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MURRAY–DARLING BASIN AUTHORITY

The 2020 Basin Plan Evaluation

Southern Basin evidence report

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin
The Murray–Darling Basin Authority pays respect to the Traditional Owners and their Nations of the Murray–Darling Basin. We acknowledge their deep cultural, social, environmental, spiritual and economic connection to their lands and waters.

The guidance and support received from the Murray Lower Darling Rivers Indigenous Nations, the Northern Basin Aboriginal Nations and our many Traditional Owner friends and colleagues is very much valued and appreciated.

Aboriginal people should be aware that this publication may contain images, names or quotations of deceased persons.

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Southern Basin evidence report

This evidence report provides an overview of the information that will be used to evaluate the effectiveness of the Basin Plan against the objectives and outcomes set out in Chapters 5, 8 and 9, and by reference to the matters listed in Schedule 12. Specifically, the scope of this evidence report.

The scope of this evidence report is the environmental outcomes achieved in the southern Basin through managing environmental water allocations to achieve hydrological connectivity.

The evaluation process uses the evidence to develop findings concerning the contribution of the Basin Plan to the achievement of a healthy working Basin and the key characteristics identified in the Basin Plan.

Theory of change

Overall, the theory of change for this theme (Figure 1) within the 2020 Evaluation is:

'The restoration of environmentally significant flow events is expected to reduce the stress on the system leading to improvements in ecosystem condition.'

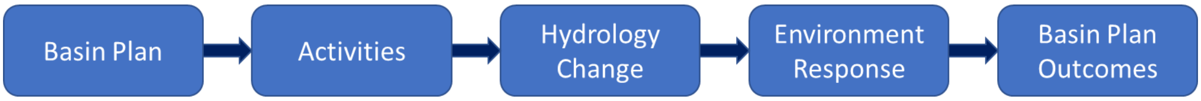

Figure 1 Summary theory of change for the Northern Basin connectivity theme.

A more detailed program logic specific to the objectives for the southern Basin theme is provided in Figure 2.

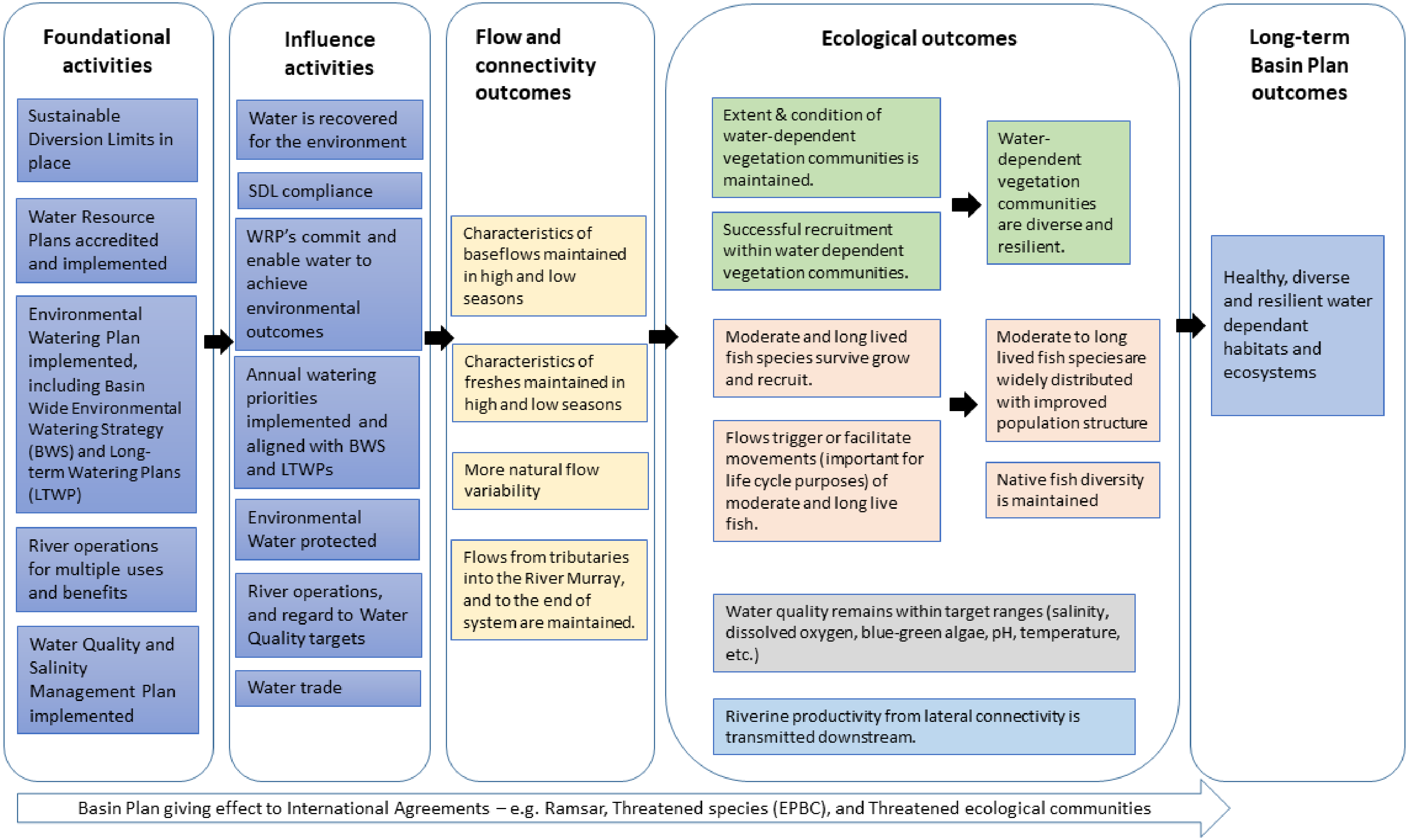

Figure 2 Southern Basin theme program logic

Key theme findings

- The period since the commencement of the Basin Plan in 2012 has been largely characterised by dry climatic conditions across the southern Basin.
- Despite the drought, there have been several improvements in key aspects of hydrology, which have in turn resulted in a contribution towards the maintenance of biodiversity. Since 2013–14 a total of 13,740 GL of environmental water has been delivered across 844 events in the southern Basin, comprising up to 25% of the total annual flow volume. This has maintained baseflows across much of the southern Basin and been effective in providing fresh flows in some rivers.
- There is evidence that environmental water has contributed to maintaining riparian vegetation in the southern Basin
- Environmental flows have also contributed to the maintenance of native fish diversity with 26 of the expected 27 species recorded in the past seven years. With respect to two iconic fish species, there are slightly different outcomes. Populations of Murray cod have been maintained, although there was a decline in abundance of this iconic species in the southern Basin following the 2016 floods and subsequent blackwater events. Golden perch populations have also been maintained. However, there is little evidence of recruitment into the adult population. This may be due to a lack of higher flow pulses, such as high freshes and bankfull events, that have not occurred in the dry conditions.

Executive summary

The southern Basin comprises the Murray, Murrumbidgee, Lachlan and Lower Darling systems in southern New South Wales; the Murray, Goulburn-Broken, Loddon, Campaspe, Ovens and Wimmera–Avoca systems in northern Victoria; and the Murray and Eastern Mount Lofty Ranges systems in South Australia. River regulation and consumptive use have modified the patterns of longitudinal connectivity in many of the southern Basin's rivers, risking the sustainability of the river system.

Since the implementation of the Basin Plan commenced in 2012, conditions across the Southern Basin have largely been dry, with the exception of 2016, when there was high rainfall resulting in a large flood event in late winter, early spring. Water recovery under the Basin Plan in the Southern Basin is estimated as 1,694.6 GL (long-term diversion limit equivalent)701GL per year[1] as of June 2020. Between 2013–14 and 2018-19 a total of 13,740 GL of environmental water was delivered across 844 events in the Southern Basin. On average this represented 17.7% of the total volume of surface water in the Southern Basin.

The hydrological regime in the southern Basin, has been largely maintained or improved since implementation of the Basin Plan commenced, despite continued dry conditions. There has been a maintenance or increase in freshes in several southern Basin rivers, although in many catchments the larger freshes and/or overbank flow are still missing from the hydrograph. Longitudinal connectivity, as indicated by the transmission of flows through the system, has also largely improved across the southern Basin, with a greater proportion of inflow volumes being discharged at the end of the system. The delivery of environmental water has played an important role in maintaining hydrological condition in the southern Basin during dry conditions.

Native riverine fish in the southern Basin have largely been maintained since the implementation of the Basin Plan. Under the Basin Plan 130 fish-targeted watering events (comprising a total of, between 2013 and 2019, 3,756 GL of water) has been delivered between 2013–14 and 2018–19. Many of these have been collaborative events involving multiple water holders. Species richness of the most common and abundant native fish species has been maintained, with 26 of the expected 27 species recorded in the past seven years. After being considered regionally extinct, there is evidence that the southern purple-spotted gudgeon is still present in the southern Basin, with a new population recorded in the Avoca Basin in 2019. It is likely, however, that another small-bodied rare native species, the Yarra pygmy perch, is no longer present in the Murray–Darling Basin after the Millennium Drought.

The distribution and population structure of Murray cod have been maintained, although, there was a decline in abundance of this iconic species in the southern Basin following the 2016 floods and subsequent blackwater events. Distribution and abundance of golden perch has also been

[1] Water recovery figures are expressed in gigalitres long term average annual yield (GL LTAAY). Water recovery figures are from https://www.agriculture.gov.au/sites/default/files/documents/surface-water-recoveries-including-sdlam.pdf

maintained post implementation of the Basin Plan. The population structure of this species is, however, continuing to decline, with little evidence of recruitment into the adult population.

Introduction

This section outlines the context and approaches used in this report. Details of the evaluation are in the following sections on:

- hydrology
- native fish
- vegetation
- productivity.

The Basin Plan 2020 Evaluation

The Basin Plan 2020 Evaluation aims to determine the effectiveness of the Basin Plan in achieving its objectives and outcomes. The approach to the evaluation is to develop evidence relating to the twelve different themes that are shown in Figure 3. Once the findings had been completed the information was drawn together to inform an overarching evaluation report and to address the key evaluation questions listed in the Basin Plan (Box 1). The evaluation outcomes are intended to inform ongoing improvement of the Basin Plan and to support communication of the effectiveness and impacts of the Basin Plan.

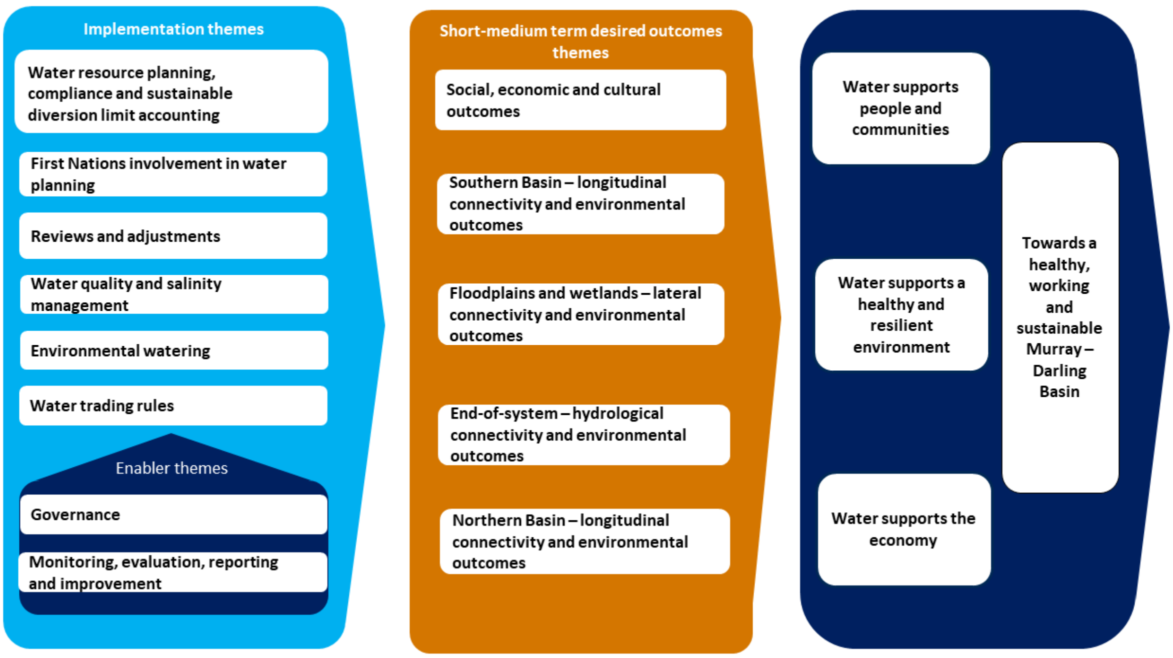

Figure 3 Basin Plan program logic

Box 1: Basin Plan Key Evaluation Questions (Chapter 13)

a. To what extent has the intended purpose of the Basin Plan set out in section 20 of the Act been achieved?
b. To what extent have the objectives targets and outcomes set out in the Basin Plan been achieved?
c. How has the Basin Plan contributed to the changes to the environmental, social and economic condition in the Murray–Darling Basin?
d. What, if any, unanticipated outcomes have resulted from the implementation of the Basin Plan?
e. How could the effectiveness of the Basin Plan be improved?
f. To what extent were the actions required by the Basin Plan suited to meeting the objectives of the Basin Plan?
g. To what extent has the program for monitoring and evaluating the effectiveness of the Basin Plan contributed to adaptive management and improving the availability of the scientific knowledge of the Murray–Darling Basin?

About this report

This report compiles the evidence on the effectiveness of the Basin Plan in achieving outcomes relating to southern Basin flows and environmental outcomes. This is one of four reports that address hydrology and environmental outcomes. The report gives some context around the southern Basin and then presents the evaluation findings. Given the complexity of analysis used in parts of the hydrology and environmental outcomes reports, specific details on the data and analysis methods are presented in attachments to the reports.

Evaluation approach

The Basin Plan requires that the MDBA's evaluation reports on *the achievement of environmental outcomes at the Basin Scale*. Basin state governments are required to report on *the achievement of environmental water at an asset scale*. The reporting timeline for these two requirements is parallel. Given the different reporting scale and the time requirements, this report focusses on Basin scale information (although some small-scale examples are provided). More detailed asset scale reports provided by Basin state governments will be made available on the MDBA website.

The field of evaluation often incorporates multiple lines of evidence to develop the best possible understanding of the value of a program or policy — numbers and statistics are important but they never tell the complete story, hence it is important to include lived experience as part of any evaluation. In the Murray–Darling Basin different types of environmental information is being collected for a range of purposes, using varying methods, and at a range of spatial and temporal scales. As a result, the information available to assess the environmental outcomes of the Basin Plan varies depending on the indicator being assessed. This means that the approach to assessing the individual indictors, and the confidence in the assessment, varies depending on the information available.

The Basin Plan Evaluation addresses questions relating to changes in the condition of the indicators pre and post Basin Plan. This allows us to understand if we are progressing towards the objectives set in the Plan, and in many cases the more detailed targets set through the Basin-wide Environmental Watering Strategy. In addition to this, the evaluation also addresses questions relating to the extent that the Basin Plan has contributed to the observed changes in the indicators.

The analysis approaches used in this report to make an assessment are:

Trend analysis against the pre-basin plan baseline. This approach has been used to assess changes in the condition of an indicator where appropriate data is available from before and after the start of implementation of the Basin Plan.

Comparisons using modelled data. In developing the Basin Plan a number of models have been created using the best available information. Models are used to predict what would occur under certain circumstances. For some indicators models have been used to compare the observed results to the predicted results.

Multiple lines of evidence collated. Evidence for assessing how the Basin Plan has contributed to changes in the condition of indictors largely comes from intervention monitoring programs that assess the impacts of environmental water at local and regional scales across the Basin. In addition to this, there are also lines of evidence relating to the delivery of flows and from research programs. These lines of evidence are drawn together to provide a narrative on the contribution of the Basin Plan.

For some indicators there was insufficient information to make an assessment at the reporting scale. In those cases, where possible, the report provides some information in the form of one or more of the following:

Preliminary lines of evidence presented. Lines of evidence from monitoring programs are presented to provide a narrative on the indictor. However, in this case the lines of evidence are not considered robust or comprehensive enough to make an assessment in this evaluation.

Case studies. An example is provided to demonstrate how the indicator has responded to intervention.

Forward opportunities statement provided. This provides a reflection on the current knowledge relating to the indicator and addresses opportunities in regard to assessment in the 2025 Basin Plan Evaluation.

Background

The southern Basin comprises the Murray, Murrumbidgee, Lachlan and Lower Darling systems in southern New South Wales; the Murray, Goulburn-Broken, Loddon, Campaspe, Ovens and Wimmera–Avoca systems in northern Victoria; and the Murray and Eastern Mount Lofty Ranges systems in South Australia. It is the largest interconnected river system in Australia and accounts for almost half of Australia’s irrigated agriculture and agricultural water use (Bureau of Meteorology 2019).

Most southern Basin rivers rise in the Great Dividing Range and flow into the Murray River, before discharging to the Southern Ocean through the Murray Mouth. Riverine habitats vary across the southern Basin from fast-flowing upland streams through to slower flowing, broad low land rivers. Connectivity through the river system allows for the movement of sediment and nutrients through the system as well as the dispersal of biota. The variety of habitat provides for a diversity of water-dependent plants and animals, with 27 native species of fish; large tracts of riparian vegetation, dominated largely by river redgum forests and woodlands; areas of in-channel vegetation, such as emergent reed beds, and diverse submerged macrophyte communities.

Since the implementation of the Basin Plan in 2012, conditions across the southern Basin have largely been dry, with the exception of 2016, when there was high rainfall and river flows in late winter and early spring (Figure 4). In many respects the climatic patterns for much of the seven years since 2012 have been similar to the conditions experienced during the Millennium Drought. Given that the Millennium Drought saw significant declines in river flows and alterations to water regimes (Heberger 2012; Leblanc et al. 2012), any changes since the Basin Plan must be considered within this context.

