

Progress towards environmental outcomes in the Murray-Darling Basin

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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 threatened 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?
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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 1a) (BOM 2016). Drought-breaking rains in 2010 resulted in the highest ever annual rainfall recorded in the Murray-Darling Basin (809mm; Figure 1b). 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.

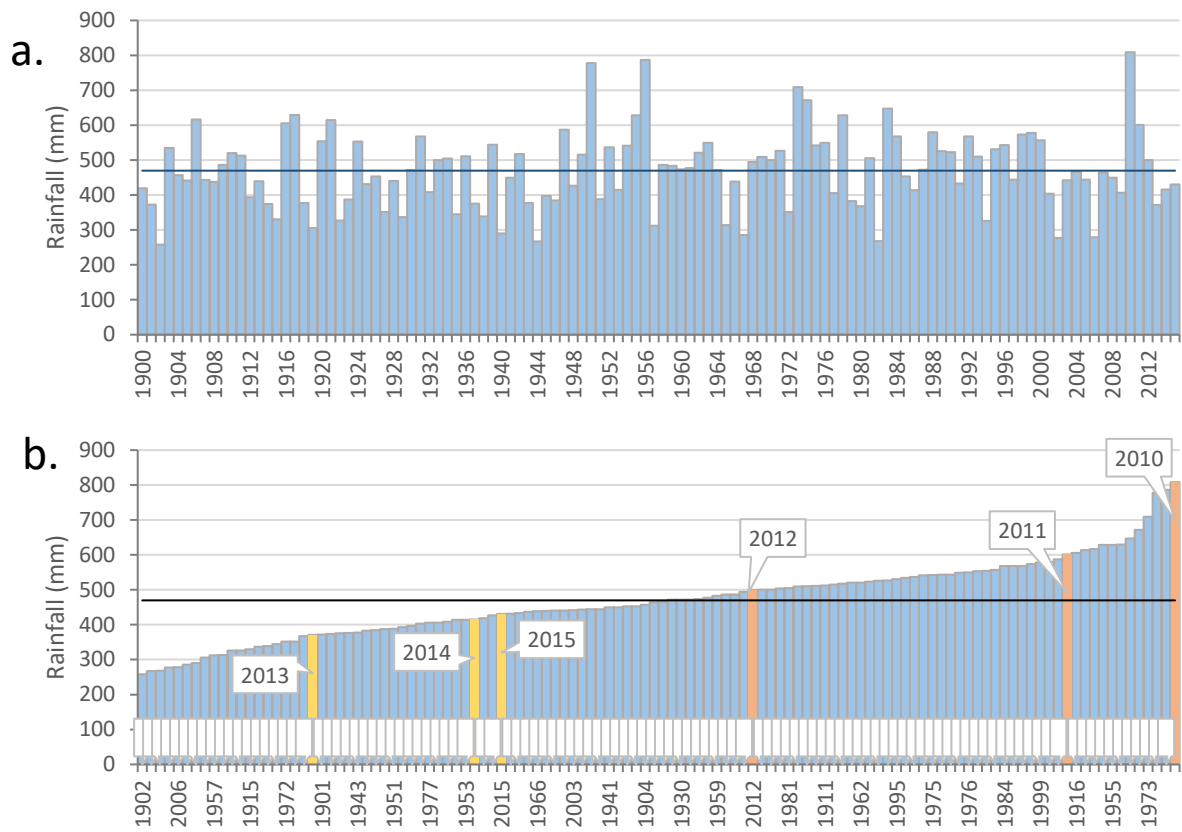


Figure 1. Average annual rainfall (mm) in the Murray-Darling Basin, arranged chronologically (a) and by amount (b) (BOM 2016).

