defined as the value of cotton production in the MDB divided by the amount of water used for cotton production in the MDB (A$/ML)

Water use efficiency of vegetables production: defined as the value of vegetables production in the MDB divided by the amount of water used for vegetables production in the MDB (A$/ML)

Number of irrigating agricultural businesses: is the number of irrigating agricultural businesses in the MDB

Number of agricultural businesses: is the total number of agricultural businesses in the MDB

Water Extraction: is the amount of water extraction for consumptive use in the MDB (GL)

Water allocation announced: is the amount of water allocation in the MDB (GL)

Water storage in MDB (GL): is the amount of water storage at the end of the year in the MDB.

Review of Water Reform in the Murray-Darling Basin
Appendix 4. Climate change in the Murray-Darling Basin

Climate change in the Murray-Darling Basin: an update

Dr Penny Whetton, Consultant and Honorary Fellow, University of Melbourne

Summary

This report provides an up-to-date assessment of how climate change is affecting the Murray-Darling Basin using published information. Two key elements of this task are to review implications for the Basin of CSIRO's latest climate change projections, and to assess the continuing relevance of the detailed hydrological climate change projections for the Basin provided by Murray-Darling Basin Sustainable Yields project in 2008.

The Basin area has warmed by around a degree since 1910, and will continue to warm (by 0.6–1.5 °C in 2030 relative to 1995, and by 0.9–2.5 °C in 2050 without mitigation), with more hot days and fewer cold days. Rainfall is projected to have a tendency to decrease, particularly in the south and in winter, with more time in drought and decreased soil moisture. However, both natural variability and model-to-model differences are large, and both increased and decreased rainfall are possible, particularly in the north. Daily extreme rainfall is projected to increase even if average rainfall declines, with implications for erosion and flooding among other impacts.

Using a climate analogue approach, sites in the Basin 'move' inland/northwest under the hottest/driest scenario and north/northeast in the coolest/wettest scenario. The analogues may be many hundreds of kilometres away and outside the Basin in 2050 under high emissions, representing a substantially different climate.

Wet and dry extreme climate scenarios used in Sustainable Yields (CSIRO 2008b) were assessed as still valid and representative given latest science, and thus the consequent hydrological scenarios are similarly still valid and representative (although latest modelling results suggest that the probability of the dry scenario may have declined slightly). For the dry scenario there are large reductions runoff and water availability throughout the Basin. For the wet scenario there are significant increases in runoff and water availability in the north grading to little change in the south.

Introduction

The purpose of this report is to provide an up-to-date assessment of how climate change is affecting the Murray-Darling Basin. The report has been commissioned by the Wentworth Group as a contribution to an independent review that it is undertaking of progress on implementation of the Murray-Darling Basin Plan.

The particular focus of this report is on the question of how climate change has affected, and is anticipated to affect, water availability in the Basin. Subsequent questions of how climate change could affect the ability to deliver Basin Plan objectives; and long-term policy implications and recommendations for managing and adapting to climate change impacts in the Murray-Darling Basin will be addressed in a subsequent report. This report will also provide detailed climate and hydrological scenarios to assist in addressing these questions.

This report is a desk top study which reviews information on climate change relevant to impacts in the Basin, based on the latest science and drawing from a range of assessments currently available. There are three major sources of information: the Murray-Darling Basin Sustainable Yields (SY) project representing the most comprehensive assessment of the impact of climate change on hydrology in the Basin (CSIRO 2008b), CSIRO's latest climate change projections released in 2015 (Climate Change in Australia – CCIA) (CSIRO; BoM 2015), and the historical climate information from the Bureau of Meteorology. Reference is also made to the regional projections of the Victorian Climate Initiative (VicCI) (Timbal et al. 2016) and the NSW/ACT Regional Climate Modelling (NARCLiM) project (Evans et al. 2014), and to the results of the South Eastern Climate Initiative (SEACI) (CSIRO 2012).

As new hydrological modelling is beyond the scope of this report, the wet and dry scenarios for water availability 2030 as documented in CSIRO's Murray-Darling Basin Sustainable Yields Project are re-presented here. Any necessary adjustments to the conditions under which they may occur given the latest climate modelling are assessed and also presented.

This report begins with an assessment of recent observed climate variability and change in the region and its causes. The latest sources of information, such as new climate modelling results, are introduced and described. Then projected future climate change for the region in 2030 and 2050 is presented based on relevant material drawn from the CCIA projections. This includes changes to means and extremes of temperature, rainfall and a range of climate variables relevant to Basin management. To further illustrate the changes in climate, sites with current climates analogous to the future climates of some key sites in the Basin are identified. Next, to provide context for the hydrological scenarios a comparison is made between current climate modelling results and those available when the SY hydrological results were produced. Finally, the Wet and Dry hydrological scenarios for 2030 from SY are presented along with a current assessment of the conditions under which they may occur. The Wet and Dry scenarios from SY are given greater emphasis here rather than Median scenario (which represents little rainfall change), as this correctly emphasises that substantial rainfall change is very plausible (even if the direction of change is uncertain) and that this needs to be considered from a risk management perspective.

Geographical regions used in this report

Here the Murray-Darling Basin region, as illustrated in Figure 1, is used for basin-wide statistics, such as area-averaged historical climate trends from the Bureau of Meteorology.

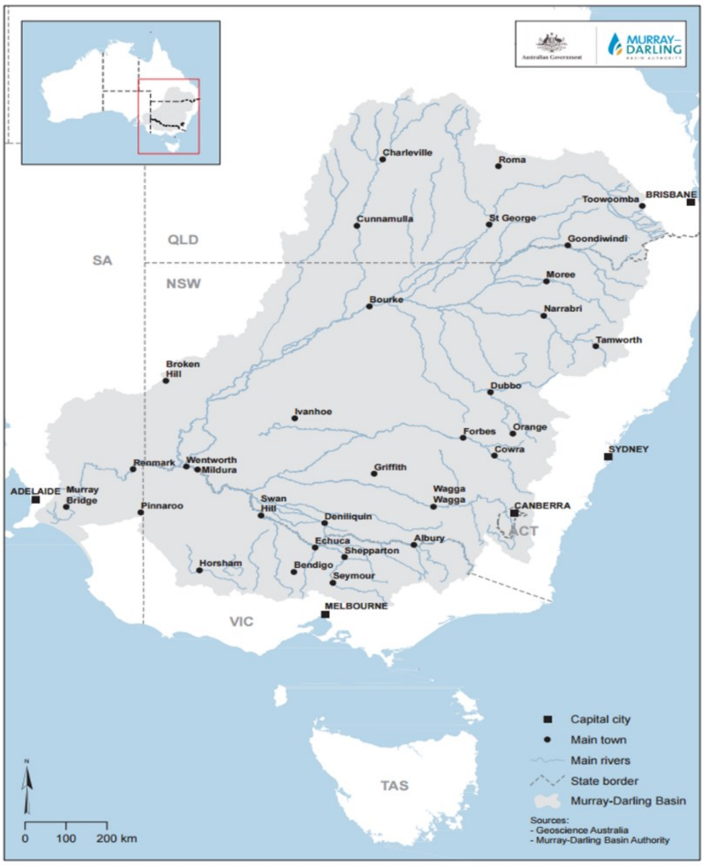

Figure 1: Murray-Darling Basin (Source: http://www mdba.gov.au/publications/maps-spatial-data)

Climate change projections in this report are based on the regionalisation of Australia used in CCIA (CSIRO; BoM 2015). This divided Australia into eight regions (known as 'clusters') based on a clustering of natural resource management regions (see Figure 2). The Basin is predominantly comprised of two of these clusters: 'Murray Basin', representing the Murray catchment, and 'Central Slopes', representing the upper Darling catchment (Figure 3). The northwest portion of the MDB also falls partially into the Rangelands cluster, but this report will focus on the climate change results for the Central Slopes and Murray Basin clusters as the hydrologically important clusters for the Basin.