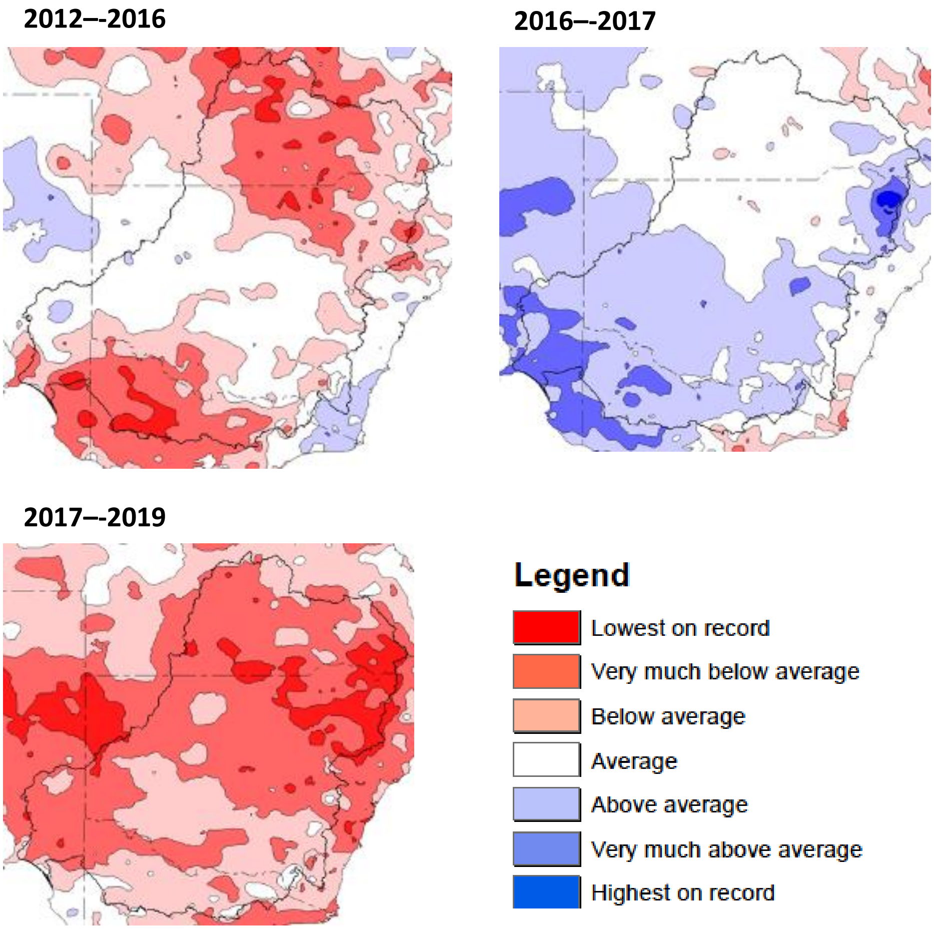

Figure 4 Annual rainfall conditions since 2012 (Bureau of Meteorology)

Non-Basin Plan influences and drivers

To remain healthy, the rivers and floodplains of the Murray–Darling Basin rely on a healthy flow regime and good water quality, which in turn support the water-dependent ecology of the system (e.g. birds, fish, vegetation etc.). Water for the environment, provided by the Basin Plan, is expected to yield tangible benefits for the environment by restoring flow regimes that support ecosystem functions. While the Basin Plan can support the flows and water quality of the Basin system, there are other factors that influence environmental conditions.

One of the biggest factors influencing the environmental condition of the Basin is the climate (long term) and the weather (shorter term). The climate of the Basin is highly variable, and extreme weather events (such as prolonged drought and floods) have a significant effect upon the Basin's environmental condition. Climatic conditions also play a critical role in determining the level of environmental water available within a season and the types of outcomes that may be targeted in any given year.

Ecological outcomes are also affected by things that occur in-stream and within the broader catchment. The historical removal of structural habitat in rivers and the obstruction of passage by weirs and dams are a well-documented threat to native fish populations. Clearing of vegetation along rivers has impacted waterbird populations and has had adverse water quality impacts that have affected instream ecology. In some cases, riparian vegetation is damaged by grazing from either invasive or domestic animals. Invasive species have adversely affected native fish and birds through increased competition and predation.

Hydrology

The approach to the analysis is provided in Attachment 1. Further to this a detailed paper on the hydrology analysis and results is located on the MDBA website [2020 Evaluation: reports and data] page.

Background and summary findings

Flow regimes are fundamental to the ecological functioning of riverine systems and, accordingly, maintaining hydrological regimes is an objective of the Basin Plan and Basin-wide environmental watering strategy (BWS; MDBA 2014). Key components of the flow regime are base flows, freshes, bankfull flows and overbank flows (Figure 5). Each component plays an important role in meeting ecological needs. These are described further as they are introduced as indictors in the assessment on condition of hydrology.

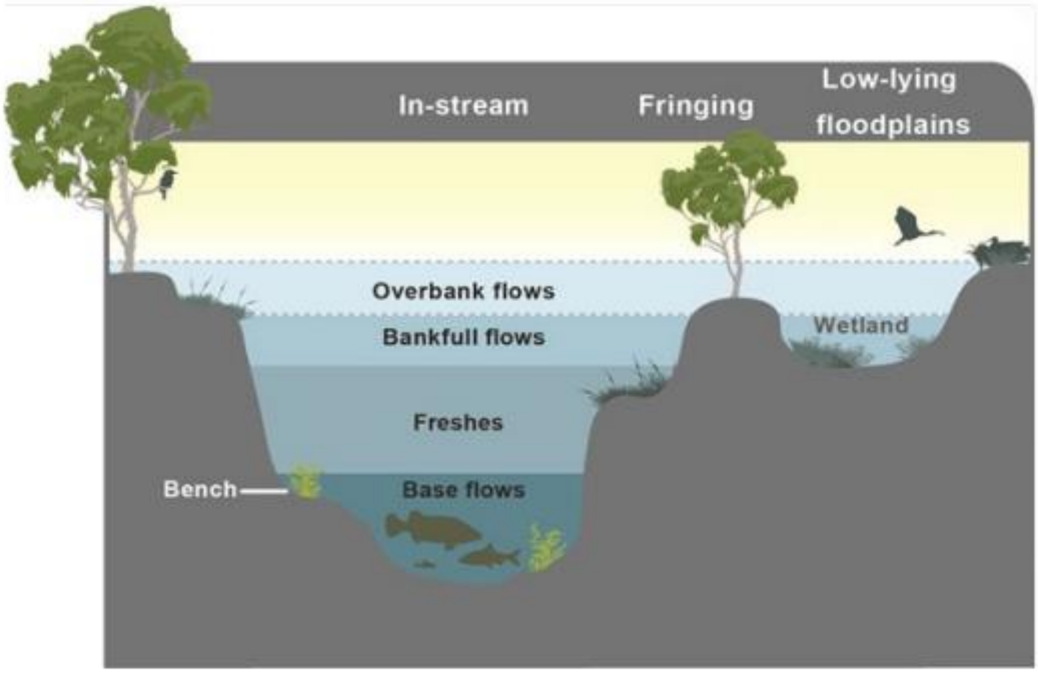

Figure 5 Illustrative river cross-section showing components of the flow regime

In the southern Basin, flow regimes have been altered not only by water resource use, but also be changes in land use and changing climatic conditions. Many of the large river systems in the southern Basin are also used for the delivery of irrigation water, which can lead to altered seasonality of flow and a reduction in flow variability.

The objective of the Basin Plan to maintain or improve hydrology in the southern Basin is defined as: no loss or degradation of flow regimes. In general, there has been an improvement in or maintenance of hydrological regimes in the southern Basin since the implementation of the Basin Plan, despite the continued dry conditions.

- Longitudinal connectivity, as indicated by the transmission of flows through the system, has largely improved across the southern Basin, with a greater proportion of inflow volumes being discharged at the end of the system.
- Without environmental water there would have been many more instances of cease- to-flow events.
- Baseflows have been maintained or improved.
- There has been a maintenance or increase in freshes in a number of southern Basin rivers. The provision of freshes was improved or maintained at six of the eight locations analysed since the commencement of the Basin Plan but declined in two locations—the Lachlan and Loddon Rivers.
- Due to the largely dry conditions that have prevailed over the last eight years, there is not yet sufficient data to fully assess the characteristics of large freshes and overbank flow throughout the Basin. However, the data suggests that in many catchments the larger freshes and/or overbank flow are still largely missing from the hydrograph — prolonged dry conditions are a key driver of this outcome, but management arrangements (e.g. constraints in water delivery levels) are also a factor.

Evaluation assessment

Table 1 Evaluation assessment against key indicators

Indicator	Condition assessment	Assessment of contribution of the Basin Plan
Baseflows	No degradation in baseflows has been achieved	The Basin Plan has made a significant contribution to baseflows.
Seasonality of baseflows	Not assessed: forward opportunities statement provided	Not assessed.
Freshes	No degradation in freshes has been achieved	The Basin Plan has made a significant contribution to low flow freshes. Moderate and high freshes are lacking.
The transmission of flows	No degradation in the transmission of flows has been achieved	The Basin Plan has made a significant contribution to the transmission of flows.
Basin Plan site-specific flow indicators	Results are mixed. Some improvements have occurred in freshes across the southern Basin. Inundation of the lower floodplain around the Barmah–Millewa Forest has also improved. Floodplain flows for the remainder of the southern connected Basin have either been maintained or decreased.	N/A

Basin Plan objectives for hydrology

The Basin Plan establishes a target for hydrology of 'no loss of or degradation in flow regimes' to be achieved by June 2019. The BWS provides the following expected outcomes by 2024 for hydrology (related to longitudinal connectivity in the southern Basin):

1. to keep base flows at least 60% of the natural level (note: this will be especially important during dry years)
2. to provide a 30% overall increase in flows in the River Murray: from increased tributary contributions from the Murrumbidgee, Goulburn, Campaspe, Loddon and Lower Darling catchments collectively.

How have we assessed hydrology?

Table 2: Methodology for assessing hydrology. EO=Ecological outcome

EO	Indicator	Analysis method		Location of data and analysis details
		Condition assessment	**Assessment of the contribution of the BP**	
1	Baseflows	Trend analysis against pre-basin plan baseline	Lines of evidence collated from intervention monitoring programs	Attachment 1
1	Seasonality of baseflows	Not assessed: preliminary evidence presented	Not assessed	
2	Freshes	Trend analysis against pre-basin plan baseline	Lines of evidence collated from intervention monitoring programs	
2	The transmission of flows	Trend analysis against pre-basin plan baseline	Lines of evidence collated from intervention monitoring programs	
2	Basin Plan site-specific flow indicators	Comparisons using modelled data	N/A	

Condition of hydrology

Baseflows

Baseflows (or low, in-channel flows) are an important component of the flow regime, maintaining aquatic habitat for fish, plants and invertebrates.

Baseflows comprise long-term seasonal flows that:

- provide drought refuge during dry periods
- contribute to nutrient dilution during wet periods or after a flood event.

These flows are generally maintained by seepage from groundwater, but also, by low surface flows.

How have the characteristics of base flows in the southern Basin changed since implementation of the Basin Plan?

A condition assessment of baseflows was undertaken utilising the Lyne and Hollick Base Flow Index. This index is a measure of the proportion of total flow volume that is made up by baseflows. A summary of these results is shown in Table 4. Baseflows have been maintained at most locations. For catchments with a non-continuous flow regime (such as the Lower Darling), careful interpretation of the baseflow index is required. In this case, the 'increased' result indicates that a larger *proportion* of the flow downstream of Weir 32 appeared as baseflow — it does not indicate that flow in general has increased. This result can be attributed to the largely dry conditions which has resulted in less unregulated or large fresh events passing through the Lower Darling, hence a larger proportion of the flow since 2012 has appeared as regulated releases.

Table 3 Condition assessment of Lyne and Hollick Base Flow Index before and after 2012 using 1994 observed baseline in southern Basin catchments

Catchment	Lyne and Hollick Base Flow Index
Lower Darling (Weir 32)	Increased
Murrumbidgee (Narrandera)	Maintained
Goulburn-Broken (McCoy's Bridge)	Maintained
Campaspe (Rochester)	Maintained
Loddon (Kerang Weir)	Maintained
Murray (Yarrawonga)	Maintained
Murray (Wentworth)	Maintained

There has been an assessment of progress towards the BWS 2024 target that base flows are kept to at least 60% of the natural level (Stewardson and Guarino 2020). This evaluation reported that only one catchment, the Central Murray, achieved the targeted outcome of 60% of natural base flows in every year of the analysis (2014–19). The Lachlan and Ovens Rivers achieved the target in three out of the five years. The Campaspe, Edward Wakool, Goulburn, Loddon and Murrumbidgee all achieved the target in two of the five years. The Lower Murray achieved the target once, during the flood year of 2016–17. The low rainfall across much of the Basin during the past five years has contributed to the low level of success in achieving the targeted improved base flows (Stewardson and Guarino 2020; Figure 6).

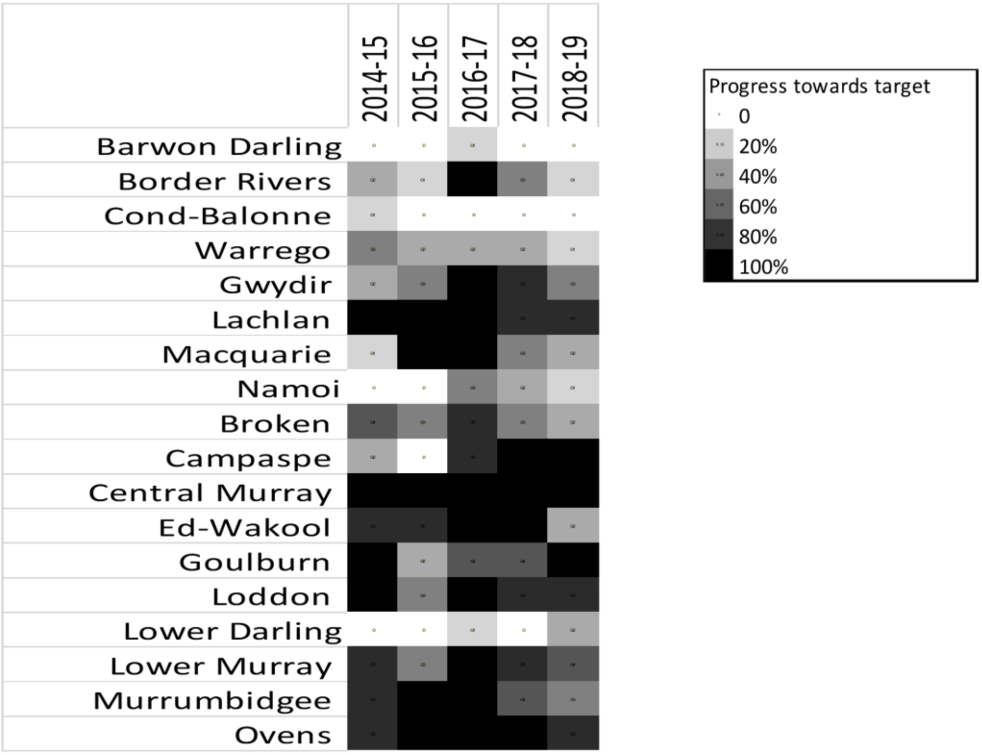

Figure 6 Progress towards meeting the 2024 BWS target for baseflows of 60% of natural level (Stewardson and Guarino 2020)

Seasonality

Forward statement

It has proved challenging to conduct a sufficiently robust initial analysis of seasonality for this evaluation. Early results and their limitations have been discussed in more detail technical report located results located on the MDBA website 2020 Evaluation: reports and data page. This work will be progressed over the coming years with the intent of a robust assessment of seasonality in the 2025 evaluation.

The seasonality of flows plays an important role in supporting ecological responses. For example, native fish species such as golden perch require combinations of water temperature and flow magnitude to trigger spawning events.

Freshes

In-channel fresh events are small-to-medium flow events which inundate benches or small anabranches but stay in the river channel.

They are generally relatively short in duration (i.e. a few days to a month) and typically occur in most years. Under natural conditions fresh events would occur multiple times within a year. These events replenish soil moisture for riparian vegetation, maintain in-stream habitats and cycle nutrients between parts of the river channel. They also inundate snags and woody debris, which form important habitat for invertebrates and the rise in water level associated with freshes can induce reproductive behaviours in native fish.

How have the characteristics of freshes in the southern Basin changed since implementation of the Basin Plan?

An assessment of the number of days above the fresh flow threshold pre- and post- Basin Plan implementation was completed for seven sites in the southern Basin. The sites were selected on the basis of the quality of information available. An assessment has been made against both a modelled and observed baseline. The use of two baselines for this assessment recognises that both observed and modelled data have respective strengths and weaknesses for this type of assessment, hence careful interpretation is required; see Attachment 1 for a description of the differences. The results for freshes varied across the southern Basin catchments. The relationship between inflows and freshes has improved or maintained at some locations post Basin Plan but declined in others (Table 2). In the Goulburn-Broken region, while the overall assessment is maintained there is evidence that freshes have increased in dry years (Figure 7). A similar but more prominent result can be seen in the Campaspe, rated as increased, with increases evident in all low inflow years (Figure 8).

Table 2 Southern Basin Freshes condition assessment summary. See Attachment 1 for explanation of model and observed baseline.