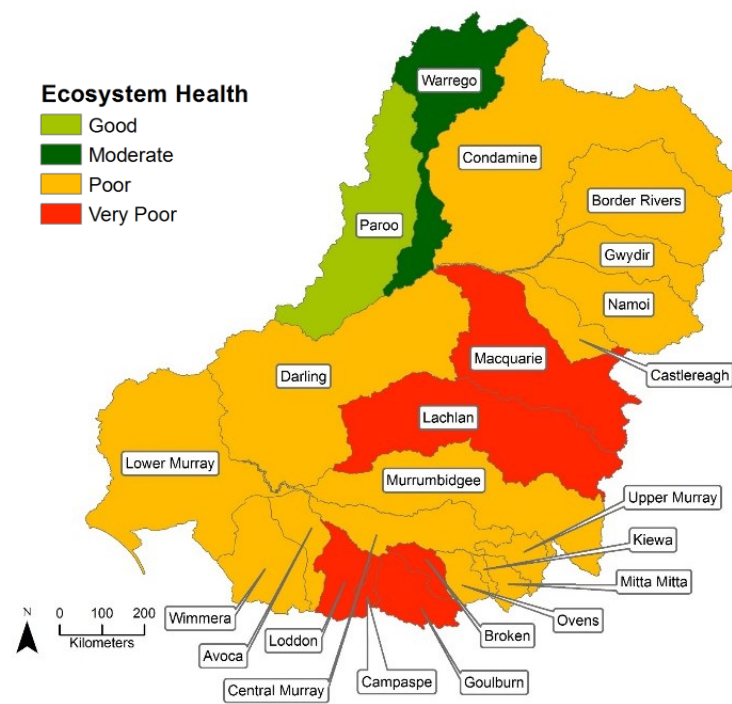


Figure 2. Ecosystem health as reported in the Sustainable Rivers Audit 2 (2008 - 10).

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)							Total
	CEWH	MDBA	NSW	QLD	VIC	SA	Other	
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

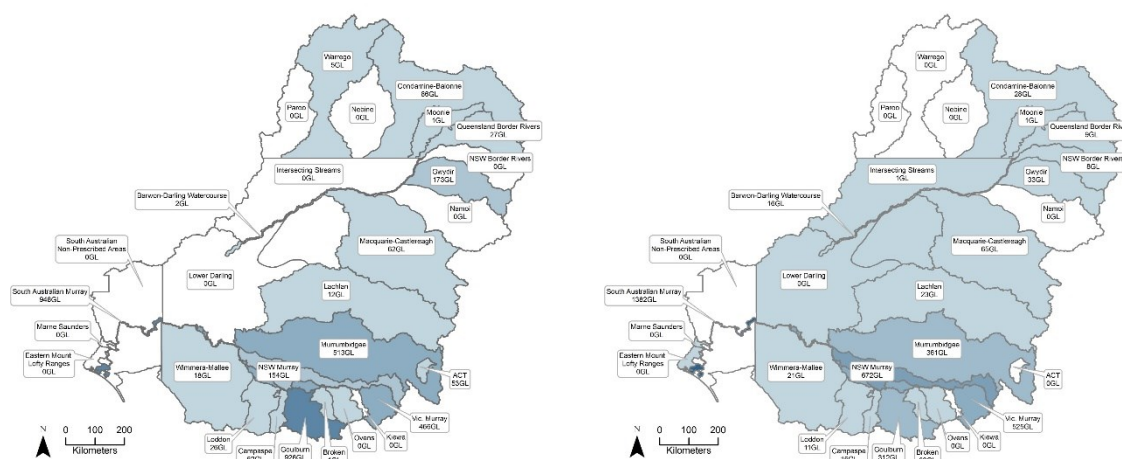


Figure 3. Environmental water delivered by Commonwealth and states in valleys of the Murray-Darling Basin in the (a) 2013-14 and (b) 2014-15 water years (compiled from Schedule 12 Matter 9 reports) (MDBA 2016c). Valley-specific data was unavailable for 2012-13.

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).