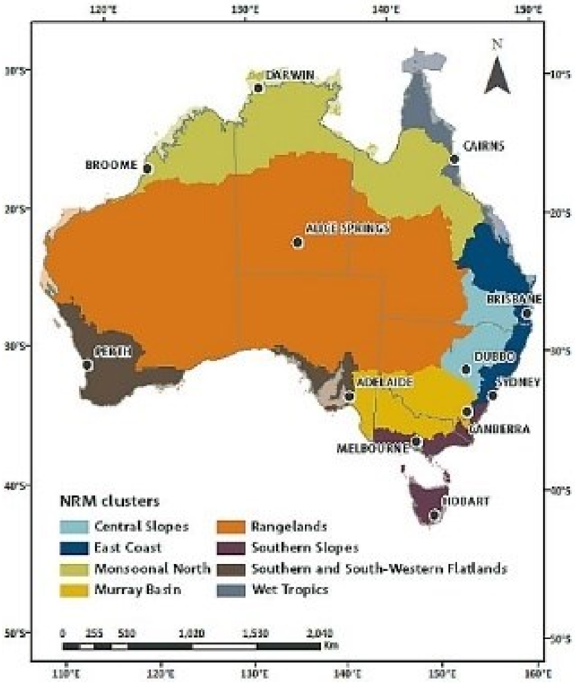

Figure 2: Regions used in the CCIA climate projections. Source: reproduced from (CSIRO; BoM 2015).

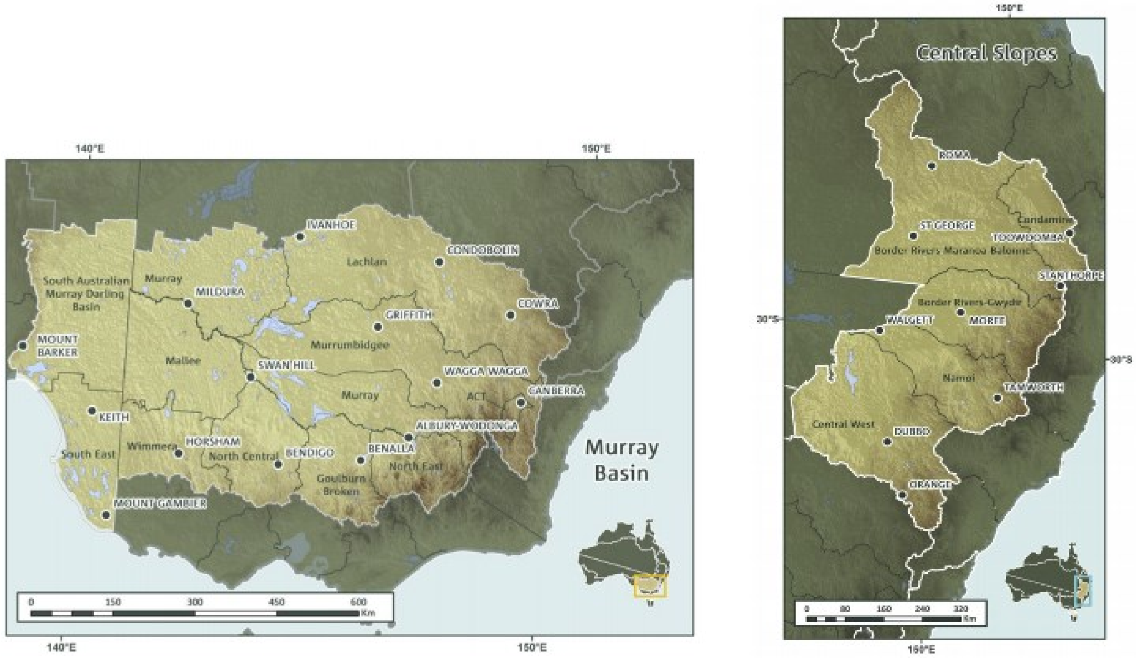

Figure 3: Murray Basin and Central Slopes clusters from CCIA. Source: reproduced from Ekström et al (2015) and Timbal et al (2015).

Historical climate change

Temperature has increased historically across the Basin since the beginning of good quality records in 1910 (Figure 4, top left). This has been more marked since 1950 and the four warmest years since 1910 have occurred in the last ten years. Warm season temperature (Figure 4, top right) shows the seasons of 2009/10 and 2010/11 as slightly anomalously cool as a consequence of wet conditions (see below), although with a return to drier conditions in recent years, temperatures have returned to those typical of the last decade. The warming since 1910 has occurred in the all parts of the Basin (Figure 4, bottom left) and in both maximum and minimum temperatures as well as mean temperatures. Calculated from the data for the Basin area downloadable from the BoM website (http://www.bom.gov.au/climate/), Basin-wide average increase in mean temperature over 1910-2015 based on BoM data is +0.9 ^{o}C, and that for maximum temperature is +0.7 ^{o}C and that for minimum temperature is +1.2 ^{o}C. There has also been a marked increasing trend in the frequency of hot years and a decreasing trend in cold years (Figure 5). Attribution of Australian region warming at least in part to anthropogenic climate change was established by Karoly and Braganza (2005).