Catchment	Model baseline	Observed baseline
Lower Darling	Unclear	Unclear
Murrumbidgee	Maintained	Increased
Goulburn-Broken	Maintained	Increased
Campaspe	Increased	Increased
Loddon	–	Maintained
Murray	Maintained	Maintain

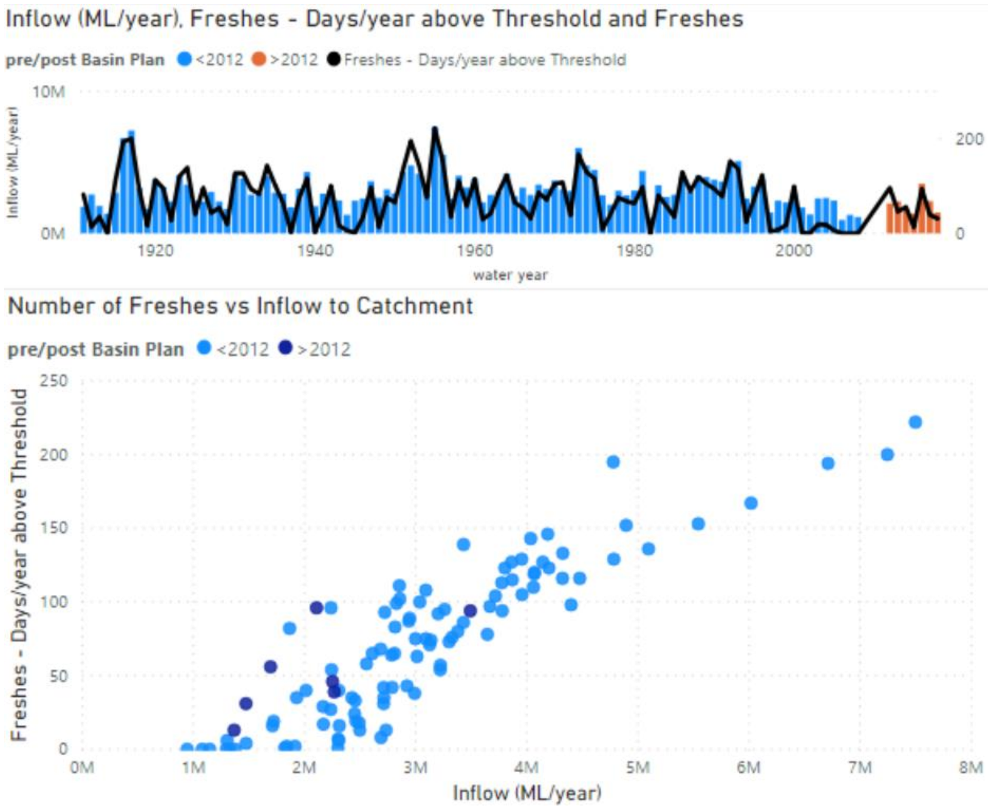

Figure 7 Provision of freshes pre-Basin Plan (light blue dots) and post Basin Plan (dark blue dots) in the Goulburn River at McCoy's Bridge (fresh threshold = 5000ML/day). M denotes 1e+6, i.e. 4M = 4,000,000 ML/yr = 4,000 GL/yr.

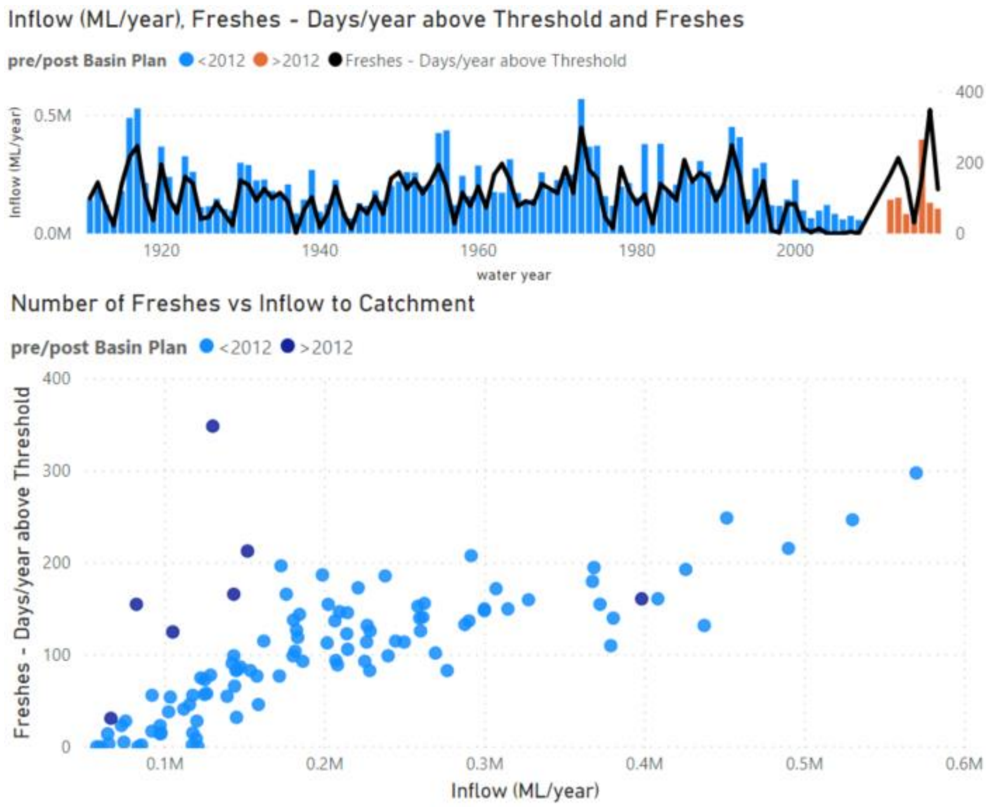

Figure 8 Provision of freshes pre-Basin Plan (blue dots) and post Basin Plan (orange dots) in the Campaspe River at Rochester (fresh threshold = 100ML/d). M denotes 1e+6, i.e. 4M = 4,000,000 ML/yr = 4,000 GL/yr.

Transmission of flows

Transmission of flows is the passage of water along the length of a stream from the headwaters to the point at which it discharges into another river, a terminal wetland or the ocean.

Transmission of flows is important for the movement of nutrients and sediments, the dispersal of biota and for flushing pollutants and salt out of a system. Water resource use has altered the connectivity of the rivers across the southern Basin through physical impediments to flow, such as dams, and in channel structures as well as by reducing the volumes of water that are transmitted along rivers.

How has the transmission of flows through the southern Basin (including volumes from tributaries) changed since implementation of the Basin Plan?

Transmission of flows for the purpose of the evaluation has been assessed using the annual ratio of inflows to outflows in a river system, where inflows have been drawn from the Bureau of Meteorology AWRA model. As above, in recognition of the respective strengths and weaknesses of the available data, an. An assessment has been made against both a modelled and observed baseline—see Attachment 1 for a description of their differences. At the scale of the southern Basin the transmission of flows has been maintained (Figure 9), with many catchments showing maintenance or improvements in flows when compared to pre-Basin Plan observed flows (Table 3).

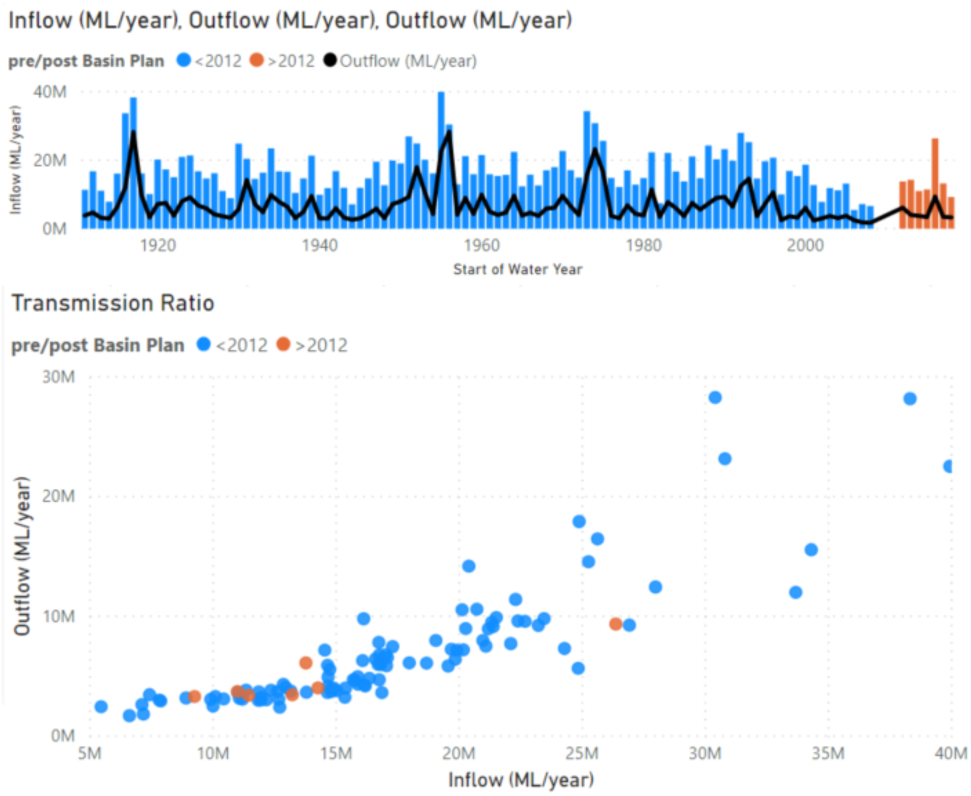

Figure 9 Transmission ratios for the southern Basin (showing pre vs post BP points). M denotes 1e+6, i.e. 20M = 20,000,000 ML/yr = 20 GL/yr.

Table 3 Southern Basin transmission ratio condition assessment summary. See Attachment 1 for description of model baseline and observed baseline.

Catchment	Model baseline	Observed baseline
Lower Darling	–	–
Murrumbidgee	Maintained	Increased
Ovens	–	Maintained
Goulburn-Broken	Maintained	Increased
Campaspe	Unclear	Increased
Loddon	–	Increased
Murray	–	–
Overall south	Maintained	Increased

This analysis is not suitable for determining or tracking the river losses as it does not distinguish between water taken for use or used on the floodplain for watering wetlands and forests or water lost through the movement of water down a river channel.

Basin Plan site-specific flow indicators

As part of the development of the Basin Plan, the MDBA developed the environmentally sustainable level of take (ESLT) method (MDBA 2011) to provide the environmental science foundation for the setting of the sustainable diversion limits (SDLs). Central to the ESLT method were the site-specific flow indicators (SFIs). The SFIs were the primary flow-to-ecology translation metrics that were used during the development of the Basin Plan and were then reapplied as part of the Northern Basin Review (MDBA 2016) and the SDL adjustment mechanism (MDBA 2017). Each SFI maps a specific hydrograph shape (e.g. *x* ML/d for *y* days) to an array of environmental outcomes. Most SFIs are associated with bankfull and overbank flows, while the remainder monitor freshes.

The SFI results were processed for observed flows since 2012. Under the ESLT approach, standard practice is to compare these results with those for the three core Basin Plan model scenarios representing without development, baseline, and a fully implemented Basin Plan respectively. However, these model scenarios have not been extended beyond the 1895–2009 period and hence this direct comparison cannot be made. Instead, a proxy comparison was made by using the existing model scenarios to interpolate probable SFI outcomes since 2012. This was achieved by analysing the model scenarios to build a relationship between the annual inflow volume and the probability of each SFI being met under each model scenario—that is, SFI probability functions. Bootstrap resampling was used to measure the uncertainty in each probability function. Based on these functions and the annual inflow volumes for the 2012–19 period, a Monte Carlo simulation was completed to provide the expected SFI results (with associated uncertainties) under the three model scenarios.

A comparison of the post-2012 SFI results to the baseline data (Table 4) indicates that there has been an increase in freshes across the southern connected Basin. Inundation of the lower floodplain around the Barmah–Millewa Forest (flow measured downstream of Yarrawonga Weir) has also improved. In contrast, floodplain flows for the remainder of the southern connected Basin have either been maintained or decreased. Due to the largely dry climate since 2012 many of the mid-to-high floodplain SFIs are not expected to be achieved in any year under any of the scenarios (including 'without development' conditions), and hence a zero achievement for these SFIs is categorised as 'maintained'.

Table 4 Summary of SFI results for the southern connected Basin

Site	Comparison to baseline		
	Fresh-to-bankfull	**Lower floodplain**	**Mid-to-high floodplain**
Barmah–Millewa	Increase	Increase	Maintained
GKP	Maintained	Maintained	Decrease
Hattah	–	Decrease	Maintained
Chowilla	Maintained	Decrease	Maintained
Mid-Bidgee	–	Maintained	Maintained
Low-Bidgee	–	Maintained	Maintained
Balranald	Increase	–	–
Goulburn	Increase	Decrease	Decrease

Contribution of the Basin Plan to hydrology

Flows delivered in the southern Basin

Water recovery under the Basin Plan in the Southern Basin is estimated as 1,694.6 GL (long-term diversion limit equivalent) 701GL per year[2] as of June 2020. Between 2013–14 and 2018–19 a total of 13,740 GL of environmental water was delivered across 844 events in the southern Basin. This represented an average of 17.7% of the total volume of surface water in the southern Basin (Figure 10). The largest contribution came from Commonwealth environmental water, which makes up approximately 60% of all environmental water. Under the Basin Plan the amount of water delivered by the Commonwealth Environmental Water Holder (CEWH) has increased from an average of 308.5 GL per year between 2008–09 and 2011–12 to an average of 1599 GL per year between 2013–14 and

[2] Water recovery figures are expressed in gigalitres long term average annual yield (GL LTAAY). Water recovery figures are from the Department of Agriculture, Water and Environment.

2018–19. There has also been water delivered throughout the southern Basin from the Victorian Environmental Water Holder (VEWH), The Living Murray program (TLM), NSW State Water, ACT and River Murray Increased Flows (RMIF). Many of the watering actions were delivered jointly through collaboration between state and Australian Government organisations. A breakdown of how water was delivered through the different catchments is presented in

SDL_NAME	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Total
Wimmera-Mallee (Surface Water)	19,813	18,271	5,158	10,821	16,639	15,383	**86,085**
Victorian Murray	322,285	158,739	361,891	103,250	355,086	155,666	**1,456,918**
South Australian Murray	805,830	997,597	941,334	1,056,258	1,380,297	878,452	**6,059,767**
Ovens	70	70	70	70	123	162	**565**
New South Wales Murray	355,705	83,586	199,584	606,727	308,102	142,715	**1,696,418**
Murrumbidgee	254,363	295,824	227,895	530,384	269,959	195,420	**1,773,845**
Lower Darling	55,243		1,000	219,283	25,810		**301,336**
Loddon	11,368	14,528	8,712	14,764	18,565	17,150	**85,086**
Lachlan	23,346	6,471	48,116	55,826	53,804	36,131	**223,693**
Goulburn	312,349	309,371	229,193	229,753	355,333	226,681	**1,662,680**
Campaspe	14,565	31,170	13,658	5,551	29,584	23,356	**117,885**
Broken	38,944	35,194	31,589	36,364	42,908	34,562	**219,560**
Australian Capital Territory (Surface Water)		53,300		2,200			**55,500**
Total	**2,213,880**	**2,004,122**	**2,068,201**	**2,871,251**	**2,856,209**	**1,725,677**	**13,739,338**

SDL_NAME	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Total
Australian Capital Territory (Surface Water)		6		2			**8**
Broken	4	3	4	1	3	4	**19**
Campaspe	3	2	1	1	1	1	**9**
Goulburn	3	1	3	1	3	4	**15**
Lachlan	4	3	5	4	3	10	**29**
Loddon	4	4	2	3	4	3	**20**
Lower Darling	2		1	3	1		**7**
Murrumbidgee	23	19	19	15	12	14	**102**
New South Wales Murray	23	19	27	23	17	10	**119**
Ovens	1	2	1	2	2	2	**10**
South Australian Murray	33	60	8	5	6	8	**120**
Victorian Murray	30	27	27	14	29	20	**147**
Wimmera-Mallee (Surface Water)	38	26	43	34	49	49	**239**
Total	**168**	**172**	**141**	**108**	**130**	**125**	**844**

Figure 11.

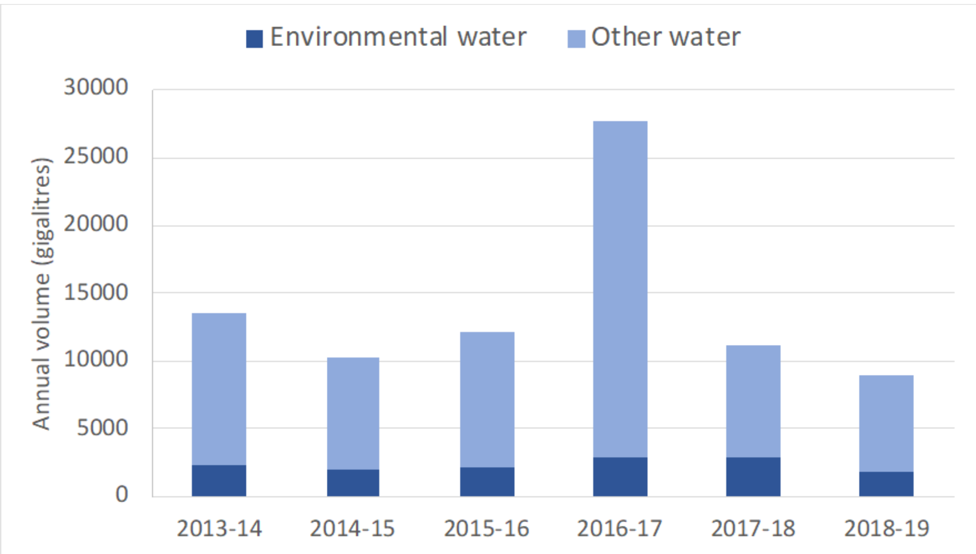

Figure 10 Volume of environmental water in the Southern Basin in the context of other southern Basin inflows 2013–19

SDL_NAME	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Total
Wimmera-Mallee (Surface Water)	19,813	18,271	5,158	10,821	16,639	15,383	**86,085**
Victorian Murray	322,285	158,739	361,891	103,250	355,086	155,666	**1,456,918**
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Campaspe	14,565	31,170	13,658	5,551	29,584	23,356	**117,885**
Broken	38,944	35,194	31,589	36,364	42,908	34,562	**219,560**
Australian Capital Territory (Surface Water)		53,300		2,200			**55,500**
Total	**2,213,880**	**2,004,122**	**2,068,201**	**2,871,251**	**2,856,209**	**1,725,677**	**13,739,338**

SDL_NAME	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Total
Australian Capital Territory (Surface Water)		6		2			**8**
Broken	4	3	4	1	3	4	**19**
Campaspe	3	2	1	1	1	1	**9**
Goulburn	3	1	3	1	3	4	**15**
Lachlan	4	3	5	4	3	10	**29**
Loddon	4	4	2	3	4	3	**20**
Lower Darling	2		1	3	1		**7**
Murrumbidgee	23	19	19	15	12	14	**102**
New South Wales Murray	23	19	27	23	17	10	**119**
Ovens	1	2	1	2	2	2	**10**
South Australian Murray	33	60	8	5	6	8	**120**
Victorian Murray	30	27	27	14	29	20	**147**
Wimmera-Mallee (Surface Water)	38	26	43	34	49	49	**239**
Total	**168**	**172**	**141**	**108**	**130**	**125**	**844**

Figure 11 Environmental water (volume top and number of events bottom) delivered per catchment per year. This data is provided to the MDBA in annual reporting from water holders.