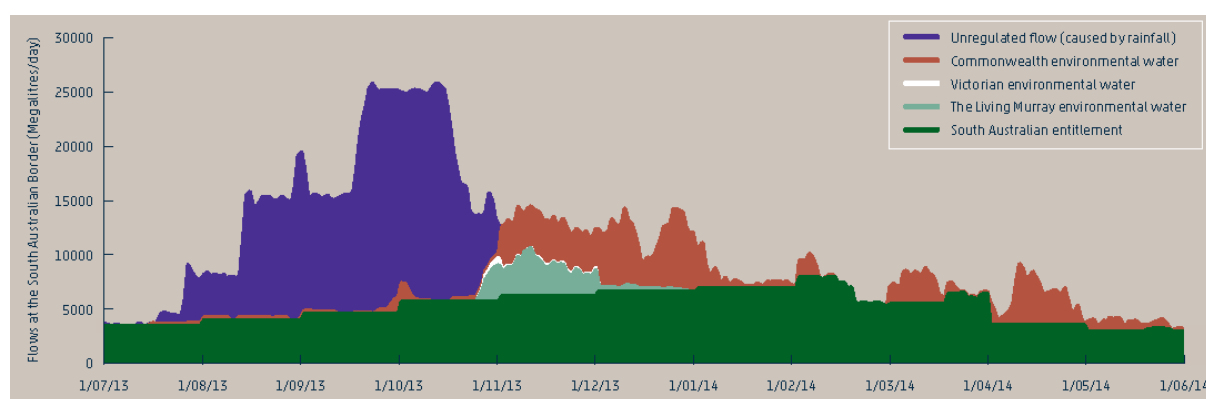


Figure 4. Hydrograph of flows at the South Australian border from July 2013 to June 2014 indicating the contribution of unregulated flow, environmental water held by Basin jurisdictions, and South Australian entitlement flow (CEWO 2014).

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	2012-13	n/a	(CEWO 2013; Southwell <i>et al.</i> 2015c)
	2,011	2013-14		
Macquarie Marshes	15,484	2013-14	n/a	(OEH 2014b; 2016)
	9,323	2014-15		
Lachlan floodplain	63,000	2013-14	n/a	(OEH 2014b)
Edward Wakool	n/a	2014-15	n/a	(Watts <i>et al.</i> 2015)
Lower Murray River, South Australia	~600	2012-13	n/a	(CEWO 2013)

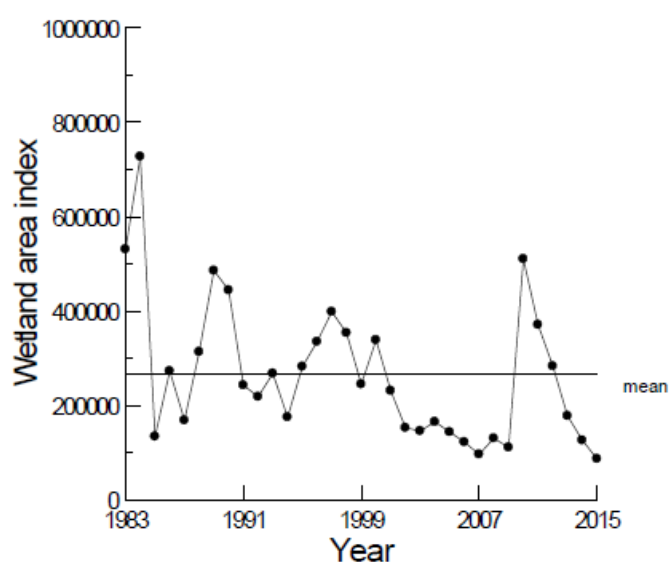


Figure 5. Wetland area index representing 13.5% of the Murray-Darling Basin between 1983 and 2015 (Porter *et al.* 2016).