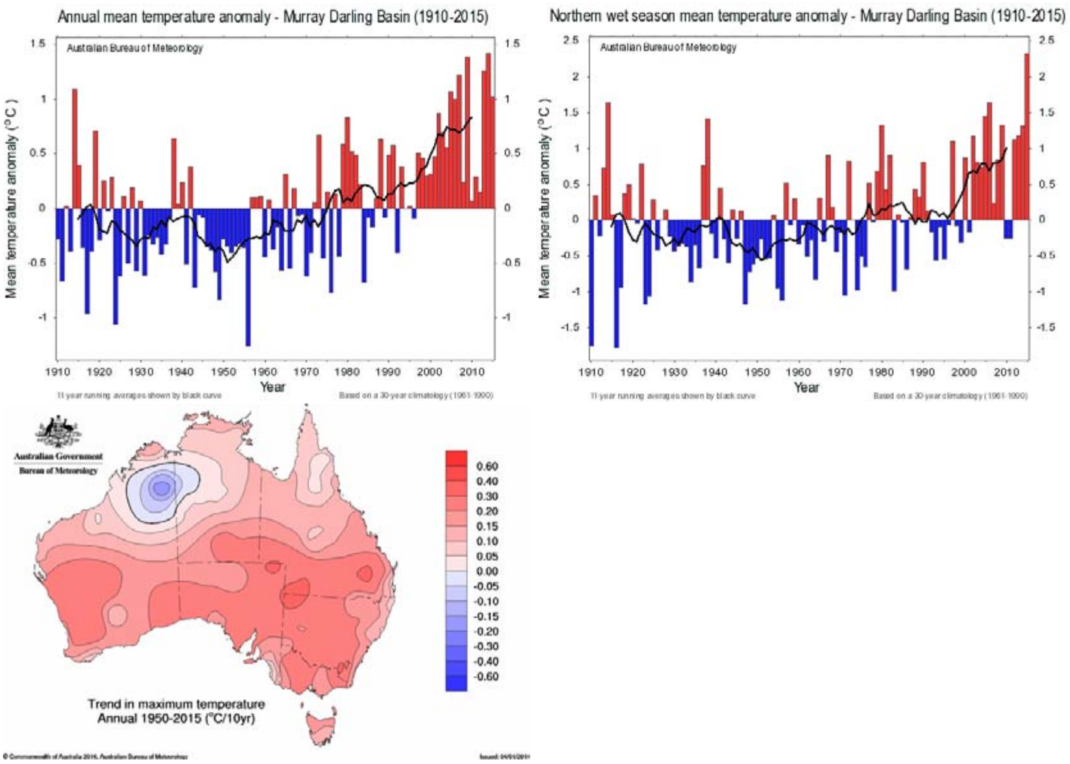

Figure 4: Mean temperature anomaly (with 11-year running mean in black) averaged across the MDB annually (top left), for October to April (top right), and the spatial distribution of the rate of temperature change for 1950 – 2015 (bottom left). Source: BoM website (http://www.bom.gov.au/climate/).

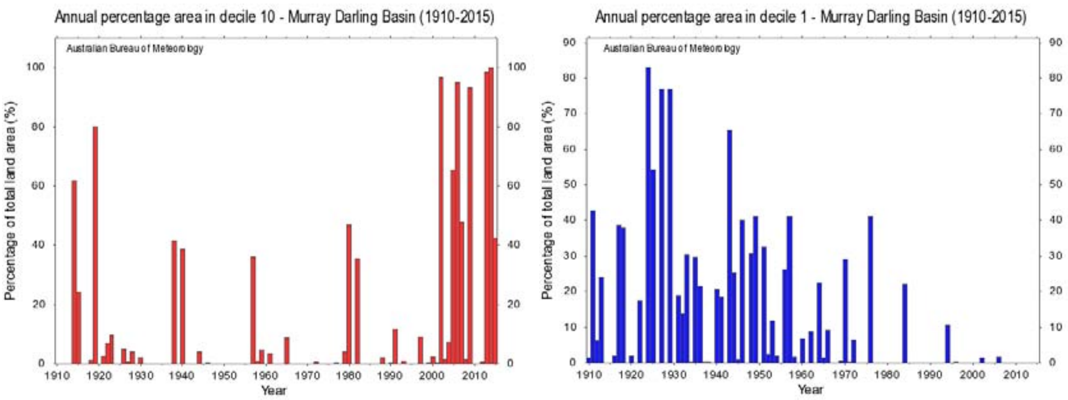

Figure 5: Variation in the area of the Basin experiencing unusually warm conditions (annual average maximum temperature anomaly of Decile 10) (left) and unusually cold conditions (annual average minimum temperature anomaly Decile 1) (right). Source BoM website (http://www.bom.gov.au/climate/).

Precipitation does not show clear trends in the same way that temperature does. Annual rainfall averaged across the Basin for 1900-2015 is shown in Figure 6 (top left). As well as the high natural variability, the Millennium drought (Leblanc et al. 2011) is particularly evident over 2001-2009, followed by the very wet 2010-2012, and finally a return to dry conditions in the subsequent years up to present. Earlier drought periods are evident, such as in the 1940s and 1930s. If the rainfall is broken down according to cool and warm seasons for the Basin (using BoM's southern and northern wet seasons, see Figure 6 caption for definition), there is a marked tendency for the Basin to have become drier in the hydrological and agriculturally important April to October period (Figure 6, compare bottom left with top right). All cool seasons have been dry since 2001 except 2005 and 2010. Drying is less marked in the warm season, for which there has been more frequent and larger positive anomalies, most notably the summers of 2009/10 and 2010/11. This cool season/warm season dichotomy in rainfall behaviour is most evident in the southern half of the Basin where the winter drying has been even stronger. In fact, for Victoria, the dominance of cool season rainfall over warm season rainfall has weakened in the past decade to its lowest recorded level (Timbal et al. 2016).

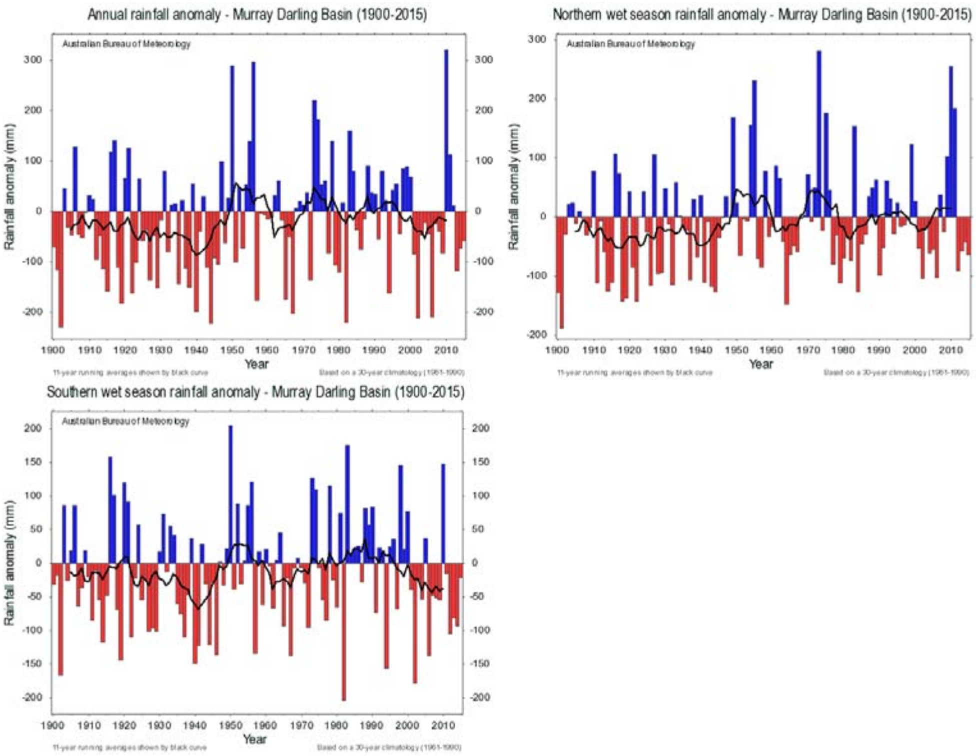

Figure 6: Precipitation anomaly averaged across the MDB annually (a), for the northern wet season, October to April (b), and the southern wet season, April to October (c). 11-year running mean indicated in black. Source: BoM website (http://www.bom.gov.au/climate/).