This report considers the contribution of the total volume of environmental water (i.e. water from all of the water holders as reported annually to the MDBA) to outcomes where possible. However, for a number of indictors the report has relied on the contribution of Commonwealth Environmental Water as the major line of evidence as a result of information availability.

At least 80% of annual environmental water used in the southern Basin was held environmental water (HEW) (Figure 12), meaning that the entitlement is held in storages and strategically delivered to achieve environmental outcomes. Less than 10% of environmental water in the southern Basin has been rules-based planned environmental water (PEW) (Figure 12), meaning that it is committed for a specified environmental purpose, usually at a specified time or in specified circumstances., and cannot be taken for any other purpose. Despite the large portion of held environmental water, there are constraints in the southern Basin, including physical structures, river management practices, and operational limits, that limit the strategic delivery of water to achieve environmental outcomes.

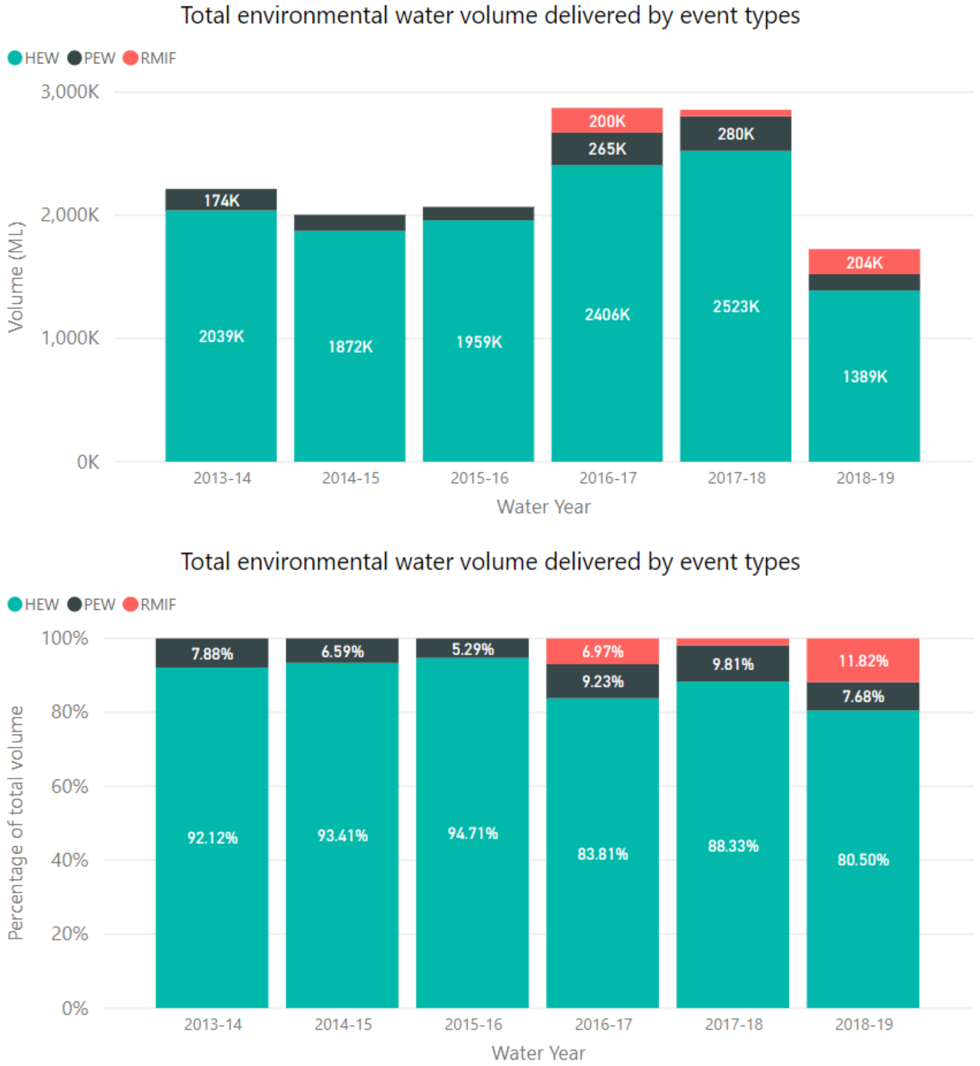


Figure 12 Environmental water volumes delivered in the southern Basin. This data is reported on an annual basis to the MDBA by all water holders. These figures include water deliverd by all water holders in the soutehrn Basin and includes held environmental water (HEW), planned environmental water (PEW) and River Murray Increased Flows (RMIF).

Environmental flows have been delivered with a variety of primary purposes. In the southern Basin the primary purpose that received the largest volume of water between 2013–14 and 2018–19 was fish, and second to this was longitudinal connectivity, followed by vegetation and end-of-Basin flows. Each of these flows is designed to meet particular ecological needs of the system, and hence return some natural elements of the hydrograph to this highly regulated river system.

Between 2013–14 and 2018–19, 67% of the total volume of environmental water delivered was delivered as joint watering events with multiple water holders contributing. Since 2016–17 the volume of water delivered as a collaborative joint event has been more than 80% of the total flow delivered. Collaboration and coordination of joint watering events has occurred in line with the principles of the Environmental Management Framework set out in the Basin Plan.

Base flows

How have the recovery, delivery and protection of environmental water contributed to base flows in the Southern Basin?

Long-term intervention monitoring (LTIM) Hydrology Basin Matter Reporting was used to assess the contribution of environmental water to baseflows (Stewardson and Guarino 2020).

This analysis considers baseflows in two categories:

1. The very-low flow baseflow score relates to the duration of exceptionally low flows at the lower end of the range that would have occurred normally prior to water resource development.
2. The low flow baseflow score relates to the duration of flows below a level that that might typically be used as a minimum environmental flow to maintain low flow habitats.

Stewardson and Guarino (2020) suggest that extended periods of very -low flows were avoided across parts of the southern Basin, with significant contributions of environmental water (Figure 13). Environmental water entitlements contributed to avoiding very-low flows in most southern Basin sites with important contributions from Commonwealth environmental water in the Lower Murray, Edward-Wakool, Goulburn, Broken and Murrumbidgee rivers. Contributions of non-Commonwealth environmental water appear to have made important contributions in the Lachlan, Campaspe and Loddon. In contrast, there were significant periods below the low flow threshold across much of the southern Basin (Figure 14). In the southern Basin, 2018–19 saw a decline in low-flow metrics in the Lachlan, Murrumbidgee, and both the central and lower Murray valleys. In contrast to other valleys, low flow conditions improved dramatically in the upper reaches of the Campaspe River, Goulburn and Broken Rivers, with important contributions from environmental water in both the Campaspe and Goulburn (Figure 14).

Commonwealth environmental water has made important contributions to improved baseflow conditions in some southern Basin valleys, including the lower and central Murray, Edward-Wakool and Goulburn. This has been particularly important in avoiding very severe baseflow conditions in these valleys. Water from other environmental water holders also appears to have played an important role in maintaining baseflow levels. Given that the volume of water delivered by the Commonwealth Environment Water Holder has increased by approximately 80% since implementation of the Basin Plan and subsequent water recovery, it is clear that that policy has contributed to this outcome. During such a dry climate sequence it is likely that, in the absence of the Basin Plan, baseflow conditions in a number of catchments would have declined.

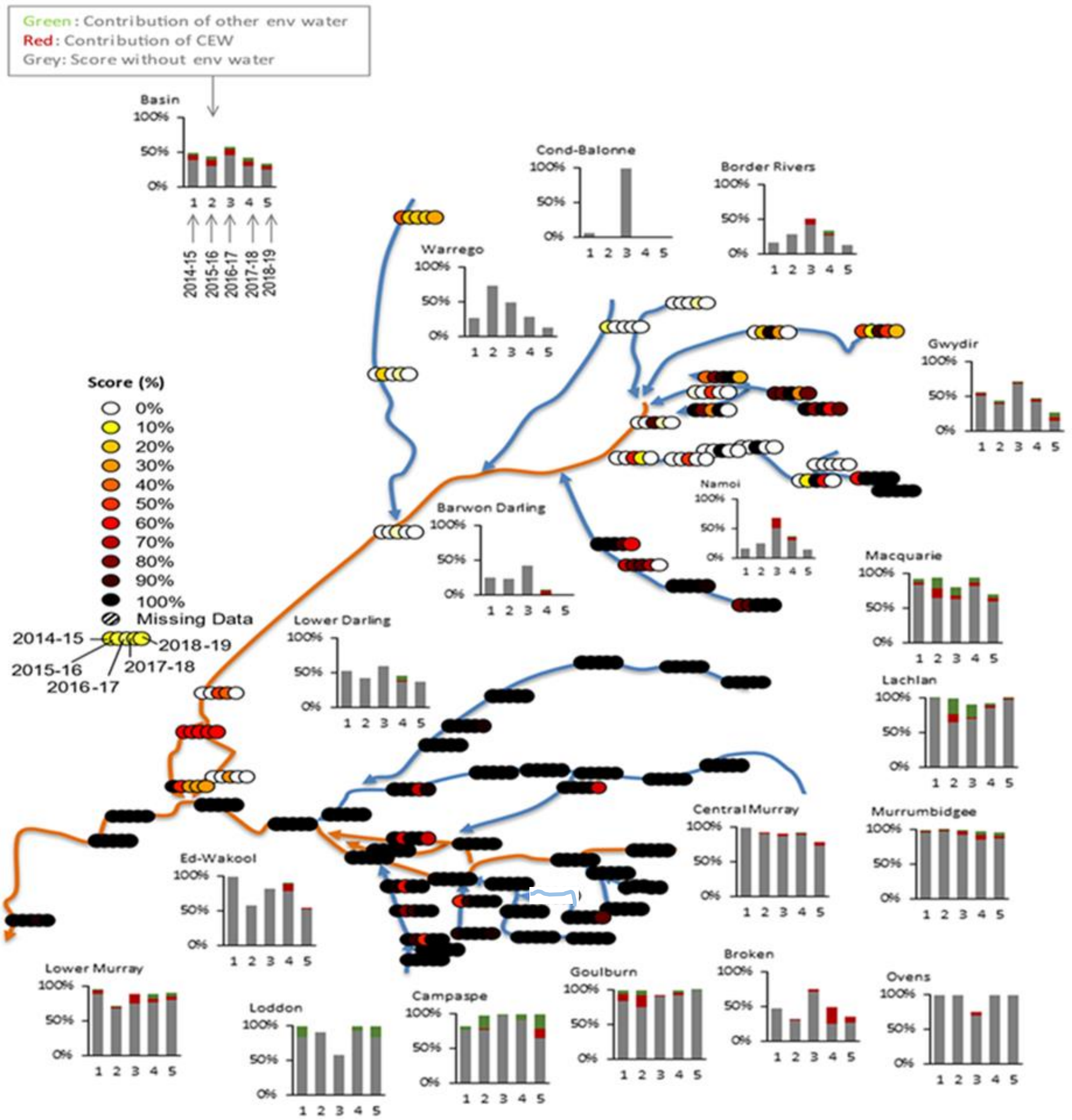


Figure 13 Annual very low baseflow score from 0% (extremely dry) to 100% (average conditions)(Stewardson and Guarino 2020)

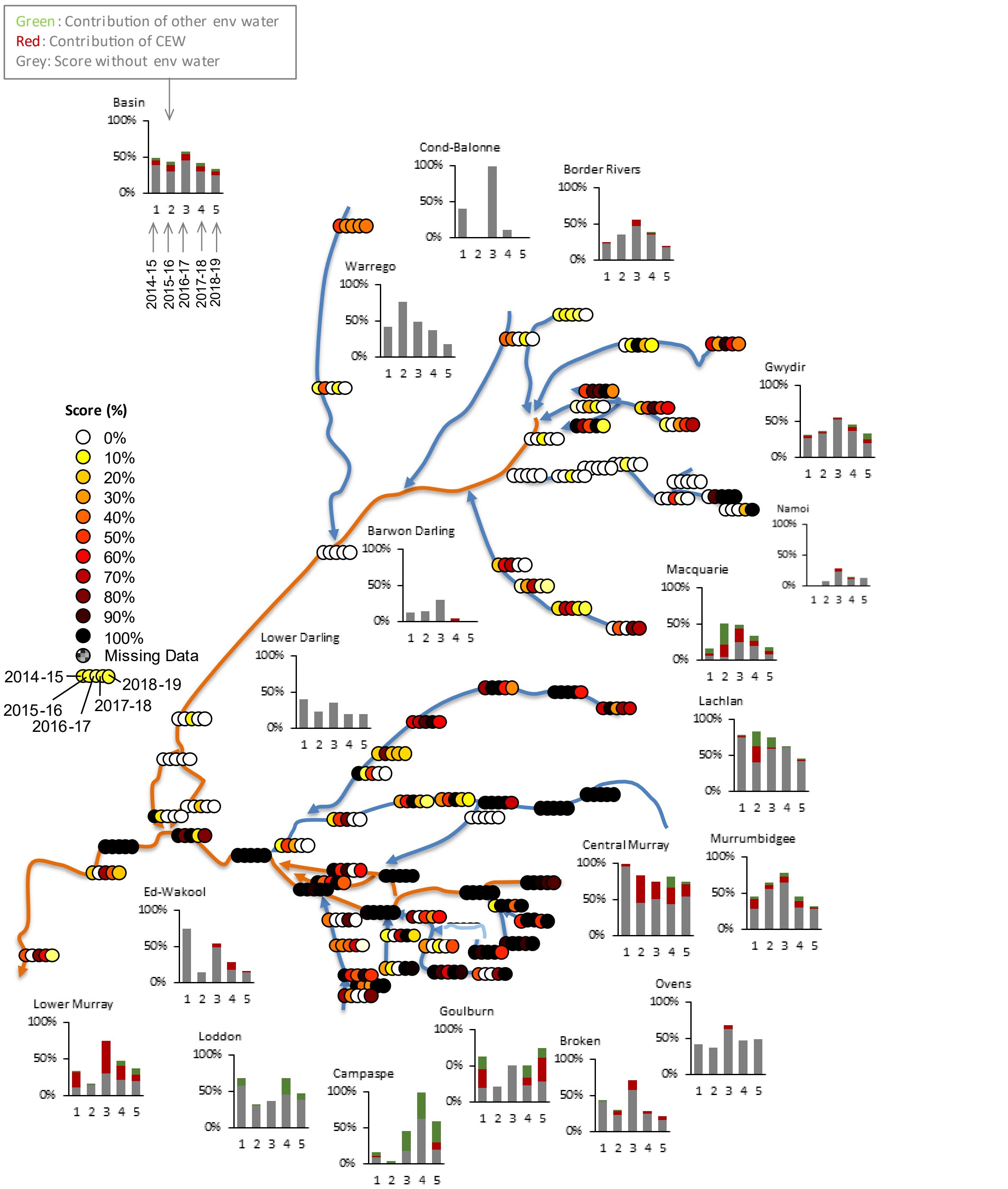


Figure 14 Annual low flow baseflow score from 0% (extremely dry) to 100% (average conditions) (Stewardson and Guarino 2020)

Freshes

How have the recovery, delivery and protection of environmental water contributed to the characteristics of freshes in the southern Basin?

LTIM Hydrology Basin Matter Reporting was used to assess the contribution of environmental water to freshes (Stewardson and Guarino 2020).

This analysis considers freshes in three categories:

1. A **low-fresh** is defined as a flow that raises water levels at least one-eighth of the height of the bank above the low flow level. Such freshes would be a very frequent occurrence in both the dry and wet seasons under pre-development conditions.
2. A **medium-fresh** is defined as a flow spell that raises water levels at least one-quarter of the height of the bank above the low flow level. This threshold would be a frequent occurrence in the pre-development regime, maintaining moist soils.
3. A **high-fresh** is defined as a flow spell that raises water levels at least half of the height of the bank above the low flow level. Freshes of this magnitude would have occurred in most years in an unaffected flow regime, often multiple times.

The LTIM work indicates that some contributions were made from environmental water to freshes in the southern Basin. In particular, environmental water has contributed substantially to improving low freshes in the Lower Murray, Campaspe and Goulburn Rivers (Figure 15). Moderate and high freshes, however, are lacking in many valleys of the southern Basin, including the Edward-Wakool, Loddon and Broken valleys, and with the exception of isolated cases in individual rivers (e.g. the Murrumbidgee in 2017–18) environmental water has not contributed significantly to restoring these flow regimes.