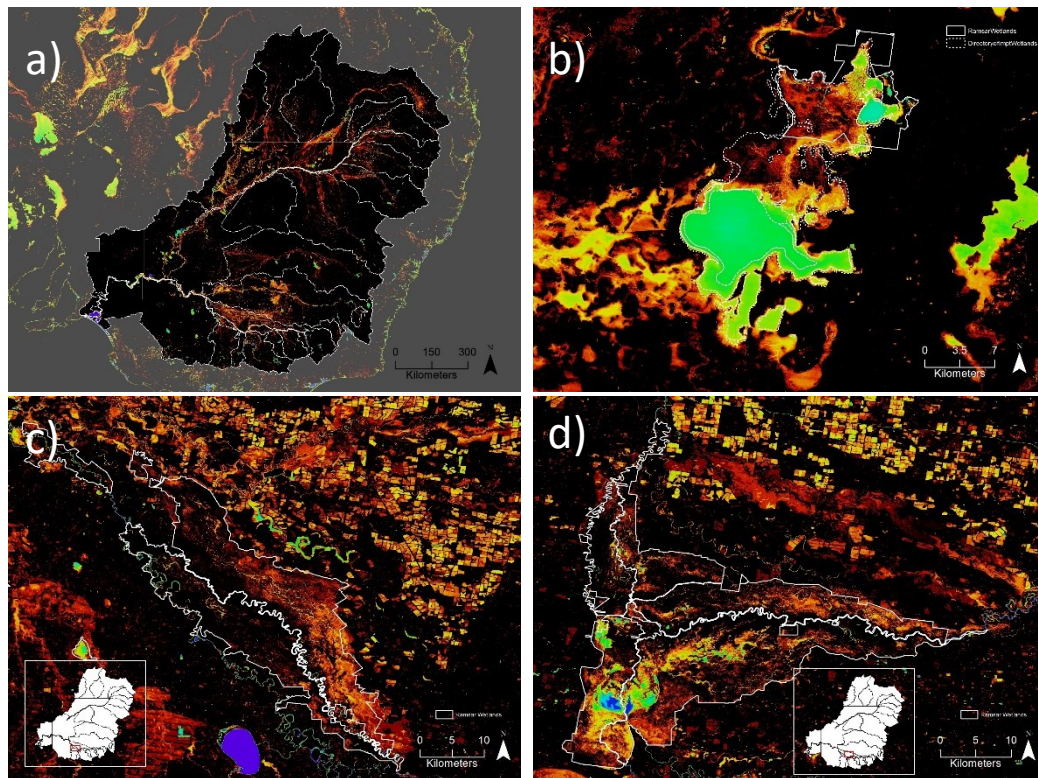


Figure 6. Historical surface water observations based on satellite imagery (Landsat 5 and 7) for the period 1987 to 2016 for the (a) Murray-Darling Basin; (b) Narran Lakes; (c) Gunbower and Koondrook forest; and (d) Barmah-Millewa forest (Geoscience Australia 2016).

Groundwater levels

Groundwater levels reported by the Bureau of Meteorology 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 particularly 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).

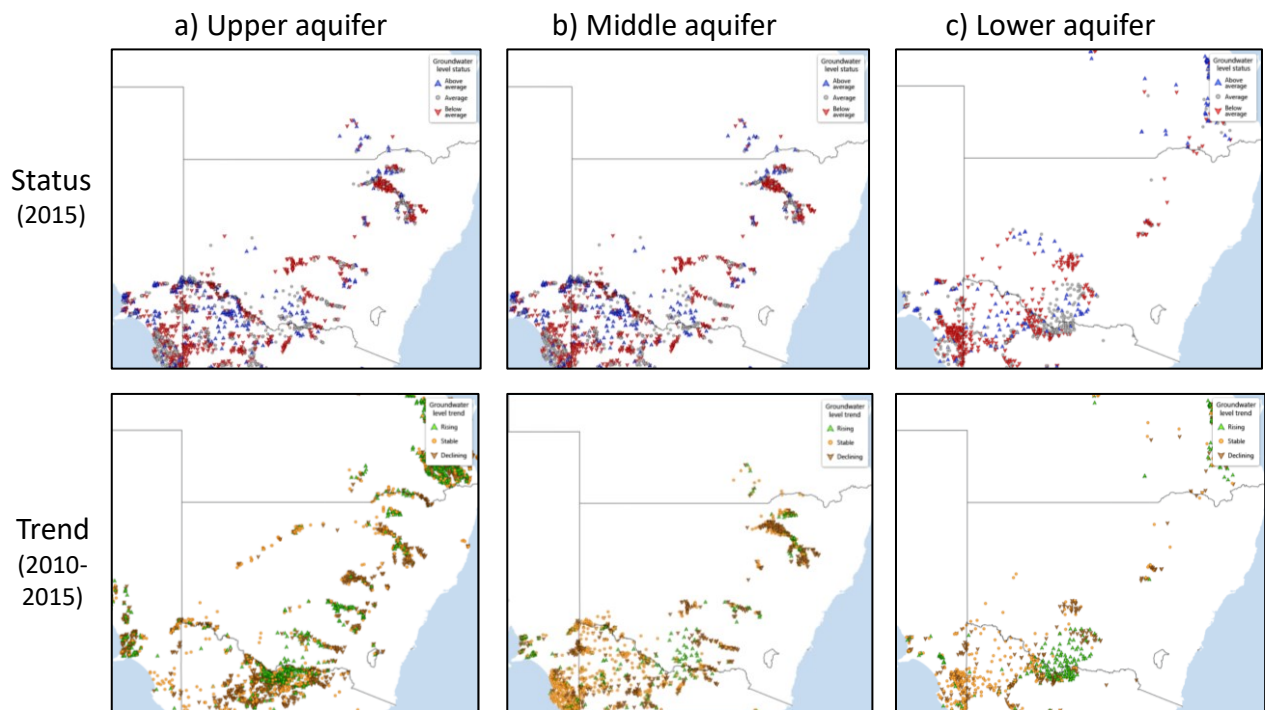


Figure 7. Recent status (2015) and five-year trend (2010-2015) of bores in the (a) upper aquifer, (b) middle aquifer and (c) lower aquifer in the Murray-Darling Basin region (BOM 2015).