The Millennium Drought was of great hydrological importance to the MDB, particularly the southern MDB (Leblanc et al. 2011). Potter et al (2010) note that the reductions in runoff were unprecedented in the historical record and estimated their return period as 1/300 years. Notably the runoff was more reduced than may have been expected given the rainfall anomaly, a tendency that has been attributed (in a study for a catchment in the Southern Basin) to increases in potential evapotranspiration and changes to rainfall variability and seasonality (Potter; Chiew 2011). MDB rainfall (Ho et al. 2015) and Murray streamflow (Gallant; Gergis 2011) records have been extended back into the pre-instrumental period using various palaeoclimatic indicators. These studies suggest that larger and more extended dry spells may have occurred in the more distant past, although Gallant and Gergis (2011) estimate the return period of the Millennium Drought as having a 1/1500 years based on past climatic variability.

The dry conditions in the cool season over southeastern Australia since 1996, and affecting the southern MDB, are associated with a southward expansion of the atmospheric Hadley cell and a southward shift of the storm track (CSIRO 2012; Post et al. 2014). The change in rainfall and circulation agree qualitatively with that simulated under enhanced greenhouse conditions and have been partially attributed to anthropogenic influence, along with natural variability (CSIRO 2012; Timbal et al. 2016). The unusually wet conditions of December 2010 may also have been influenced by anthropogenic climate conditions, as the La Nina- related high rainfall appears to have been enhanced by unusually high regional sea surface temperatures (Evans; Boyer-Souchet 2012).

Basis for Projections

The quantitative projections to be presented here are drawn from the CCIA projections (CSIRO; BoM 2015). The basis of these projections are the results of the CMIP5 ensemble of climate models run under scenarios of increasing levels of greenhouse gases and atmospheric aerosols, known as the Representative Concentration Pathways (RCPs). The CMIP5 ensemble represents the latest round of climate model simulations from the major modelling centres around the world, and are also the simulations used by the IPCC (Taylor et al. 2012). The RCPs comprise: RCP8.5 (high emissions and thus greatest impact on the climate), RCP4.5 and RCP6.0 (intermediate emissions and climate impact) and RCP2.6 (low emissions and least climate impact) (Van Vuuren et al. 2011). The RCP8.5 future involves little reduction to current emission patterns, whereas at the other extreme, RCP2.6 represents a very ambitious program where emissions peak by 2020 and decline rapidly after that to eventually less than zero. See further discussion in CSIRO & BoM (2015). Results presented here are primarily for RCP4.5 and RCP8.5.

Projections for future climate change are conditional on a particular RCP, although results differ little according to RCP in the near term (2030). The effect of RCP differences is a little more important by 2050 (and very important later in the century).

Even for a given RCP, projections need to be presented as ranges. This is because there is a range of regional responses to enhanced greenhouse conditions that currently can be seen as plausible, and the spread of results between different climate models can be used as an estimate of this range. Natural variability of climate (present in models and in the real world, but with different phasing) also contributes to the ranges produced, particularly in the near term when signals may be weak compared to natural variability. Selecting some models over others based on their ability to simulate aspects of current regional climate can provide increased apparent certainty (e.g., Smith and Chandler (2010) using earlier generation GCMs), but after an extensive review CCIA concluded that this approach was not sufficiently justified for the Australian results of the CMIP5 ensemble and CCIA used all available CMIP5 models to form ranges of change (see further discussion in CSIRO & BoM (2015)). That conclusion is accepted here.

Projections for the basin

Temperature

Projected mean temperature change for 2030 and 2050 relative to 1995 for the southern and northeast regions are given in Table 1, based on the analysis of CCIA (CSIRO; BoM 2015). Projected warming in 2030 relative to 1995 is around 0.6 – 1.5 ^{o}C, with the main source of variation being model differences (variations in the emission scenario have little effect). Projected warming is slightly stronger in the north, than in the south. By 2050 sensitivity to assumed emissions is more noticeable with projected warming of 0.9 - 1.9 ^{o}C for RCP4.5 and 1.3 -2.5 ^{o}C for RCP8.5 and with warming a little higher in the north than in the south. It is notable that the increase to date in mean temperature, relative to 1995, is already around 0.5 ^{o}C (see Figure 4), suggesting that the lower bound of 0.6 ^{o}C for the projected warming is very likely to be exceeded.

These warmings are large compared to natural variability (see Figure 7 for an example of projected warming as a time series using the results from a single climate model under RCP8.5). Warming for maximum and minimum temperature are similar to that for mean temperature (CSIRO; BoM 2015).

Table 1: Average warming in °C for the Murray Basin and Central Slopes in 2030 and 2050 and under RCP2.6, RCP4.5 and RCP8.5. Baseline is 1995 (1986-2005). Source: Climate Change in Australia website.

		RCP2.6	RCP4.5	RCP8.5
2030 (2020-2039)	Murray Basin	0.8 (0.6-1.0)	0.8 (0.6-1.1)	0.9 (0.7-1.3)
	Central Slopes	0.9 (0.6-1.2)	1.0 (0.6-1.3)	1.1 (0.7-1.5)
2050 (2040-2059)	Murray Basin	1.0 (0.6-1.3)	1.3 (0.9-1.7)	1.7 (1.3-2.1)
	Central Slopes	1.0 (0.7-1.6)	1.4 (1.0-1.9)	1.9 (1.3-2.5)

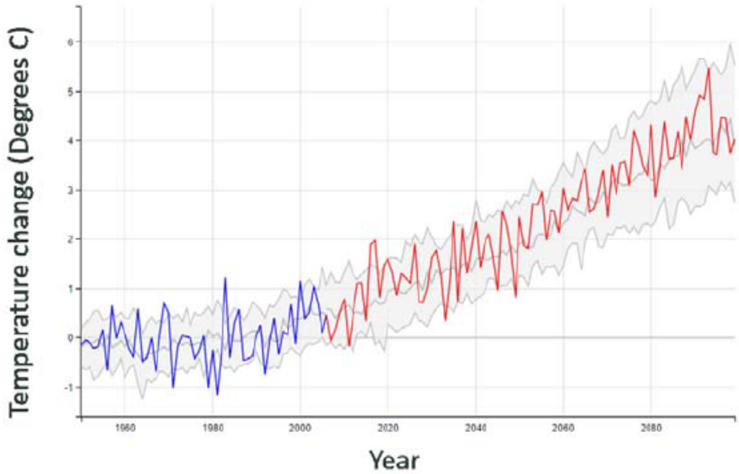

Figure 7: Example of model simulated historical (blue) and projected (red) annual temperature (in C) for Murray Basin region from a single global climate model (ACCESS-3 model, RCP8.5). Grey envelope indicates results from multiple models. Source: Time Series Explorer, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/time-series-explorer/)

These projected warmings are expected to apply to daily temperature extremes, increasing the temperature of hot days and cold nights, and increasing the frequency of hot nights but reducing the frequency of cold nights. CCIA concluded for Murray Basin based on model results and physical understanding: "A substantial increase in the temperature reached on the hottest days, the frequency of hot days and the duration of warm spells are projected with very high confidence" (Timbal et al. 2015). Similarly they concluded: "a decrease in the frequency of frost days is projected with high confidence" (Timbal et al. 2015). CCIA conclusions for the northeast of the Basin (Central Slopes) were similar (Ekstrom et al. 2015). Table 2 gives an example of projected changes in the frequency of days over 40 °C and frosty nights for a site in the Basin (Bendigo).

Table 2: Projected mean frequency of days at Bendigo with maximum temperature over 40 °C and days with minimum temperature under 2 °C. Source: Threshold Explorer, Climate Change in Australia website.