Despite the finding that moderate and high freshes are lacking in some valleys, including the Loddon, the assessment of condition of freshes post implementation of the Basin Plan found evidence that in some catchments, including the Loddon, the number of days above the flow threshold was higher during dry years than it was pre-Basin Plan. This suggests scores may have been worse without the delivery of environmental water under the Basin Plan.

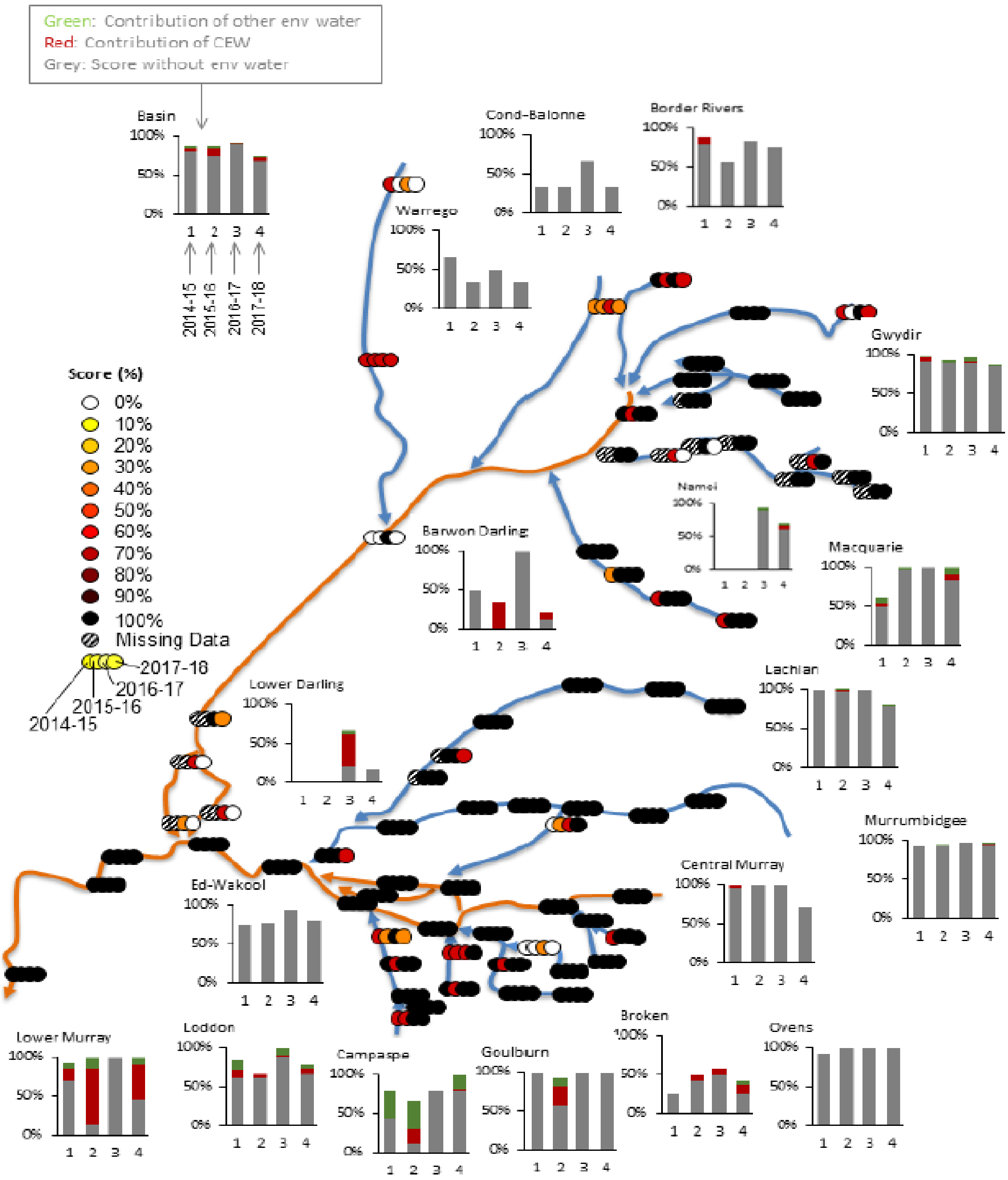


Figure 15 Annual low-fresh score from 0% (extremely dry) to 100% (average conditions) (Stewardson and Guarino 2020)

Transmission of flows

How have the recovery, delivery and protection of environmental water contributed to the transmission of flows in the southern Basin?

Delivery of 13,740 GL of environmental water under the Basin Plan has made a significant contribution to the transmission of flows in the southern Basin, more so in dry years, where it accounts for a significant proportion of the total surface water (Figure 16).

In the southern Basin catchments, between 0% and 100% of the total annual flow in each river system has been contributed by environmental water (Figure 16). Contributions have been significant in the Goulburn and lower Murray. In general, the contribution of environmental water increased further downstream, this reflects increased opportunities for environmental water management in the lower reaches of the system. While this pattern is evident across most of the southern Basin, it is not the case in the Lower Darling, where the contribution of environmental water to end-of-system flows was very little for four of the last five years, but was close to 100% of the total surface flow at some sites in 2016–17.

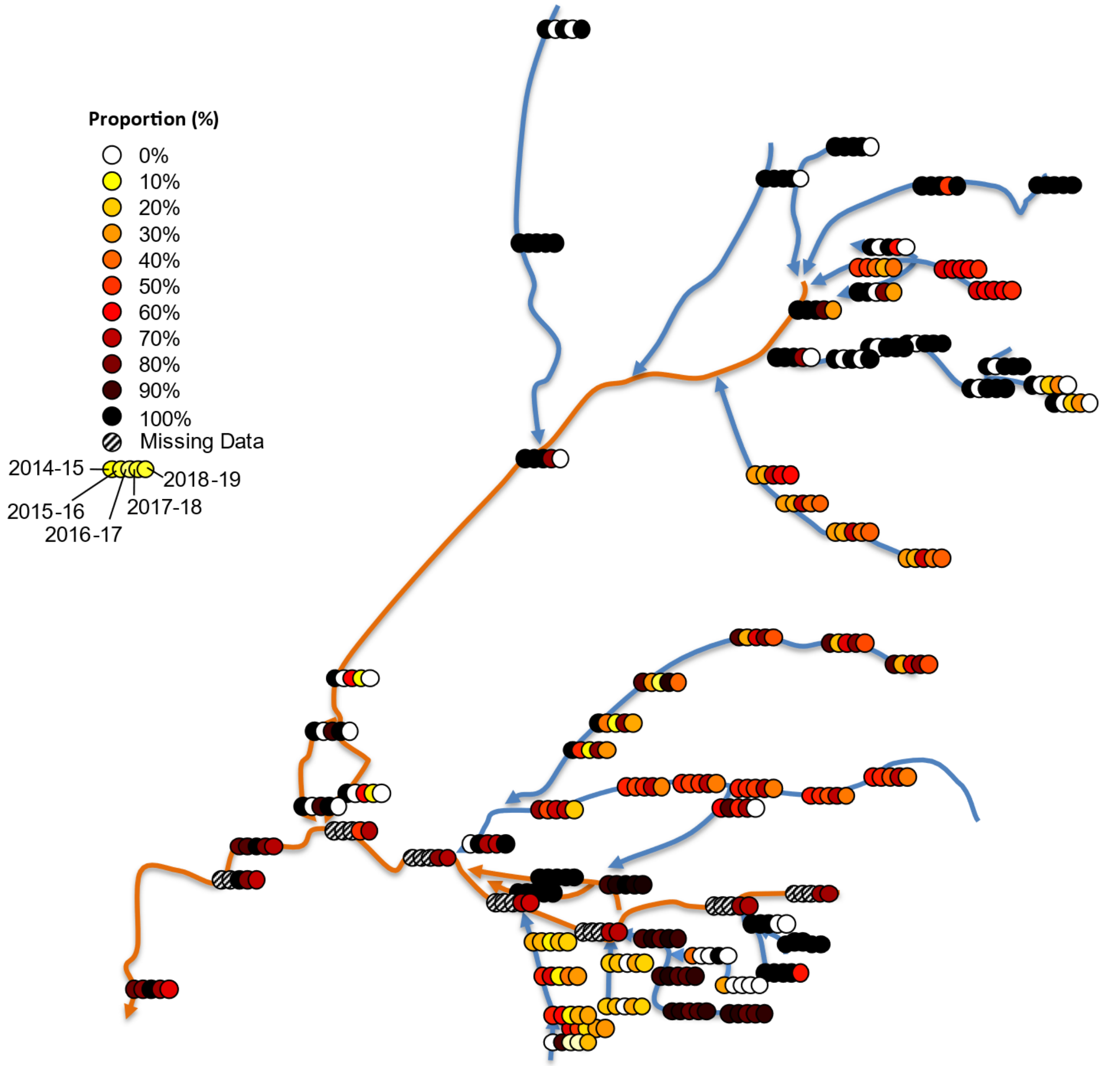


Figure 16 Percentage of annual flow that is sourced from an environmental entitlement (Stewardson and Guarino 2020)

Native fish

The analysis approach is provided at Attachment 2.

Background and summary findings

The Murray–Darling Basin is home to more than 60 species of fish, 46 of which are native, including freshwater, estuarine, marine and migratory species. Currently, 27 species of freshwater native fish have been identified in the southern Basin. While the southern Basin has relatively few native freshwater species, the species present represent a diversity of size, form and life history requirements (Merrick and Schmida 1984; Humphries et al. 1999).

Fish play important roles in aquatic ecosystems. They provide a food source to birds, aquatic animals, such as the native water rat, and other fish. They regulate numbers of crustaceans, other fish species, and aquatic insects, including mosquito larvae. Through their life processes they cycle nutrients and act as ecosystem engineers (Humphries and Walker 2013).

In addition to an important ecological role, native fish are also important to the Basin's people, supporting cultural and social values, and providing an economic resource. Large freshwater species such as the Murray cod, golden perch, silver perch and freshwater catfish have historically provided an important food source for Aboriginal people (Rowland 1989; Trueman 2011) and the southern Basin continues to support important recreational fisheries.

Native riverine fish in the southern Basin have largely been maintained since the implementation of the Basin Plan. Species richness of the most common and abundant species has been maintained, with 26 of the expected 27 species recorded in the past seven years. There is evidence that the southern purple-spotted gudgeon is still present in the southern Basin, after being considered regionally extinct, with a new healthy population recorded in the Avoca Basin in 2019. It is likely, however, that another small-bodied rare native species, the Yarra pygmy perch, is no longer present in the Murray–Darling Basin post the Millennium Drought.

The distribution and population structure of Murray cod have been maintained, although there was a decline in abundance of this iconic species in the southern Basin following the 2016 floods and subsequent blackwater events.

The distribution and abundance of golden perch has also been maintained post the Basin Plan. The population structure of this species is, however, continuing to decline, with little evidence of recruitment into the adult population.

Under the Basin Plan 130 fish-targeted watering events (comprising a total of 3,756 GL of water) has been delivered between 2013–14 and 2018–19. Many of these have been collaborative events involving multiple water holders. Environmental water has contributed to maintaining baseflows and low freshes during the dry climate sequence—which will have had benefits for water quality and productivity, assisting the survival of native fish populations. While the delivery of flows was found to promote spawning of golden perch on several occasions, the delivery of flows has not supported recruitment. There has been some success in supporting Murray cod recruitment through the delivery of environmental water.

Evaluation assessment

Table 5 Evaluation assessment of outcomes for native fish

Indicator	Condition assessment	Assessment of contribution of the Basin Plan
Species richness	The target of no loss of key native fish species has been achieved	Not assessed: future opportunities statement provided
Murray cod and golden perch populations (population structure and abundance)	Populations of Murray cod have been maintained. Populations of golden perch have not been maintained, and the population is aging.	Environmental water through the Basin Plan has contributed to the breeding and recruitment of Murray cod. Environmental water has been unsuccessful in achieving recruitment of golden perch in the southern Basin.
Fish movement	Not assessed	Not assessed: preliminary lines of evidence and forward opportunities statement provided
Fish distribution	Not assessed: forward opportunities statement provided	Not assessed

The Basin Plan objectives for native fish in the southern Basin

The Basin Plan establishes a target for biota of ’no loss of or degradation in recruitment and populations of native, water-dependent species including vegetation, birds, **fish** and macroinvertebrates’ to be achieved by June 2019.

The Basin-wide environmental watering strategy (BWS) provides the following broad expected outcomes (EO) by 2024 for native fish (relevant to longitudinal connectivity in the southern Basin):

1. no loss of native species currently present within the Basin
2. improved population structure of key species through regular recruitment
3. increased movement of key species
4. expanded distribution of key species and populations in the southern Basin.

The BWS expected outcomes are to be achieved by 2024, illustrating the time scale for expected fish responses the Basin Plan (Figure 17). In the first few years post Plan implementation, it can be expected that ecological processes for native fish will be supported (e.g. spawning, growth, movement). This could lead to adult recruitment in the medium term. Evidence of improved population structures leading to healthy and resilient populations, however, will take longer.

Key fish species are listed in the BWS and these were selected by an expert panel due to the links between their lifecycle characteristics and flows. The riverine key fish species in the southern Basin are: silver perch, golden perch, Murray cod, trout cod, Macquarie perch, freshwater catfish, river blackfish, two-spined blackfish, southern pygmy perch, and the southern purple-spotted gudgeon.

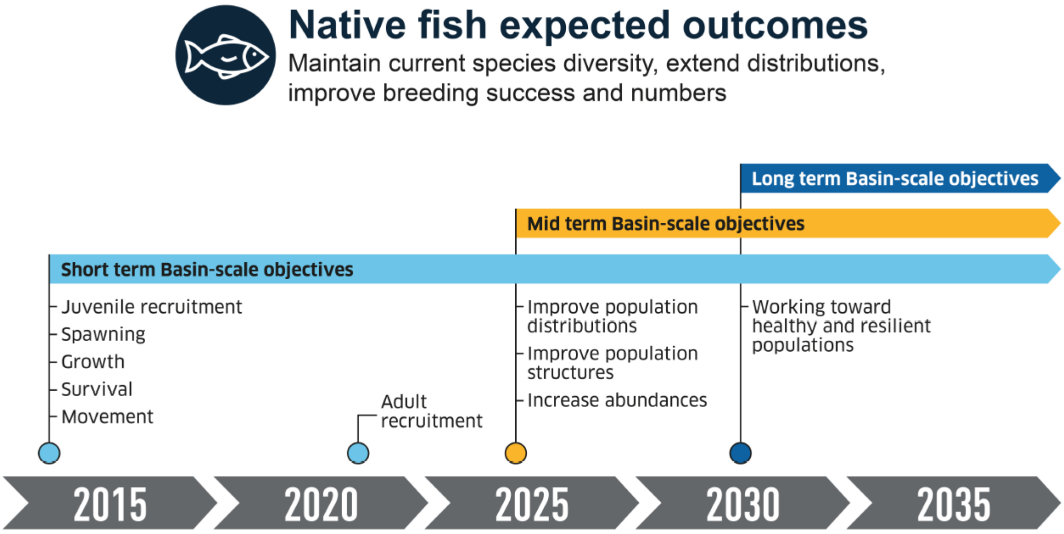


Figure 17 Timeline of expected fish responses

How have we assessed native fish?

Table 6 Approach to assessing outcomes for native fish. EO stands for expected environmental outcome.

EO	Indicator	Analysis method		Location of data and analysis details
		Condition assessment	**Assessment of the contribution of the Basin Plan**	
1	Species richness	Trend analysis against pre-basin plan baseline (Murray–Darling Basin Fish Strategy dataset).	Not assessed: future opportunities statement provided.	Attachment 2
2	Murray cod and golden perch populations (population structure and abundance)	Trend analysis against pre-basin plan baseline (Murray–Darling Basin Fish Strategy dataset).	Lines of evidence collated from intervention monitoring programs.	
3	Fish movement	Not assessed.	Not assessed: preliminary lines of evidence and forward	

			opportunities statement provided.	
4	Fish distribution	Not assessed: future opportunities statement provided.	Not assessed.	

The indicators in Table 6 represent each of the BWS expected outcomes, noting that only Murray cod and Golden perch were assessed against EO 2 as they were the only species for which data was available at the Basin scale. The MDBA acknowledge that there are additional research and monitoring data sets at the asset scale held by State agencies, NGOs, Universities and consultants. However, many of these programs are relatively new or use different data collection or analytical methods, hence they could not be adequately collated for the 2020 Basin Plan evaluation, and will instead be considered in the MDBA's future monitoring and evaluation work.

Condition of native fish

Species richness

How has the species richness of riverine native fish species in the southern Basin changed since implementation of the Basin Plan began?

Species richness of native species has been maintained in most valleys and in the southern Basin as a whole (Figure 18). The one species located pre-Basin Plan but not post-Basin Plan was the spangled perch, which was reported in the Lower Murray, but is generally not found in the Southern Basin and may have washed down during high flows. Minor differences in species richness, such as the slight increases and decreases pre- and post- Basin Plan, were largely related to cryptic small-bodied native fish such as galaxiids. These small-bodied species are often not detected using standard sampling methods and, as such, it is difficult to determine where changes are related to sampling limitations or true changes in species richness.