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.

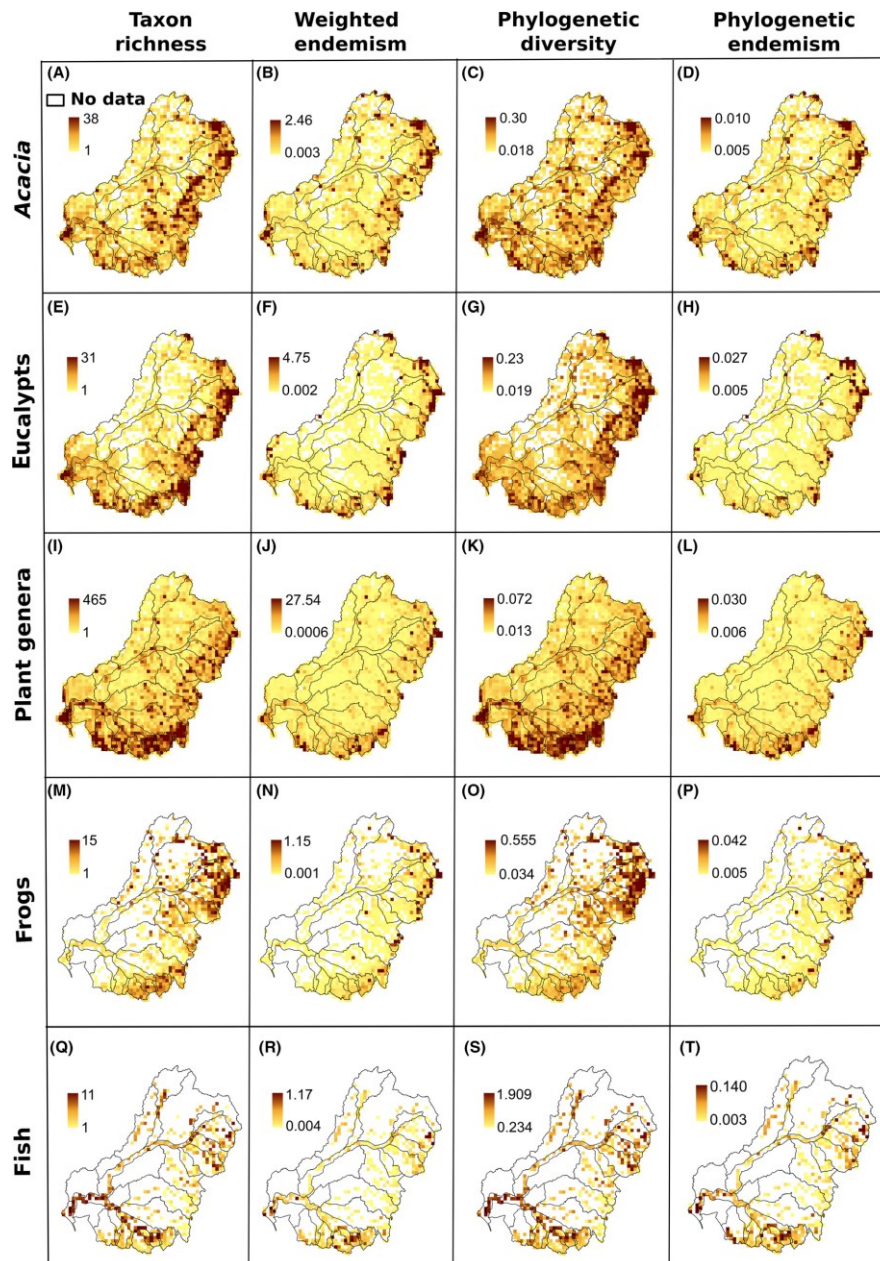


Figure 8. Diversity and endemism for fish, frogs, plant genera, Eucalyptus and Acacia in the Murray-Darling Basin (from González-Orozco *et al.* 2015)

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 $\mu\text{S}/\text{cm}$)	Non-exceedance salinity at 95% of the time ($\mu\text{S}/\text{cm}$)*	% 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
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*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 Tuppall Creek in 2012-13) (CEWO 2013) and Tuppall Creek in 2014-15 (CEWO 2015; Watts *et al.* 2015). There were no negative salinity outcomes reported in relation to environmental watering events.