Bendigo area	Current	2030 RCP4.5	2050 RCP4.5	2050 RCP8.5
Days over 40 °C	1	2-4	3-5	3-6
Days under 2 °C	35	24-29	18-29	15-22

Precipitation

A tendency for reductions in cool season rainfall under enhanced greenhouse conditions has been a consistent result from climate modelling for many years (CSIRO; BoM 2007). This is most important for the southern MDB where cool season rainfall predominates. The process behind this change appears to be essentially a southward shift of mid-latitude weather systems and an expansion of the tropics (CSIRO 2012; CSIRO; BoM 2015; Hope et al. 2015). Warm season simulated rainfall change in southern Australia is less clear and ranges from an increase to a decrease (CSIRO; BoM 2015). In all seasons, natural variability is high relative to the signal and may obscure the forced change for some decades (CSIRO; BoM 2015). Presented below are CMIP5-simulated rainfall changes from CCIA for the two regions most relevant to the MDB.

It should be noted that dynamically downscaled projected rainfall change over NSW is also available from the NSW Government based on the earlier CMIP3 model ensemble (NSW/ACT Regional Climate Modelling (NARCliM) project http://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW) and that these projections lie closer to the wetter end of the range of rainfall change of CMIP5. Dynamical downscaling using the CCAM model reported in CCIA (CSIRO; BoM 2015) also showed this tendency. Grose et al. (2015) has compared the NARCLiM projections with those of CMIP5 and other downscaling for the Central Slopes, and whilst they noted that the fine resolution technique may more reliably reflect topographical influences in some places, the broad trend for a less drying and a more wetting climate in the NARCLiM projections was not well understood and not necessarily to be preferred.

Projected changes in precipitation based on CCIA are tabulated for 2030 and 2050 for southern and northeast portions of the Basin in Table 3 (annual changes) and Table 4 (seasonal changes). Annual average precipitation change in 2030 is -11 to +5% in the south and -13 to +8% in the north. By 2050 these ranges are around -17 to +8% and -16% to +11%. Thus the range of change extends from drying to wetting but with a greater tendency for drying, particularly in the south. Indeed, projected drying is stronger still in the Victorian-only component of the Murray Basin region (Timbal et al. 2016). The wetting case is most evident in the north in summer and autumn (around -25 to +25% in 2050), and the drying case is most evident in spring, especially in the south (around -15 to +10% in 2030 and -30 to +10% in 2050). Forced changes are much smaller compared to natural variability than they were for temperature (see Figure 8 for an example of the time evolution of precipitation in a drying model), with the result that the effect of varying emission scenarios is not strongly evident. Natural variability has probably contributed to the observed cool season rainfall decrease since 1995 already being comparable to the dry end of the projected rainfall change for 2030, although this fact also raises the concern that the models may be underestimating the rainfall response.

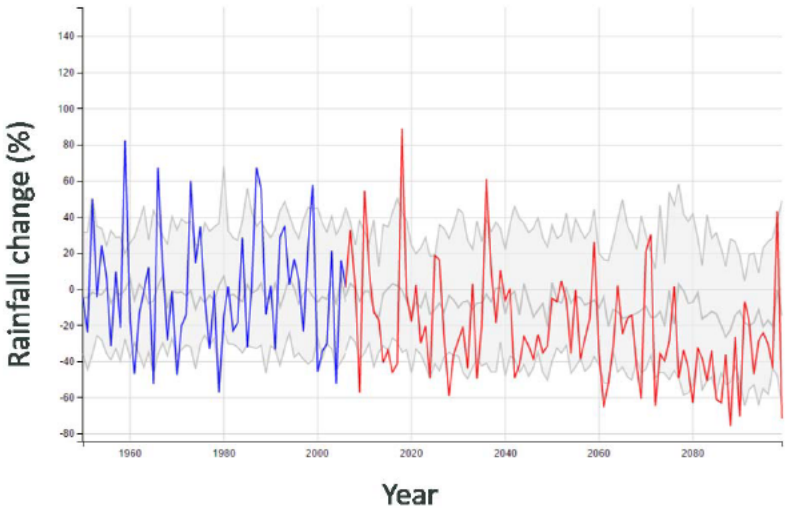

Figure 8. Example of model simulated historical (blue) and projected (red) winter precipitation anomaly (in %) for Murray Basin region from a single global climate model (GFDL-ESM2M model, RCP8.5). Grey envelope indicates results from multiple models. Source: Time Series Explorer, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/time-series-explorer/

Table 3: Average annual precipitation change (10th to 90th percentiles) in Murray Basin and Central Slopes in 2030 and 2050 and under RCP2.6, RCP4.5 and RCP8.5. Baseline is 1995 (1986-2005). Source: Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/en/)

	Region	RCP2.6	RCP4.5	RCP8.5
2030 (2020-2039)	Murray Basin	-11 to +4	-9 to +5	-11 to +5
	Central Slopes	-11 to +8	-11 to +7	-13 to +8
2050 (2040-2059)	Murray Basin	-17 to +5	-13 to +7	-14 to +8
	Central Slopes	-15 to +9	-13 to +7	-16 to +11

Table 4: Average seasonal precipitation change (10th to 90th percentiles) in Murray Basin and Central Slopes in 2030 (2020-2039) and 2050 (2040-2059) and under RCP4.5 and RCP8.5. Baseline is 1995 (1986-2005). Source: Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/en/)

		Murray Basin		Central Slopes	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
2030	DJF	-15 to +13	-9 to +16	-9 to +16	-12 to +23
	MAM	-24 to +12	-21 to +12	-22 to +19	-17 to +14
	JJA	-15 to +8	-17 to +7	-20 to +11	-27 to +15
	SON	-16 to +12	-17 to +7	-18 to +12	-23 to +12
2050	DJF	-15 to +20	-17 to +14	-9 to +20	-19 to +19
	MAM	-18 to +15	-20 to +20	-21 to +18	-25 to +26
	JJA	-13 to +6	-16 to +9	-21 to +12	-27 to +12
	SON	-24 to +9	-28 to +10	-20 to +13	-31 to +14

Unlike mean rainfall where the direction of change is not clear, magnitude of extreme daily rainfalls is very likely to increase. CCIA concluded for the Murray Basin: "Understanding of physical processes coupled with high model agreement gives high confidence that the intensity of heavy rainfall events will increase" (Timbal et al. 2015), and also drew very similar conclusions for the Central Slopes (Ekstrom et al. 2015). In fact, this tendency applies globally, as shown by the recent IPCC report (IPCC 2013). However, CCIA also concluded: "There is low confidence in the magnitude of change, and therefore the time when any change may be evident against natural variability, cannot be reliably projected" (CSIRO; BoM 2015). Increased daily rainfall extremes poses the risk of increased flooding and erosion, among other impacts.

On the other hand, changes to meteorological drought occurrence (drought occurrence defined in terms of rainfall deficits) largely follow the projected changes to mean rainfall (increase or decrease, but with decrease more likely). Based on its analysis of the CMIP5 models results, CCIA concluded that: "There is medium confidence that the time spent in meteorological drought will increase over the course of the century under RCP8.5" for the Murray Basin and Central Slopes (Ekstrom et al. 2015; Timbal et al. 2015).