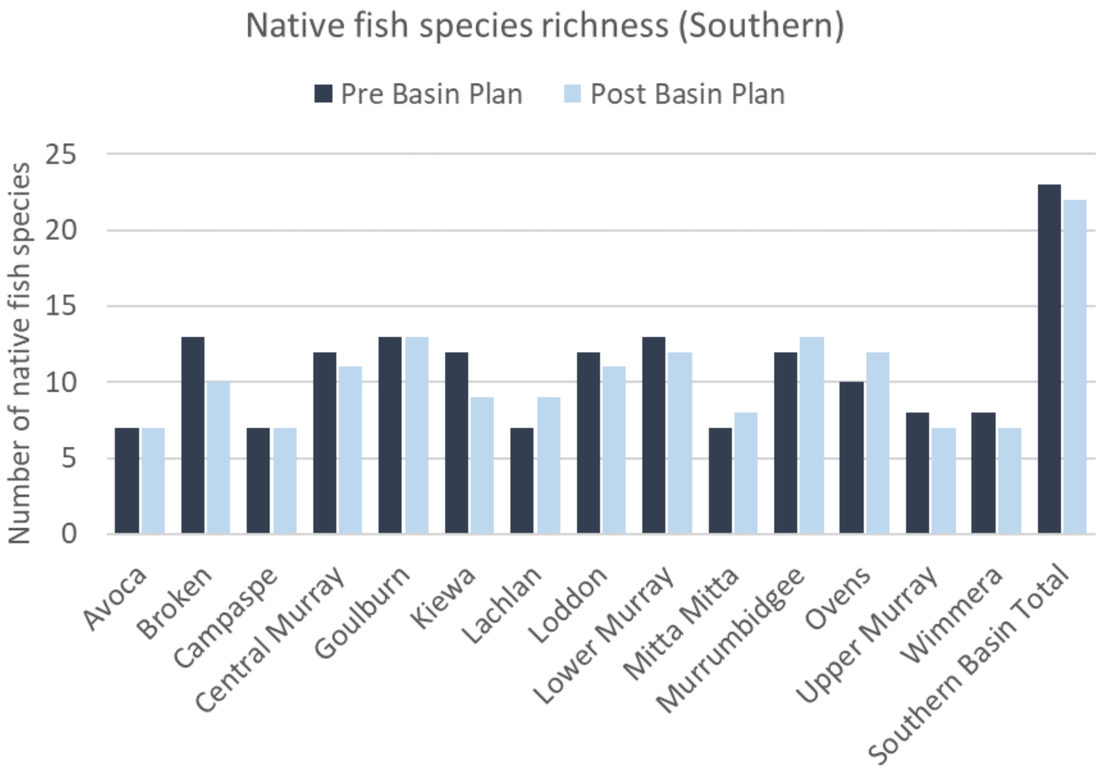


Figure 18 Native fish species richness at standard sampling sites in the valleys of the southern Basin pre (2005 to 2013) and post (2014–2019) Basin Plan

A review of the status of six small-bodied native fish—highlighted significant declines in all these species and local and regional loss of some species in the southern Basin (Whiterod et al. 2019). The review showed:

- Flat-headed galaxias — has significantly declined throughout its range and is only irregularly recorded in very low numbers.
- Murray hardyhead — is persisting in the wild and has benefited from successful reintroduction programs and strategic environmental watering (Whiterod et al. 2019).
- Olive perchlet — is now considered extirpated from the southern Basin, other than a remnant population in the Lachlan River Catchment.
- Southern pygmy perch —continues to decline and is at very low numbers throughout the southern Basin, although there has been some localised recovery (Whiterod et al. 2019).
- Southern purple-spotted gudgeon —had not been detected in the southern Basin for many years and was considered regionally extinct. The species was recorded, however, in 2019 in the Avoca River system, with some indications of a healthy sustainable population (T. Raadik, Arthur Rylah Institute, personal communication). The species is thought to be regionally extinct in NSW. The future of the species remains precarious in the southern Basin (Whiterod et al. 2019).
- The Yarra pygmy perch, which had been present in the Lower Lakes prior to the Millennium Drought, is now suspected to be extinct in the Basin (Wedderburn et al. 2019). Captive backup populations also appear to be in peril, and urgent actions are required for this species (Whiterod et al. 2019).

Populations of Murray cod and golden perch

Evaluation of riverine key fish species populations and recruitment are key elements for assessing the effectiveness of the Basin Plan in achieving biodiversity and ecosystem function outcomes. For native fish populations, determining length-frequency distributions are useful metrics of population dynamics. Increases in the abundance of adult fish suggest that Murray cod are breeding and successfully recruiting into the population. The overall proportion of adults, sub-adults and young-of-the-year (YOY) (i.e. life classes) can be used as indicators of maintenance of species population through time.

The current Murray–Darling Basin Fish Survey is limited in its capacity to assess changes in the population structure for a number of key species. It does provide sufficient information to assess changes in the most abundant large-bodied species in the Basin, golden perch and Murray cod. The golden perch represents a group of species that are flow-dependent specialists. The Murray cod represents a group of species that are considered to be in-channel specialists (flow dependent). These two large-bodied species are well known throughout the Basin and popular with recreational fishers.

How have Murray cod and golden perch populations in the southern Basin changed since implementation of the Basin Plan began?

The population structure for Murray cod has been maintained across the southern Basin since the implementation of the Basin Plan. The mix of adult, sub-adult and YOY proportions of the population suggests that both spawning and recruitment into the adult population is occurring (Figure 17:). Populations of Murray cod, as evidenced by average abundance, had been increasing post implementation of the Basin Plan (2011 to 2016). The floods in late 2016, however, resulted in a large hypoxia event in parts of the system and the death of many Murray cod adults (Thiem et al. 2020). Recruitment since the floods has been found to be patchy and recruit abundances low (King et al. 2020). Despite this, the trend Murray cod populations in the southern Basin is considered as being maintained.

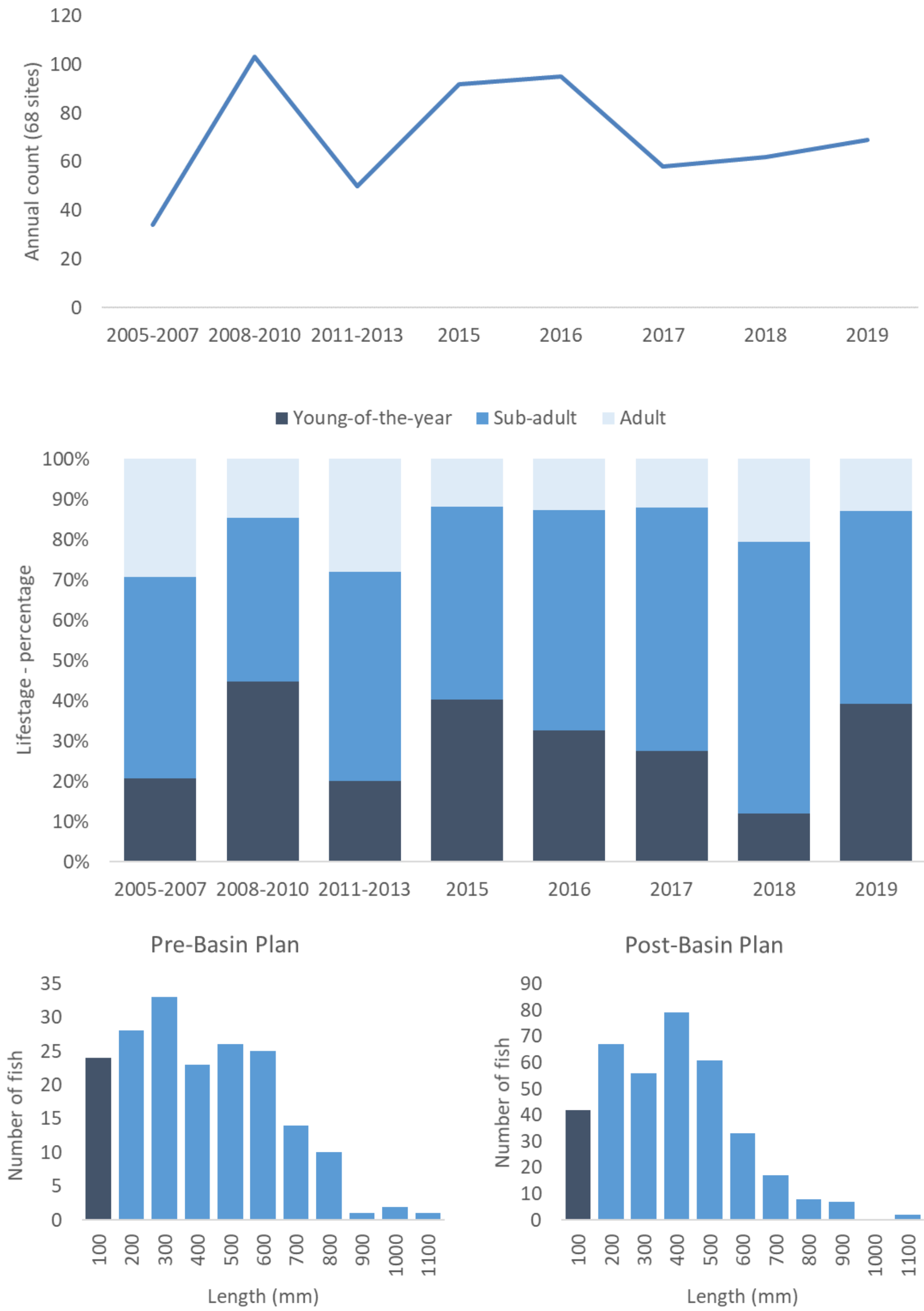


Figure 17: Murray cod abundance (top) and population structure as indicated by proportion of individuals in three life stages (middle) and length frequency distributions pre/post Basin Plan (bottom). Darker shading in the bottom plots identifies young-of-the-year (< 100 mm in length).

The population structure of golden perch in the southern Basin was poor prior to the Basin Plan, with very low levels of early life stages and little evidence of recruitment into the adult population (Figure 18:). Very few YOY golden perch have been detected in sampling in the southern Basin since the implementation of the Basin Plan and no YOY were detected in the 2018 sampling. This coincided with a decline in population, as evidenced by average abundance (Figure 18:). The population of golden perch, as evidenced by average abundance, seemed to have recovered just one year later by 2019, but with poor length frequency distributions, indicating an aging fish population.

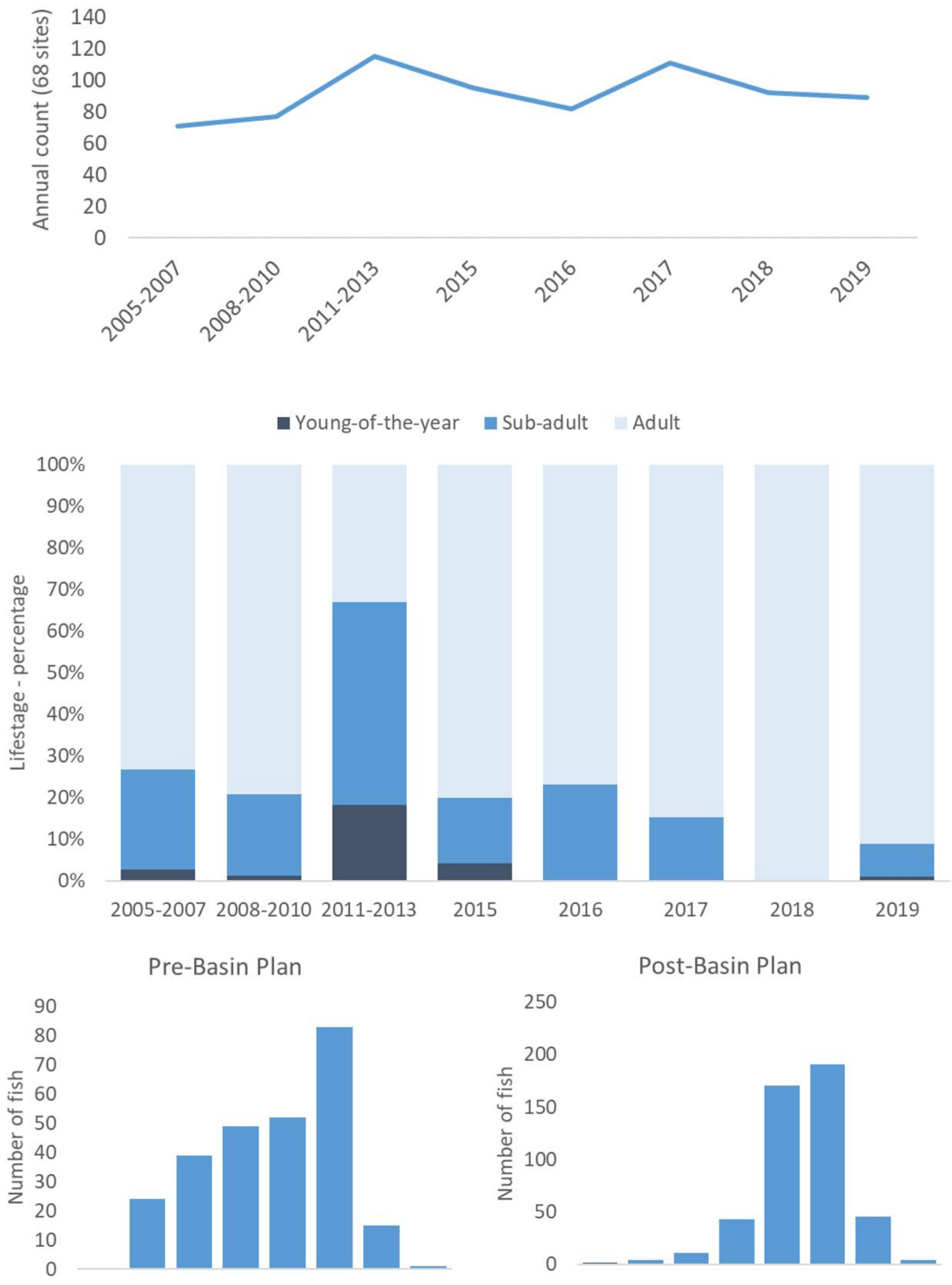


Figure 18: Golden perch abundance (top) and population structure as indicated by proportion of individuals in three life stages (middle) and length frequency distributions pre/post Basin Plan (bottom). Darker shading in the bottom plots identifies young-of-the-year (< 75 mm in length).

Distribution

Future opportunities

The coarse nature of the Murray–Darling Basin Fish Survey (MDBFS) makes it difficult to identify meaningful changes in distribution since the implementation of the Basin Plan. The current survey only incorporates around 100 sites across the entire Murray–Darling Basin. Comparison of the distribution of the most common large-bodied species, Murray cod and golden perch, between 2004–2013 (using the comparable sub-set of Sustainable Rivers Audit data) and 2013–2019 only shows small differences (Figure 19; Figure 20).

Figure 19 Murray cod distribution a) 2004–2013 and b) 2013–2019. The full green dots represent sites where the species was detected on all sampling occasions and the half green dots are sites where the species was detected on some sampling occasions. White dots are the sites sampled where the species was not detected.

Figure 20 Golden perch distribution a) 2004–2013 and b) 2013–2019. The full green dots represent sites where the species was detected on all sampling occasions and the half green dots are sites where the species was detected on some sampling occasions. White dots are the sites sampled where the species was not detected.

Prior to the implementation of the Basin Plan the Sustainable Rivers Audit (SRA) collected a more comprehensive data set, which contributed to documentation of the distribution of fishes in the Basin (Lintermans 2007), and highlighted the poor condition of native fish populations. Yet the methods used to collect SRA fish data were inadequate to detect some small and cryptic species, resulting in a poor understanding of the distribution of a number of key native fish species.

For the 2025 evaluation it is anticipated that two improvements will enable a robust evaluation. First, State Matter 8 reporting on their monitoring programs will be available, for example VEFAMP monitoring in Victoria. Second, the development of a monitoring strategy will enable consideration of opportunities associated with improving technology. These opportunities include environmental DNA and other genetic tracking tools, opportunities exist to develop a more comprehensive understanding of the distribution of native fish for the 2025 Basin Plan Evaluation. This type of monitoring is also likely to overcome the challenges associated with surveying small and cryptic species, allowing for assessment of the distribution of all key native fish species.

Contribution of the Basin Plan to native fish

How flows support native fish

Fish need water to survive. Aspects of water, including its quality and flow regime, maintain critical life history elements and key population processes for native fish—and these support ongoing, viable populations of fish in the Murray–Darling Basin. Flows promote the exchange of nutrients and productivity in aquatic ecosystems and provide connectivity between aquatic habitats, such as rivers and floodplain habitats, valleys or reaches within a valley. Flows are also linked to key life history components of Murray–Darling fishes, such as spawning, survival of young (recruitment), growth, dispersal or movement, habitat maintenance (including refuges) and generation of food for survival (Humphries et al. 1999, 2020; Koehn et al. 2014, Ellis et al 2016).

Factors other than flow

While flow regimes are the key driver of native fish populations in the southern Basin, there are a range of other factors and threats that act together with flow to influence fish diversity, abundance and condition.

The Native Fish Recovery Strategy (MDBA 2020) identifies several non-flow factors that influence native fish in the Basin:

- Climate change
- Habitat degradation
- Infrastructure in rivers and floodplains
- introduced fish species
- Over-fishing
- Parasites and disease
- Poor water quality
- Translocation and stocking of fish

Flows delivered for native fish

The 13,739 GL of environmental water was delivered throughout the southern Basin from 2013–14 to 2018–19 is all likely to have had some benefits to native fish. In the southern Basin, 3567 GL of that water was delivered across 130 watering events with the primary purpose of achieving outcomes for native fish (Figure 21). A further 2600 GL was delivered across 25 events for longitudinal connectivity, most often explicitly for fish movement.