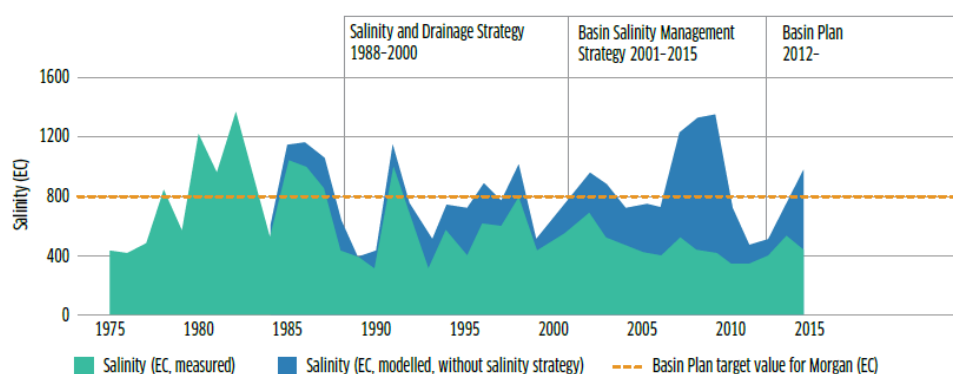


Figure 9. Salinity at Morgan on the River Murray from 1975 – 2015 (MDBA 2014a).

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).

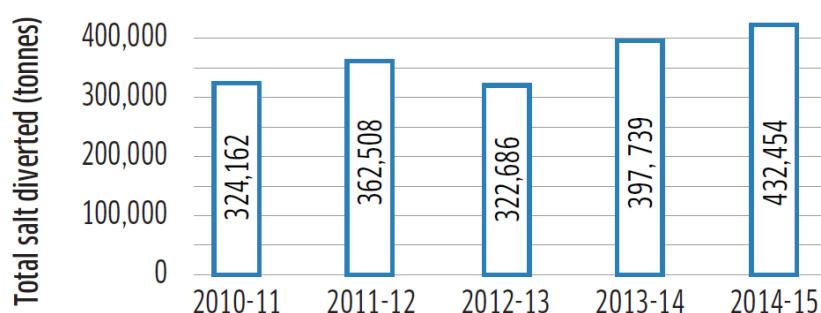


Figure 10. Tonnes of salt diverted from the River Murray from 2010 to 2015 (MDBA 2015a).

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.