Other variables: Evapotranspiration, soil moisture, snow, fire weather, sea level rise (from CCIA)

Projected warming is associated with increased potential evapotranspiration throughout Australia, including the regions in the MDB. The magnitude of the increase in 2030 is around a 1-6% (CSIRO; BoM 2015; Ekstrom et al. 2015; Timbal et al. 2015).

The increase in potential evapotranspiration results in a tendency for reductions in soil moisture on average in the Basin that are stronger than one may expect from rainfall changes alone (CSIRO; BoM 2015; Ekstrom et al. 2015; Timbal et al. 2015).

Primarily due to increased temperature, fire weather conditions would become harsher. This change is also moderated by rainfall changes, and would be most evident with reduced rainfall (CSIRO; BoM 2015; Ekstrom et al. 2015; Timbal et al. 2015).

Higher temperatures lead a reduced likelihood of precipitation falling as snow, and faster melt of any snow on the ground. CCIA concluded that snowfall and maximum snow depth would decline with high confidence (CSIRO; BoM 2015; Timbal et al. 2015). This would have the effect of shifting the period of peak runoff to earlier in the season in snow-affected catchments.

Sea level rise at the Murray mouth may be estimated from the relevant regional sea level rise projections in CCIA. Projected increase in 2030 (relative to 1995) at Victor Harbour is 0.12 m (0.08-0.16 m) under RCP4.5 and 0.13 m (0.08 – 0.17 m) under RCP8.5 (Timbal et al. 2015). CCIA does not provide regional projections for sea level rise in 2050, but by 2090 it is 0.45 m (0.28-0.63 m) under RCP4.5 and 0.60 m (0.39 – 0.83 m) under RCP8.5 (Timbal et al. 2015).

Wet and dry climate scenarios: Climate analogues

In this section we explore further what the combination of changes to precipitation and temperature may imply for the climates of individual sites in the Basin. The approach used was to select a site of interest and then find locations that currently have the projected future climate for the target site, under the climate scenario considered. This was done using the 'Analogues explorer' on the CCIA website, and analogues were sought based on annual average maximum temperature and precipitation (within tolerances of up to +/- 1 ^{0}C and +/-15%, but usually much less).

Across the two variables, the model range was represented by a hottest and driest case and a coolest (least warming) and wettest case as provided on the CCIA website. The RCP4.5 emission scenario was used for 2030, and the RCP8.5 scenario was used for 2050, noting that results for RCP4.5 in 2050 would lie between these two extremes. The magnitude of the rainfall and temperature changes in these four cases are indicated in the first row of Table 5. Note that these changes are based on individual model results and do not align directly with the 10th and 90th percentile of model ranges provided in the previous section.

It should be noted that these analogue results are to be treated as no more than broadly indicative. Changes in rainfall seasonality are ignored, and for small changes (2030) the signal can be clouded somewhat by the tolerances used.

The resulting climate analogues for range of selected sites in the MDB are listed in Table 5 and mapped in Figure 9. Sites in the Basin 'move' to lower elevation sites further inland and/or to lower latitude (which is generally to the northwest) under the hottest/driest scenario. Under the coolest/wettest scenario, sites 'move' to lower latitude without going further inland (and generally move north-eastward). In the 2050 under RCP8.5, climate analogues may be many hundreds of kilometres away in areas of differing agricultural production and sometimes outside the Basin.

Table 5: Climate analogue sites for nine locations in the Basin under the climate scenarios indicated. Temperature and precipitation changes indicated for each MB (Murray Basin) and CS (Central Slopes). Source: Climate Analogues Explorer, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/)

	Hottest and driest 2030 RCP4.5 MB, +1.1 C, -7% CS +1.1 C, -9%	Coolest and wettest 2030 RCP4.5 MB, +0.9 C, 0% CS. +0.9 C, 10%	Hottest and driest 2050 RCP8.5 MB, +2.1 C, -21% CS, +2.5 C, – 20%	Coolest and wettest 2050 RCP8.5 MB, +1.3 C, 8% CS +2.0 C, 7%
Bendigo	Kyabram	Corowa	Griffith Leeton	Wagga Wagga, Cootamundra
Griffith	Hay, Balranald	Cobar	Ivanhoe	Condobolin
Wagga Wagga	West Wyalong, Condobolin	Parkes Forbes	Griffith, Cobar	Dubbo, Parkes
Forbes	Condobolin	Gilgandra	Nyngan, Cobar	Gunnedah, Scone
Renmark	Port Augusta	Menindee	Leigh Creek	Menindee
Dubbo	Coonamble	Gunnedah	Nyngan Lightning Ridge	Narrabri Moree
Goondiwindi	Roma	Gayndah	Tambo	Collinsville
St George	Charleville	Taroom	Barcaldine	Charters towers Emerald
Moree	Roma St George	Goondiwindi	Tambo Charleville	Gayndah

Wet and dry hydrological scenarios

Any changes to precipitation will drive corresponding changes in runoff, with an amplification factor estimated in Australian conditions to be up to a factor of three (Chiew 2006; Reisinger et al. 2014). The Murray-Darling Basin Sustainable Yields project (SY) (CSIRO 2008b) is still the most up to date source of detailed projections of hydrological conditions in the Basin. The results are summarised in CSIRO (2008b), with more detail of the climate scenarios used in Chiew et al. (2008a) and of the hydrological modelling in Chiew et al (2008b). Related results are also given in the report of the South East Australia Climate Initiative (CSIRO 2012). As well as the primary driver of rainfall change, the SY modelling allowed for the effect of projected increase in potential evaporation, but did not include the possible effect of changes to forest water use (Chiew et al. 2008b). Driven primarily by the tendency for projected rainfall decline, the SY study projected decreases in runoff and water availability in the Basin but with a range extending from increases in their 'wet scenario' to strong decreases in their 'dry scenario'. More details of the wet and dry hydrological scenarios from SY will be presented here, but before doing so, the climate scenarios used in SY need to be assessed in the light of the current regional climate projections (as reviewed above), to see if there is any significant change in their plausibility and representativeness.