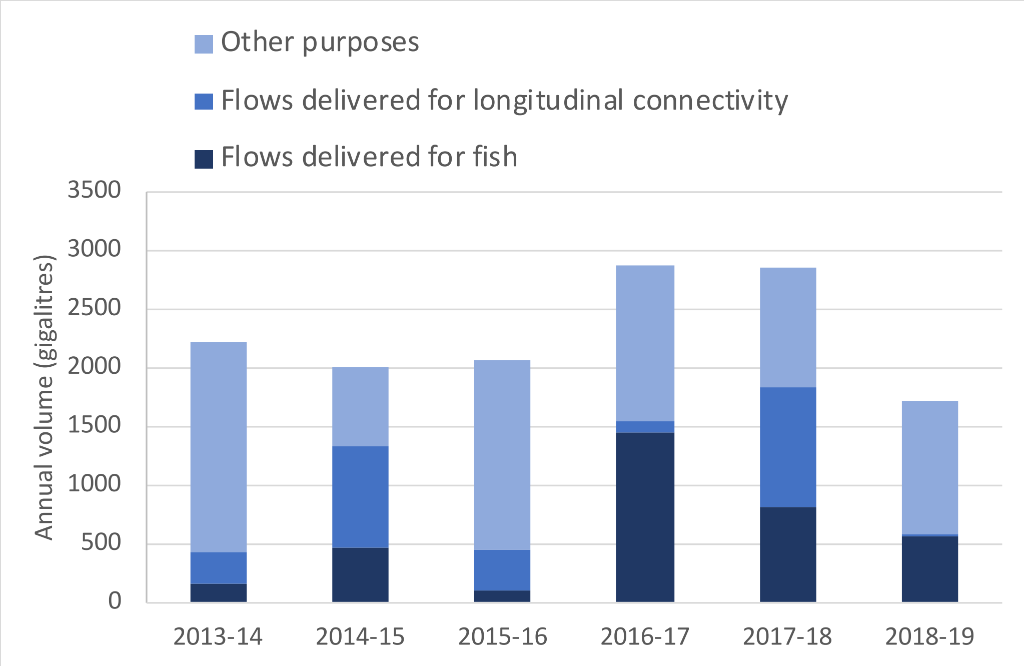


Figure 21 Flows delivered for fish outcomes and longitudinal connectivity in the context of all environmental water

Of the 155 flow events delivered with fish or longitudinal connectivity as the primary purpose, around 28% of these flow events were joint watering events that combined water from multiple water holders. The Environmental Management Framework sets out the principles for collaboration and coordination, which have resulted in cross-jurisdictional groups, such as the Southern Connected Basin Environmental Watering Committee, that work together to optimise delivery of environmental water to achieve outcomes.

Water holders in the southern Basin have worked to restore natural elements of the flow regime which benefit native fish. Environmental water delivered under the Basin Plan has been found to substantially contribute to protecting baseflows and improving low flow freshes in some catchments. Baseflows are important for maintaining aquatic habitat for fish (Ellis, et al. 2016) and the maintenance of baseflows through delivery of water under the Basin Plan is likely to have played an important role in ensuring survival of and maintaining condition of native fish.

Freshes are believed to provide spawning and movement cues for golden perch, as well as access to habitat for young fish and to stimulate the production of food. Environmental water contributed substantially to improving the low fresh threshold in the Lower Murray, Goulburn and Campaspe catchments. However, moderate and high freshes were found to be lacking in many valleys. Despite this, some valleys, including the Loddon and Goulburn, were found to have more days over the fresh threshold in dry years post-Basin Plan than pre-Basin Plan. This suggests that the frequency of freshes would have been worse during the dry climate sequence post 2012 in the absence of the Basin Plan.

Species richness

Future opportunities

The extremely poor condition of Murray hardyhead, southern pygmy perch, southern purple spotted gudgeon, Yarra pygmy perch, olive perchlet and flathead galaxias in the southern Basin (see Whiterod et al. 2019) highlights the need for restoring critical wetland and floodplain habitats. The topic of lateral connectivity is addressed in its own theme report for this evaluation. The report is available on the [2020 Evaluation: reports and data page.](#) The lateral connectivity report provides a case study demonstrating the use of environmental water to support the reintroduction of Murray hardyhead populations. While these species are considered floodplain specialists it is important to recognise that in-channel habitats also provide important habitat for some of these species, and they all rely on longitudinal connectivity to support life-cycle requirements and facilitate dispersal.

Given the dire situation of these small-bodied species, the Tri-State Murray NRM Regional Alliance is developing a plan for their recovery along the Murray corridor. This provides an opportunity for environmental water managers to work closely with the Alliance to better understand the watering needs of these small-bodied species in the southern Basin and to target water delivery to support their survival.

Breeding and recruitment

Golden perch and Murray cod populations are in poor condition across the Basin and it is believed that one of the major drivers of the decline has been the effects of flow modification on breeding and recruitment of fish to the adult population. The delivery of flows to support native fish breeding and recruitment has been a high priority of water holders in the southern Basin (Figure 21).

To what extent has the Basin Plan contributed to breeding and recruitment of golden perch and Murray cod?

Golden perch

Spawning and recruitment of golden perch is known to correspond with increases in water temperature and discharge, either in-channel or overbank (Mallen-Cooper and Stuart 2003; Zampatti and Leigh 2013a, 2013b; King et al. 2016). Since implementation of the Basin Plan, a number of intervention monitoring programs at specific locations have reported that the delivery of environmental water has triggered the spawning of golden perch in the southern Basin. Examples of these reports include: the Lower Darling River (Stuart and Sharpe 2020; Stuart and Sharpe 2018), Goulburn River (Webb et al. 2019), Lower Murray (Ye et al. 2020), Murrumbidgee River (Wassens et al. 2020) and the Edwards Wakool (Watts 2019). However, despite significant learning and the application of adaptive management, the spawning responses of golden perch have been found to be variable, with not all flushes resulting in a spawning response (Webb et al. 2019). Future monitoring and research are needed to improve the understanding of the spawning requirements for golden perch.

Despite successful spawning in response to flows since the implementation of the Basin Plan, little to no recruitment is occurring in the southern Basin, and the golden perch populations are ageing (King et al. 2020, MDBFS, Price et al. 2019). Future successful spawning and recruitment events will be vital for maintaining the species (MDBFS, King et al. 2020). Research in 2018 on the natal origin and movement of golden perch adults has shown substantial variation in recruitment sources, including local and migrant fish and the dominance of hatchery-bred fish in the southern Basin (Price et al. 2019, Brenton Zampatti, pers. comm.). The Lower Darling, lower, mid and upper Murray and Murrumbidgee rivers are apparent recruitment sources in the southern Basin, but recruitment may be episodic, particularly in the lower and upper Murray, and Lower Darling river. Spatially reconciled age data also demonstrated the positive effect of flow pulses during the spawning period on young-of-year (YOY, fish in their first year of life) abundance, in the southern Basin (Price et al. 2019, Brenton Zampatti, pers. comm.).

Some hypotheses have focused on providing flows to promote spawning and recruitment in the northern Basin and then flows for dispersal of the young fish to the southern Basin to support golden perch populations in the southern Basin (Stuart and Sharpe 2020). However, there is still much to learn about the recruitment dynamics of golden perch in the southern Basin and providing suitable conditions to promote golden perch recruitment should not be ignored. Future targeted research is urgently needed to better understand the factors influencing the recruitment of golden perch in the southern Basin, and these studies need to particularly occur during wetter conditions and large flow pulses.

Murray cod

The Long-Term Intervention Monitoring (LTIM) project found that Murray cod spawning occurred in most years and most rivers where Commonwealth environmental water was delivered (King et al. 2020). At the Basin-scale, Murray cod recruitment occurred in all LTIM monitored valleys from 2014 to 2016. However, catches of Murray cod YOY have been low in many locations since 2016, following the flood driven hypoxic blackwater event in the southern Basin. This is particularly the case in two of the hardest hit valleys—the Edward–Wakool and Lachlan River Systems. Basin-scale modelling reveals that YOY abundances are increasing since 2016-17 and Murray cod recruitment should naturally start to increase in future years as the adult breeding populations increase and with appropriate flow conditions (King et al. 2020).

Monitoring programs in four locations have reported that environmental flows are likely to have supported recruitment of Murray cod, including in the central Murray (Bloink and Robinson 2016, Stuart et al. 2019), Lachlan River (Dyer et al. 2016), Macquarie River (Stocks et al. 2015), and Lower Darling River (Stuart and Sharpe 2018). At Gunbower Creek, in the central Murray River, a purposefully designed hydrograph, including the use of environmental water and management of water levels, has been used since 2013 to target the spawning and recruitment of Murray cod. Annual monitoring has shown significant increases in Murray cod YOY since the implementation of the targeted water management (Stuart et al. 2019).

In late 2016 and early 2017, a carefully designed Murray cod hydrograph was implemented in the Lower Darling River to support the spawning and recruitment of Murray cod (in addition to achieving outcomes for golden perch) (Stuart and Sharpe 2018). This watering event was the result of a combination of Commonwealth environmental water, The Living Murray water and manipulation of operational water. Hydrographs for this event were designed using the latest scientific knowledge. Consideration was given to flows and hydraulic diversity that would support life history requirements from courting and nest selection by adults through to larval drift and promoting productivity to support growth (Sharpe and Stuart 2018). Murray cod were found to successfully spawn and recruit in the Lower Darling River (Stuart and Sharpe 2018). Whilst many of these new recruits may have been lost during subsequent hypoxic water events in the region, some recruits may have survived in downstream reaches. The learnings from this event are important for future management of the system.

Successful recruitment of Murray cod through carefully designed hydrographs highlights the value that environmental water can bring to supporting Murray cod populations. However, during dry climate periods, such as those seen since implementation of the Basin Plan, with limited water availability and channels in the southern Basin heavily used to transfer irrigation water, the opportunities to manipulate a hydrograph to benefit so many key components of a Murray cod lifecycle are rare.

Fish movement

Restoring connectivity through providing appropriately planned flows (i.e. timing, frequency, magnitude) is expected to improve opportunities for fish movement in and between channels, as well as provide flows sufficient to drown-out barriers (weirs) and/or operate fishways to provide fish passage. Monitoring the movement of large-bodied species (i.e. Murray cod, golden perch, silver perch, and pouched lamprey) throughout the system provides insight into the movement and dispersal opportunities provided by the delivery of environmental water and other mechanisms of the Basin Plan.

Longitudinal connectivity is a key outcome in Chapters 5 and 8 of the Basin Plan—and is a key lifecycle requirement of many native fish species. Many native fish species utilise different habitats and locations to breed, grow as juveniles and sub-adults, and to live as adults; thus, considering connectivity for all life stages is critical. Furthermore, connectivity to support movement plays an important role in improving fish distribution and supporting recolonisation when fish deaths occur as a result of poor water quality.

Preliminary lines of evidence

The Sea to Hume fish passage program has been restoring longitudinal connectivity for native fish along the Murray River through the installation of fishways. Since 2004, 7,860 individual fish have been detected across all the MDBA fishway sites and this demonstrates that fish movements through fishways have occurred pre- and post-commencement of the Basin Plan. From 2014–2019, 1,395 individual tagged fish have been detected moving throughout the system, with 503 detections from key species (Pomorin et al. 2019). Preliminary analysis suggests that fish commenced moving from September, coinciding with rising river temperatures, but there was no obvious spike in detections or fish movements with significant flow events through the Locks (Pomorin et al. 2019). There is evidence of poor or patchy fish passage at Lock 11, and further investigation and restoration should be undertaken to improve the movement of fish.

Silver perch have made some of the longest migrations from below Lock 1 (at Blanchtown in South Australia) to Lock 26 (Torrumbarry Weir), which is over 1,350km and Yarrawonga Weir, over 1,700km. Silver perch were recorded moving both upstream and downstream.

Golden perch regularly move upstream to Lock 10 (at Wentworth), but are rarely detected at Lock 11 (at Mildura). This suggests there could be a problem with the fishway at Lock 11, or that golden perch migrate up the Darling River. Data shows that golden perch have moved from Lock 1 to Lock 10, which is over 550km.

Throughout the southern Basin, fish movement is a common target for environmental watering events and managed flows (Watts et al. 2019; Webb et al. 2019; Stuart and Sharpe 2020; Thiem et al. 2020). There are a number of examples from these programs that provide evidence of the effect of environmental water on fish movement:

- Watering actions undertaken during LTIM, particularly spring watering, facilitated movements of silver perch, golden perch and Murray cod in the Edwards–Wakool River system. The winter watering in 2017 greatly increased river connectivity and fish moved longer distances than in previous periods of operational shutdown during winter (Watts et al. 2019).
- There was movement of sub-adult silver perch from the Murray into the lower Goulburn in March–April 2017 coinciding with a within-channel environmental flow fresh in the Goulburn River (Webb et al. 2017; Tonkin et al. 2019). This suggests that migration of silver perch can be achieved using flow management in Victorian tributaries, however, the magnitude of meta-population outcomes within the tributary is dependent on flow delivery and density of silver perch in the mid-Murray River (Tonkin et al. 2019).
- Provision of environmental water in 2016–17 enabled some juvenile golden perch juvenile fish to disperse downstream from the Menindee Lakes into populations in the Lower Darling River, Great Darling Anabranch, and southern Murray River (Stuart and Sharpe 2020).

Recent research on pouched lamprey movement has detected the species moving 20 to 431 km upstream of the Coorong (Bice et al. 2019). This species is thought to have been historically common in the River Murray, with migrations potentially extending up to 2,000km upstream. More recently they are considered rare in the system, with barriers to migration and flow regulation cited as key factors impacting upon the migration of this species up the River Murray to meet life cycle needs (Bice et al. 2019). Whilst research of this species is ongoing, improved longitudinal connectivity as a result of the sea to Hume fishways and delivery of environmental water under the Basin Plan are both considered to be contributing factors to recent migrations (Bice et al. 2019).

Future opportunities

Given the large scale of fish movements occurring in the Murray–Darling Basin, jurisdictions have joined through the Joint Venture Monitoring and Evaluation program to develop a large-scale acoustic telemetry array to detect fish movements throughout the Basin. This program, combined with the Sea to Hume fishway monitoring program and other intervention monitoring programs, will provide extensive insight into the relationship between fish movement and the delivery of environmental water. This will support a more detailed assessment of fish movement in the 2025 Basin Plan evaluation.

Vegetation

Background and summary findings

Vegetation communities in riparian habitats are critical components of riverine ecosystems and landscapes in the Murray–Darling Basin. Typically supporting more plant species with greater structural complexity than the surrounding uplands, vegetation communities in these habitats support high levels of biodiversity in both the aquatic and terrestrial realms—as well as a wide range of essential ecological functions and valuable ecosystem services (Capon et al. 2013).

In low-lying regions of the Basin, woody vegetation in riparian habitats is usually dominated by a few, very widespread species that typically occur in predictable locations (Roberts et al. 2016). River red gums tend to line channels, creating forest ecosystems in wetter areas and woodlands in places subject to slightly drier conditions. Many shrub and woody sub-shrub species, especially those belonging to the chenopod family, are also often present in riparian habitats of the Basin.

Hundreds of herbaceous plant species have been recorded from riverine habitats in the Murray–Darling Basin. These encompass a wide range of life forms (e.g. grasses, sedges, rushes, forbs, ferns) and life histories (e.g. annual and perennial) and include aquatic, amphibious and more terrestrial species (Capon and James 2020). Many herbaceous plant species in these habitats form large, long-lived soil seed banks, which allow them to persist through unfavourable conditions, including drought and floods (Capon et al. 2016). Under wetter conditions, however, aquatic and amphibious herbs tend to regenerate and spread mainly via vegetative mechanisms, e.g. rhizomes (Cronk and Fennessy 2016).

Riparian vegetation communities of the Basin tend to be dynamic, exhibiting significant shifts in composition and structure over time, largely in response to hydrological changes. During very dry periods, vegetation may be limited to long-lived trees and shrubs with very little groundcover present. Because of plant adaptations, including soil seed banks, flooding can induce rapid responses, such as:

- mortality of flood-intolerant plants (e.g. many chenopod shrubs)
- opportunistic growth and flowering in many woody species (e.g. lignum)
- germination and establishment of many herbaceous species – the latter occurring among aquatic and amphibious species during inundation, mainly from vegetative propagules.

Most riparian plants, however, tend to establish from soil seed banks under the waterlogged and damp conditions that occur following the drawdown of floodwaters (Capon et al. 2016).

The composition, structure and condition of vegetation communities that establish in response to flooding are highly dependent on hydrological characteristics, including flood timing and duration. Variation in the patterns of wetting and drying across the landscape therefore generates a high level of spatial heterogeneity in vegetation composition and structure. This ‘dynamic patch mosaic’ of vegetation promotes ecological resilience and adaptive capacity (Gawne et al. 2018).

Vegetation responses to environmental watering have been observed in riparian and in-channel habitats of the southern Basin since the inception of the Basin Plan, over both short-term and longer time frames. There is evidence that environmental water is maintaining or improving riparian vegetation in what has been a dry period. For example, spring freshes delivered in numerous rivers in the southern Basin have been observed to promote the growth of both within channel aquatic vegetation and riverbank vegetation. There are, however, incidents of water management that have had detrimental impacts upon riparian and in-channel vegetation, such as the negative impacts of Inter-valley transfers of water from the Goulburn Valley to the mid Murray.

Evaluation assessment

Table 7 Assessment parameters for riparian vegetation

Indicator	Condition assessment	Assessment of contribution of the Basin Plan
Riparian vegetation	Not assessed	Not assessed: preliminary lines of evidence presented

Basin Plan objectives for riparian vegetation

The Basin Environmental Watering Strategy (BWS) seeks to maintain the extent of, and maintain or improve the condition of, water-dependent vegetation in habitats which can be influenced by environmental water, while recognising the potential influence of many external factors, e.g. natural flooding, weather conditions, land use, fire etc. Vegetation outcomes are to be achieved under the BWS by reinstating lateral and longitudinal connectivity.

The expected outcomes of the BWS relevant to the southern Basin can be broadly summarised as follows:

1. Non-woody vegetation:
    a. to maintain the current extent of non-woody vegetation
    b. by 2024, increased periods of growth for communities that:
        i. closely fringe or occur within the main river corridors.