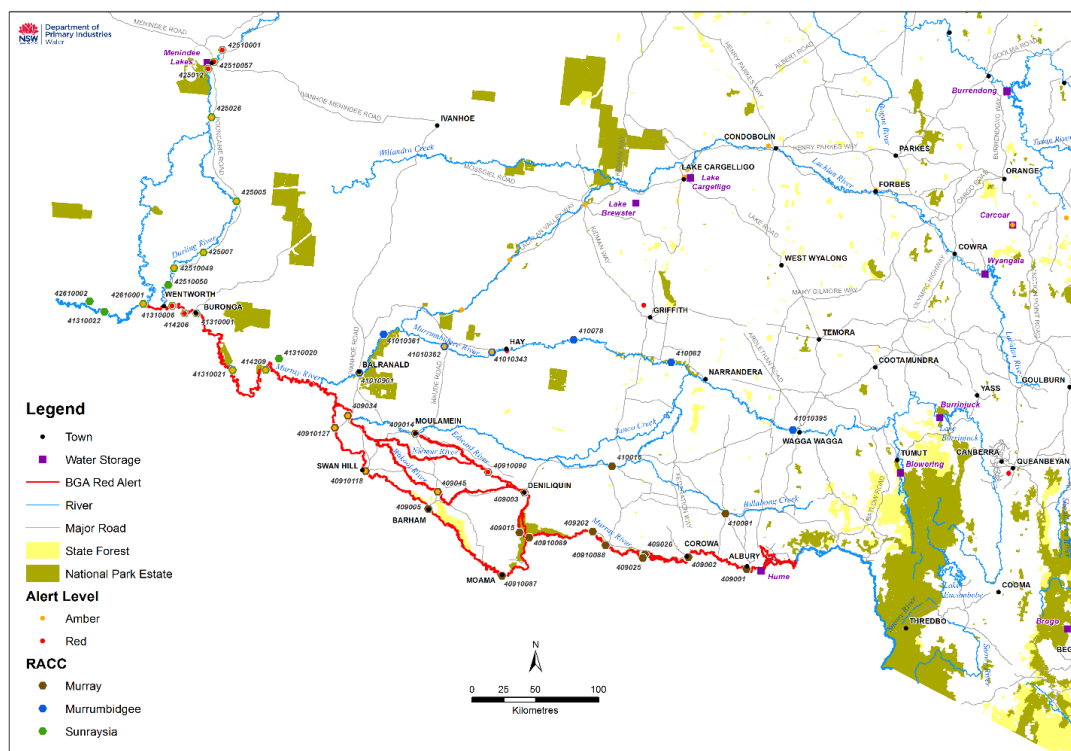


Figure 11. Location of the reach of the Murray River where a blue-green algae red alert was issued in early 2016 (DPI Water 2016).

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.

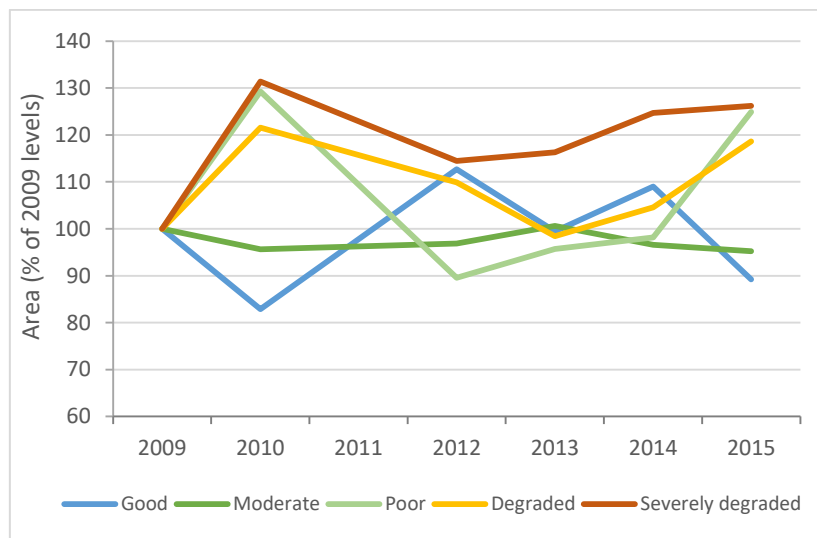


Figure 12. Change in area of floodplain forests and woodlands of different condition across seven Living Murray sites (total of 134,200 ha) relative to 2009 areas. (Source: Compiled from MDBA's stand condition reports; error not quantified). (MDBA 2016d)

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)

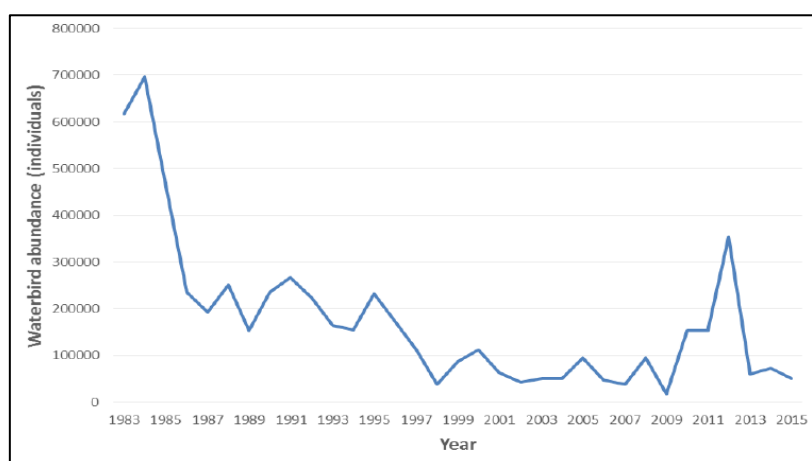


Figure 13. Waterbird abundance across the Murray-Darling Basin 1983–2015 (as estimated during aerial waterbird surveys). (Porter *et al.* 2016)

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)