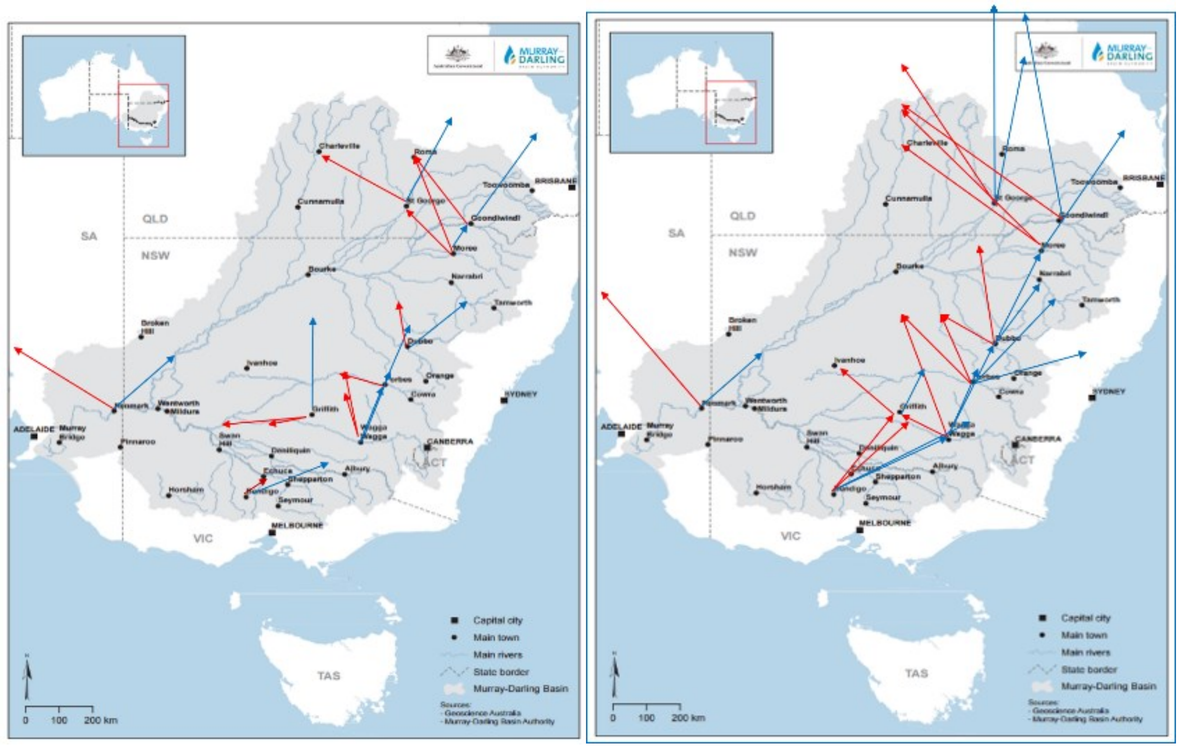

Figure 9: Map depiction of the climate analogues shown in Table 5. Left panel 2030 and right panel 2050. Red arrows hottest and driest case, and blue arrow coolest and wettest case.

The climate scenarios used in SY were based on the earlier CMIP3 ensemble of global climate model results (Meehl et al. 2007), and from these a wet, median and dry precipitation scenario was formed (both at grid points and averaged across the Basin, see Chiew et al. (2008a), based on the 10th, 50th and 90th percentiles of the CMIP3 model results. Figure 10 (CSIRO; BoM 2015) compares the range of the full CMIP3 and CMIP5 model ensembles for precipitation change over Australia. The results from these two ensembles are very similar: a range from wetting to drying (see 10th and 90th percentiles), with a tendency more to drying (see 50th percentiles), and with the wetting case being weaker (and the drying a little stronger) in the southern Basin. However, overall the bias to drying is slightly weaker in the CMIP5 ensemble.

We can also compare the MDB average annual rainfall changes used in SY, with 10th, 50th and 90th percentile rainfall changes from CMIP5 for the Murray Basin and Central Slopes regions from CCIA, see Table 6. The comparison is not exactly like for like (due to the differences in regionalisations and emission scenarios), but the results strongly indicate that were wet and dry scenarios constructed as they were in SY but using the

CMIP5 model ensemble, they would not differ substantially. It should also be noted that projected increases in potential evaporation used in SY of 2-4% in 2030 are also consistent with the CMIP5-based results reported in CCIA (Chiew et al. 2008a; CSIRO; BoM 2015). As noted above, the NARCLiM high resolution downscaled projections based on CMIP3 models were not as dry as in the GCMs, although statistical approaches do not show this tendency (Grose et al. 2015).

Based on the above, it may be concluded that the dry and wet climate scenarios for 2030 as used in Sustainable Yields (CSIRO 2012) are still valid and representative (although the probability of the dry scenario may have declined slightly).

Nevertheless, the need to undertake new hydrological modelling using updated climate scenarios would be justified (depending on the available resources) as new specific questions arise, and as climate projections and hydrological modelling science evolves. In particular, the revised Basin Plan due in 2026 would require hydrological projections to be generated for the period that aligns with its planning horizon which will extend well beyond 2030. There will also be at least another decade of observed climate and hydrological additional data that will need to be considered.

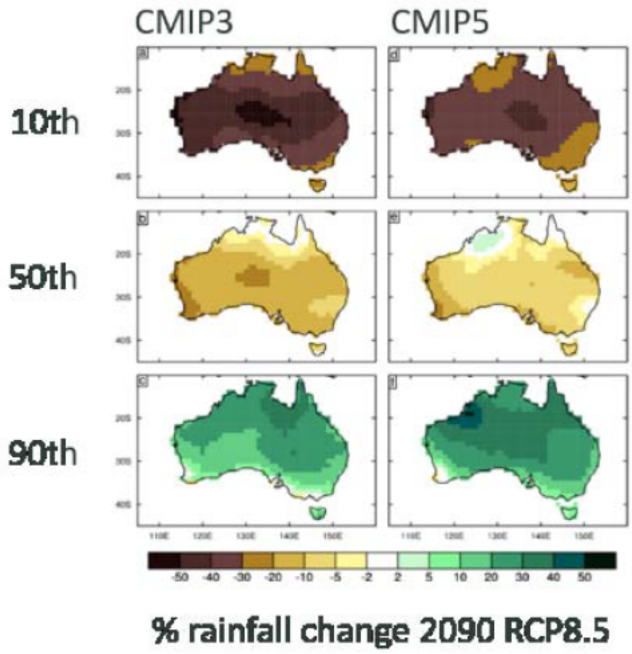

Figure 10: 10th, 50th and 90th percentiles of precipitation change in 2090 (RCP 8.5) for the CMIP3 and CMIP5 model ensembles. Source: reproduced from CSIRO & BoM (2015).

Table 6: Comparison of projected precipitation change in 2030, dry, median and wet cases for the MDB from SY, and 10th, 50th and 90th percentiles for Murray Basin and Central Slopes from CCIA. CCIA results are for RCP8.5, as SY used high emissions to define its wet and dry cases (Chiew et al. 2008a).

	Dry	Median	Wet
MDB average, CMIP3-based (CSIRO 2008b)	-13	-3	+8
Central Slopes, 10th, 50th & 90th percentiles, CMIP5-based (CSIRO; BoM 2015)	-13	-1	+8
Murray Basin, 10th, 50th & 90th percentiles, CMIP5-based (CSIRO; BoM 2015)	-11	-1	+5

Projected changes annual, summer and winter runoff across the Basin in 2030 from SY are presented in Figure 11. Averaged the across the Basin, runoff declines by 33% in the dry scenario and increases by 16% in the wet scenario (CSIRO 2008b). Regionally (Figure 11, top right), the range is around -40% to little change in the southern most catchments of the Basin, and around -30% to +30% in the northern catchments. The dry scenario reduces flow more strongly in winter, and the wet scenario increases flows more strongly in summer (Figure 11, bottom left and right).

Impacts on water availability in each catchment as calculated in SY is indicated in Figure 12. Similar to percentage runoff changes, the southern catchments see little increase in the wet scenario and substantial decreases in the dry scenario. The northern catchments see increases or decreases depending on the scenario. Summed across regions, changes ranges from 11 percent increase (2631 GL/year) under the wet extreme to a 34 percent reduction (7893 GL/year) under the dry extreme climate (CSIRO 2008b). With relevance to the condition of the lower lakes and Murray mouth, estimated end-of-system flows in 2030 assuming current development are an increase of 20% in the wet scenario but a decrease of 69% in the dry scenario (CSIRO 2008a). Crosbie et al. (2010) used the SY scenarios to simulate changes to groundwater recharge in the Basin and found that recharge changes were more biased to increase (stronger increases and weaker decreases) than the surface water changes. More detailed hydrological impact information for these two scenarios may be found in CSIRO (2008b) and Chiew et al. (2008b)

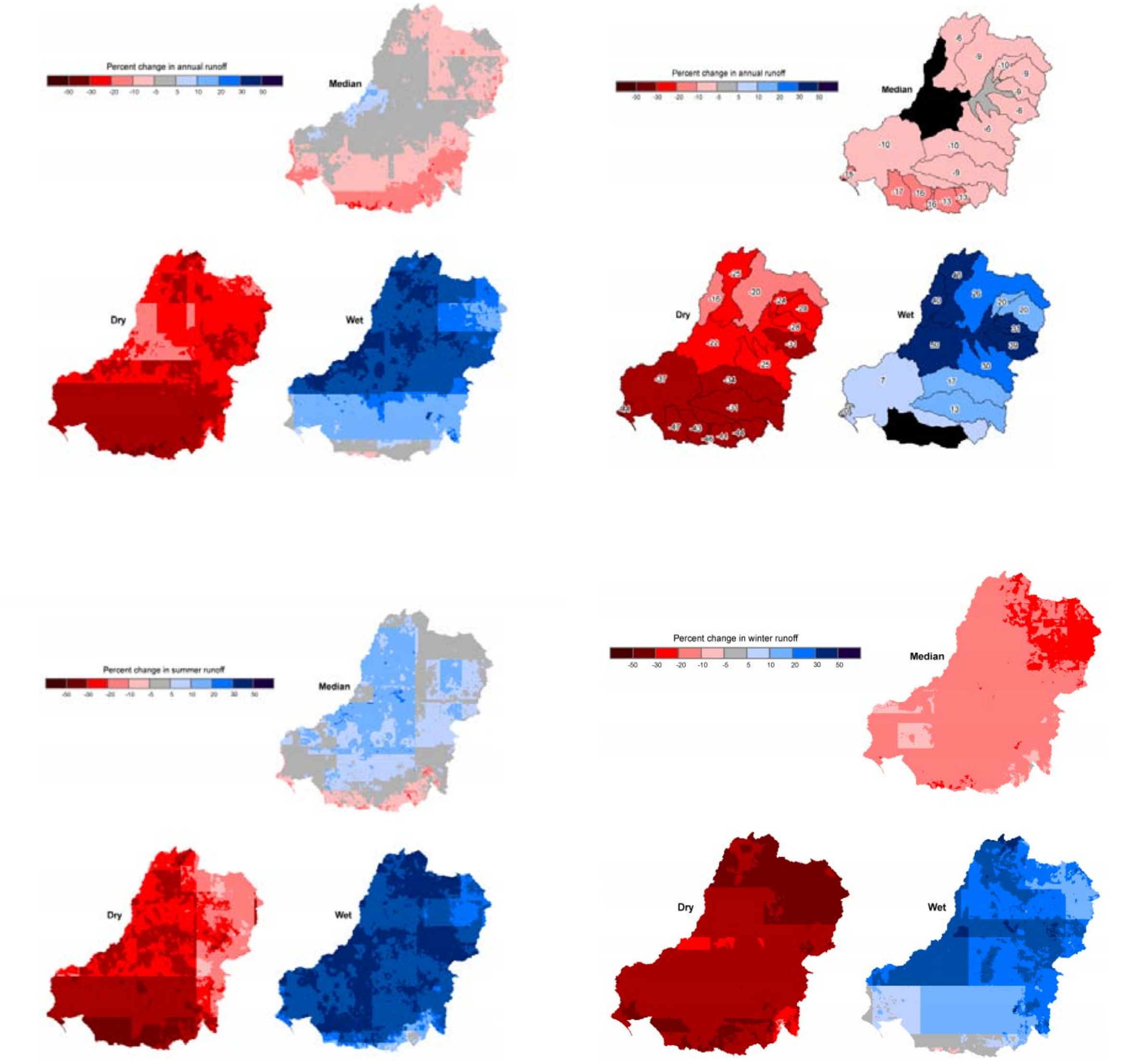

Figure 11: Median, Dry and Wet scenarios from SY for percentage runoff change in 2030: annual gridded data (top left), annual subcatchment average (top right), summer gridded data (bottom left), winter gridded data (bottom right). Source: reproduced from Chiew et al. (2008b).

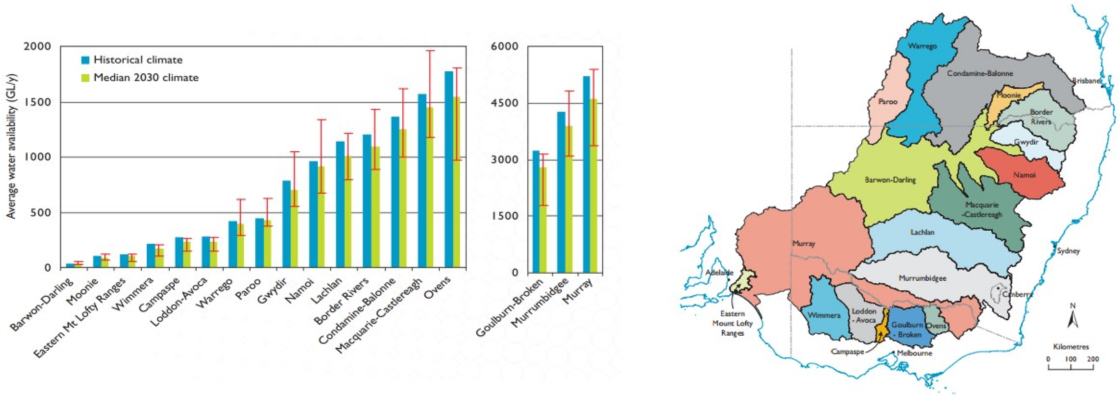

Figure 12 Average surface water availability in GL/year (left) for regions (right) in the MDB. Historical and median future climate for 2030 shown in bars and the wet and dry scenarios by the red bar. Source: reproduced from CSIRO (2008b).

Conclusions

The Murray-Darling Basin area has warmed by around a degree since 1910, and will continue to warm (projected ranges is 0.6–1.5 ^{o}C in 2030 relative to 1995, and by 0.9–2.5 ^{o}C in 2050 without mitigation), with more hot days and fewer cold days. Rainfall is projected to have a tendency to decrease, particularly in the south and in winter, with more time in drought and decreased soil moisture. However, both natural variability and model-to-model difference are large, and both increase and decrease rainfall is possible, particularly in the north. Daily extreme rainfall is projected to increase even when average rainfall declines, with implications for erosion and flooding. Using a climate analogue approach, sites in the Basin 'move' inland/northwest under the hottest/driest scenario and north/northeast in the coolest/wettest scenario. The analogues may be many hundreds of kilometres away and outside the Basin in 2050 under high emissions.

Wet and dry extreme climate scenarios used in Sustainable Yields (CSIRO 2008) were assessed as still valid and representative given latest science, and thus the consequent hydrological scenarios are similarly still valid and representative (although the latest modelling results suggest that probability of the dry scenario may have declined slightly). For the dry scenario there are large reductions runoff and water availability throughout the basin. For the wet scenario there are significant increases in runoff and water availability in the north grading to little change in the south.

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