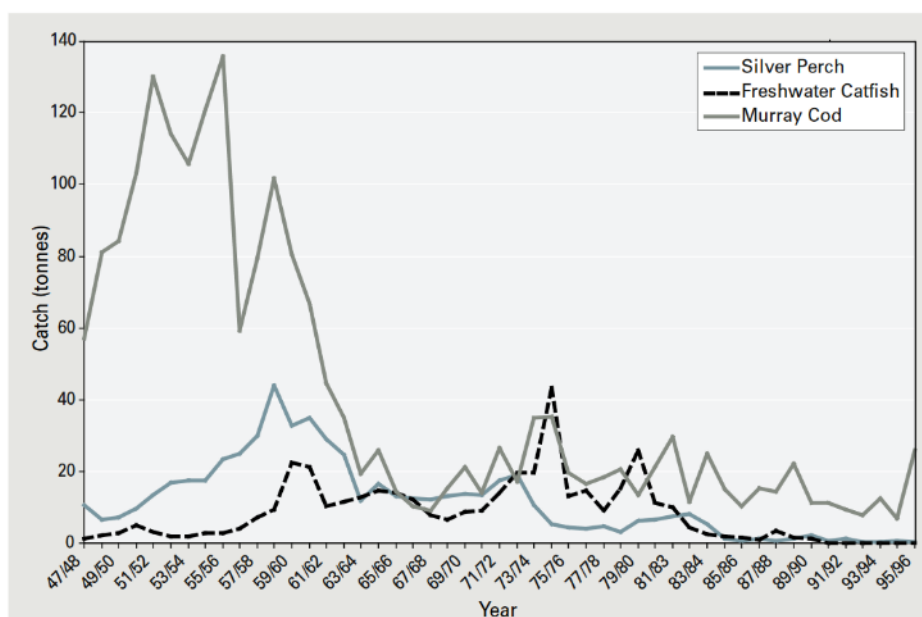


Figure 14. Decline in commercial catches of Murray cod, Freshwater catfish and Silver perch in NSW between 1947 and 1996 (Source: Reid *et al.* (1997) in Lintermans (2009)).

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)

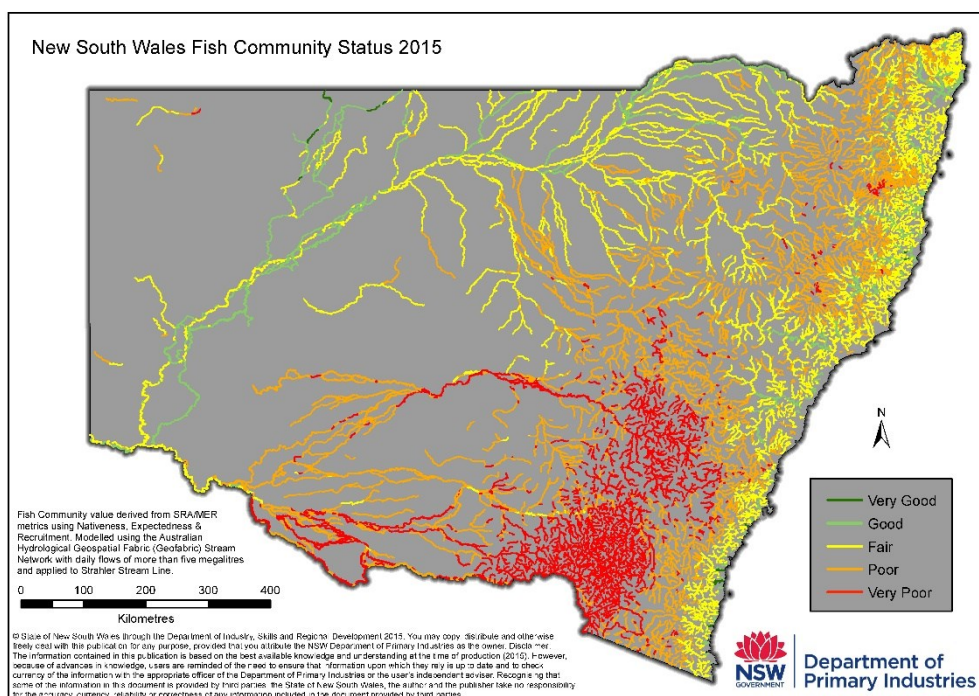


Figure 15. Fish community status in New South Wales.(NSW DPI 2015)

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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