Note that the BWS also sets expected outcomes for forest and woody vegetation, as well as shrublands. These indicators are examined in the lateral connectivity theme of this evaluation.

How have we assessed vegetation?

Table 8 Approach to assessing outcomes for riparian vegetation

Indicator	Condition assessment	Assessment of contribution of the BP
Riparian vegetation	Not assessed	Not assessed: preliminary lines of evidence presented

The BWS expected outcome shown in Table 10 was the only one for which data was available. The MDBA acknowledge that there are additional research and monitoring data sets at the asset scale held by State agencies, NGOs, Universities and consultants, however, challenges in getting access, integrating and analysing these data precluded their use in the 2020 Basin scale evaluation.

Contribution of the Basin Plan to vegetation

How flows support vegetation

Flow is the primary influence on the growth, reproduction, dispersal, germination and establishment of plants in riparian habitats (Brock et al. 2006). Plant responses to wetting at different life history stages vary between species and will depend on plant age/size as well as the flow characteristics (e.g. timing, duration etc.). For example, flood intolerant species, such as many chenopod shrubs, will be killed by flows of any significant duration, while germination and growth of aquatic and amphibious plants will be triggered by inundation.

Flows delivered for vegetation

In the southern Basin 2,574 GL of environmental water was delivered across 383 events with the specific objective of achieving outcomes for vegetation (Figure 22). This represented between 11% and 28% of the total amount of environmental water delivered each year. This includes flows not only delivered in-channel for riparian vegetation, but also wetland inundation for floodplain and wetland vegetation communities. The condition and contribution of the Basin Plan to floodplain and wetland vegetation communities is not addressed in this evidence report but is addressed in the lateral connectivity theme of the 2020 Basin Plan Evaluation.

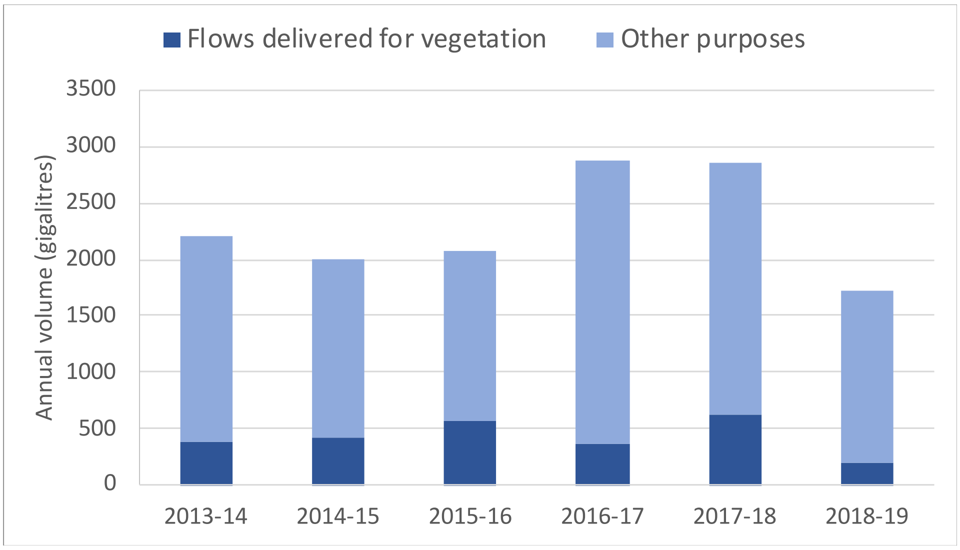


Figure 22 Flows delivered for vegetation outcomes in the context of all environmental water. Note: These flows were primarily delivered for wetland and floodplain vegetation, which is addressed in the lateral connectivity theme of this evaluation.

Riparian vegetation

Preliminary lines of evidence

Vegetation responses to environmental watering have been observed in riparian and in-channel habitats of the southern Basin since the inception of the Basin Plan, over both short-term and longer-term time frames.

Spring freshes delivered in numerous rivers in the southern Basin have been observed to promote the growth of both within-channel aquatic vegetation and riverbank vegetation. In the Campaspe River, for example, spring freshes have benefitted some species, with repeated freshes particularly beneficial to native common-tussock grass (ARI 2018). In the Wimmera River, delivery of environmental water has promoted the persistence of in-stream and fringing vegetation as well as plant recruitment on riverbanks, following recession of flows (ARI 2019). Increased vegetation cover on riverbanks of the Goulburn River, especially of water-dependent species, has also been attributed to the delivery of spring freshes over the last five years (Webb et al. 2015, 2016, 2019). Spring freshes in the Goulburn have also contributed to the diversity of riverbank vegetation by driving zonation of plant species in relation to elevation (Webb et al. 2016).

Similarly, environmental water delivered within the Edward–Wakool river system has promoted greater cover and diversity of aquatic and fringing vegetation over the last five years, including the recovery of vegetation following losses associated with the large natural floods in 2016 (Watts et al. 2019). For example, greater recovery of and richness in amphibious plant species after these floods occurred in zones that had received regular environmental watering (Watts et al. 2018). Areas that have received regular environmental water in this system support more plants and different plant species than non-watered areas, with regular watering driving gradual increases in vegetation cover and abundances of amphibious taxa such as mud grass, flowing pondweed and milfoil (Watts et al. 2015, 2016).

Monitoring and evaluation of the responses of aquatic and riverbank vegetation to environmental watering has also yielded some valuable learnings. For example, very little response of aquatic vegetation cover occurred in response to environmental watering actions delivered in the Edward–Wakool river system in 2016–17 because large natural floods prior to these had virtually eliminated aquatic cover at this time (Watts et al. 2017). Environmental watering in subsequent years, however, promoted vegetation recovery (Watts et al. 2018). Similarly, while some positive outcomes of environmental watering were seen in the Campaspe, the spring freshes were found to be too short to control exotic species such as couch and coolah grass (ARI 2019). In the Loddon Rover, positive responses of vegetation to environmental flow were limited by disturbance from stock grazing (ARI 2019).

Inter-valley transfers of water from the Goulburn Valley to the mid Murray for irrigation purposes have been found to have detrimental impacts on riparian vegetation (Webb et al. 2019). Monitoring of the condition of banks found bank notching and some slumping following inter-valley transfers in the summer of 2017–18. Anecdotal evidence suggests this has resulted in detrimental impacts on riparian vegetation along the Goulburn River (Webb et al. 2019).

Overall, there is strong evidence to indicate that environmental watering has enhanced both the diversity of plant species and the diversity of vegetation communities in the southern Basin over last five years (Capon and James 2020).

Productivity

Background and summary findings

Productivity is a critical ecosystem function that influences the amount and type of food available to populations of animals further up the food chain. It is expected that increases in gross primary productivity (GPP) and ecosystem respiration (ER) in riverine systems will provide the baseline for food webs within the southern Basin and are also of importance in understanding the responses of taxa in relation to flows. LTIM found that even small increases in flows can result in increases in primary production and community respiration and that this benefit was seen with in channel flows. This was previously not known.

Factors other than flows

Over time, flow is the primary influence on vegetation dynamics in riparian habitats, however, many other factors can modify the capacity of plants and vegetation communities to respond to wetting. These factors can, at times, interact with the effects of flow. Weather conditions (e.g. temperature and rainfall) before and after flows are particularly important in determining which species germinate and survive. Fire will also modify wetland vegetation responses to flow, as may water and/or soil quality. Salinisation and acidification of water and soils can be expected to limit vegetation responses to flow where these occur in the southern Basin (Baldwin and Capon 2011). Growing evidence also indicates that stock grazing significantly constrains riparian vegetation responses to flows in the southern Basin (e.g. ARI 2019). With respect to BWS targets related to vegetation extent, vegetation clearing is also an obvious driver.

Evaluation assessment

Table 11: Assessment parameters for productivity

Indicator	Condition assessment	Assessment of contribution of the Basin Plan
Productivity	Not assessed	Not assessed: preliminary lines of evidence and future opportunities statement

Basin Plan objectives for productivity

While there is no specific objective for productivity in the BWS, the Basin Plan objectives include that 'water-dependent ecosystems are able to support episodically high ecological productivity and its ecological dispersal' (Ch. 8.05.2c). Productivity is sensitive to changes in flow. The effect of flow on habitat, water quality depth and turbulence all impact on productivity. Therefore, different flow types e.g. baseflow or freshes, are expected to have different patterns of productivity.

How have we assessed productivity?

The lack of pre-Basin Plan data for productivity means that we cannot assess changes in condition for productivity. Instead, in this section we look at the contribution that the use of Commonwealth environmental water has made to productivity in the southern Basin.

Table 9 Approach to assessing outcomes for productivity

Indicator	Analysis method		Location of data and analysis details
	Condition assessment	**Assessment of the contribution of the Basin Plan**	
Productivity	Not assessed	Not assessed: preliminary lines of evidence and future opportunities statement presented	N/A

Contribution of the Basin Plan to productivity

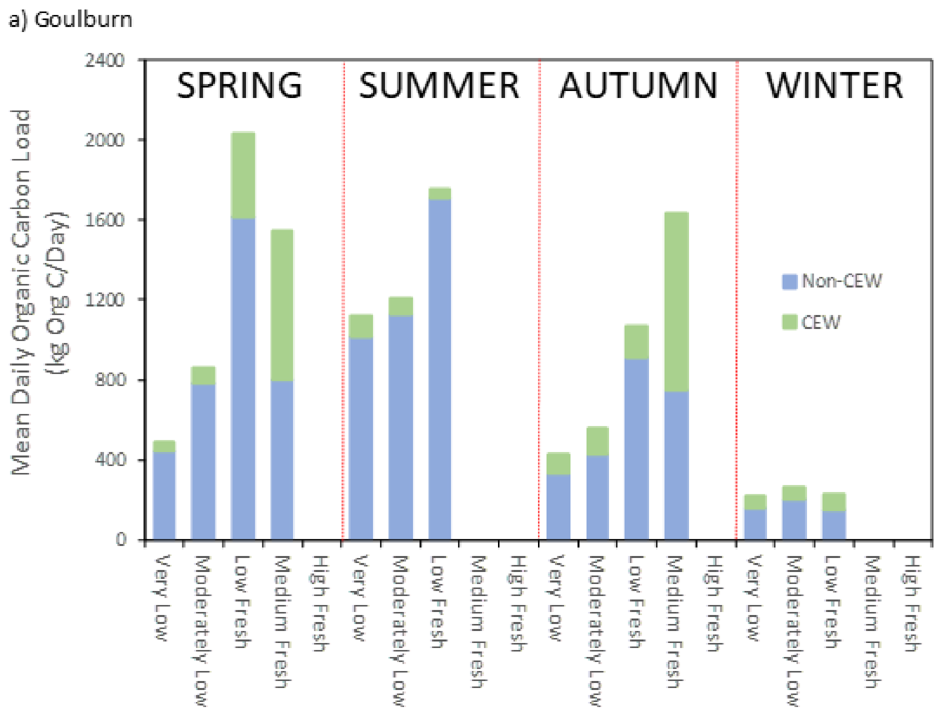
Preliminary lines of evidence

The LTIM project monitoring found strong evidence that increases in discharge (via natural flows or watering events) increase production of organic carbon (hence energy supply) at the base of the food web. Environmental flows that enhance discharge will therefore provide environmental benefit (Grace 2020). The magnitude of the change generally increases with the increase in volume, day length and temperature. Figure 23 illustrates the contribution that Commonwealth environmental flows made to the daily production of organic carbon in the Goulburn and Edward–Wakool rivers.

The hydrological evaluation found that there has been an increase in freshes in a number of southern Basin rivers, although in many catchments the larger freshes and/or overbank flow are still largely missing from the hydrograph, due mainly to the prolonged dry conditions. The provision of freshes was improved or maintained at six of the eight locations analysed after the Basin Plan, but declined in two locations, the Lachlan and Loddon rivers.

Integration of the hydrological and LTIM analysis provides evidence that the allocation of environmental flows have contributed to increased productivity and given these are largely in channel flows, it appears reasonable to assume that this increased productivity was, at least partially, dispersed downstream.

Due to the dry conditions and constraints in delivering water to the floodplain, larger freshes and overbank flows are missing in the hydrograph, and also in the LTIM sampling, which means it is not currently possible to draw conclusions about the influence of these water actions on productivity. There is, however, an extensive body of literature that highlights the effects of overbank flows on productivity that led Grace (2020) to conclude ’Inundation of wetlands may entrain nutrients and organic matter which have the potential to enhance metabolism within the river channel, but this requires water to return from the backwaters and wetlands to the river’. Clear evidence of this was found during the floods in 2010 in the Murray River, where inundation of the Barmah Forest was associated with significant increases in productivity as water returned to the channel (Cook et al. 2015). There have been examples of overbank environmental flows where flows have returned to the main channel, and it is likely that these were associated with increased productivity.



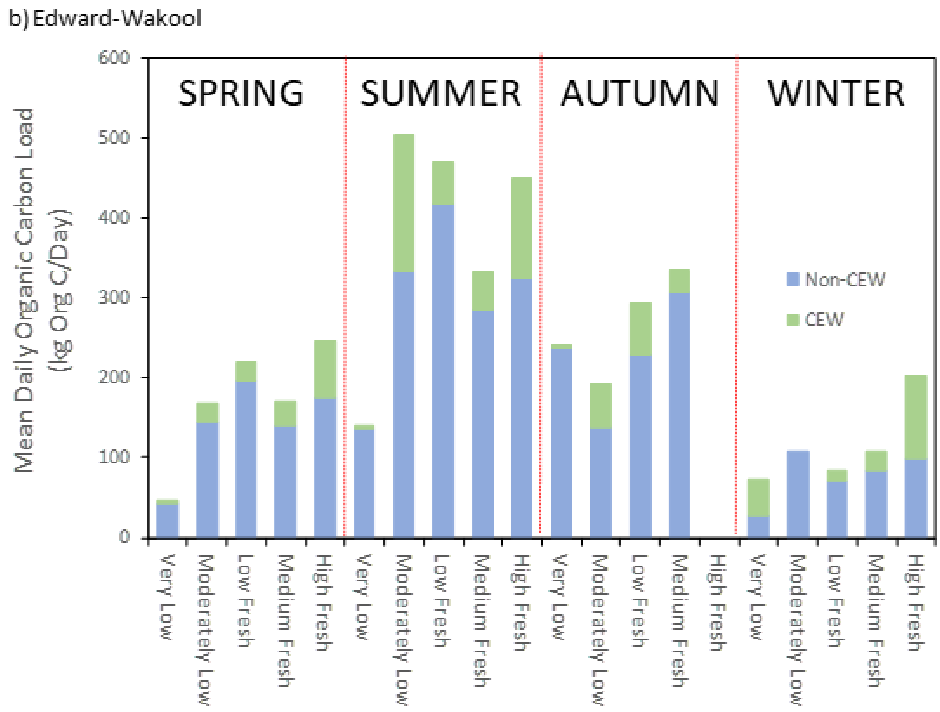


Figure 23 Contribution of Commonwealth Environmental Water (CEW) to the mean daily organic carbon load produced by gross primary production (kg Org C/Day), stratified into seasons, using the full five-year data set. Plots are for a) the Goulburn River selected area, and b) the Edward-Wakool selected area.

Overall, in the southern Basin riverine productivity has been variable spatially and temporally (between seasons and years) since 2014 (Grace 2020).

There is very strong evidence, particularly in the southern Basin, that riverine productivity increased with flow. Importantly, riverine productivity benefits were derived from relatively small increases in in-channel flows, highlighting that both in-stream and lateral flows have important roles to play.

The lack of a baseline, or reference condition, against which to compare the data obtained through the LTIM program over 2014 to 2019 means that it is not possible to know whether the results of the assessment of productivity for the southern Basin are lower or higher than the long-term average.

There is no firm data yet to confirm increases in metabolism associated with significant wetland and floodplain inundation. Whilst widespread floodplain inundation occurred in the southern Basin during October–December 2016, the anoxic conditions associated with the event prevented measurement of an expected increase in productivity.

Future opportunities

As further data becomes available over subsequent years, particularly in relation to watering events that result in significant wetland or floodplain inundation, it will be very informative to determine whether the 2014 to 2019 observed stream metabolism rates and organic carbon loads are unusually high or low, and the extent to which hydrology and/or other factors drive riverine productivity within the Basin. Research continues into whether low rates of productivity mean that food webs in the Basin are resource/energy limited.

There will also be opportunities to examine the influence of other threats (invasive species, land use) and how complementary measures can enhance the outcomes of environmental flow delivery. Finally, over time, the social and economic benefits of environmental flows and healthy ecosystems will become manifest. It will be important that consideration of these outcomes is considered in the adaption of monitoring programs.

Water quality

Background

Water quality is a key parameter in a healthy river system that underpins social, cultural and environmental values and the primary determinant of whether water is fit for purpose (Ch. 5.02.2.a). Fish and other aquatic organisms depend on the maintenance of good water quality, such as dissolved oxygen and salinity, to ensure their survival. The maintenance of good water quality is also essential for human use of water, including consumption, recreation and irrigation. Water quality is highly dependent on flow levels, temperatures and land management practices.

Threats to water quality include:

- Salinity occurs naturally in groundwater, however human practices such as irrigation and land clearing cause water tables to rise, bringing salt to the surface and into rivers. Salinity can affect the health of the environment, reduce drinking water quality, and affect crops and livestock.
- Blue-green algae is found naturally in fresh water but become an issue when they bloom—with bloom formation influenced by factors such as elevated water temperatures, sunny days and increased nutrient loads. Nutrients commonly used in farming, such as phosphorus and nitrogen, can enter the Basin's waterways, stimulating algal growth. Algal blooms pose a risk to both humans (because several species produce harmful toxins) and animal health (because the growth and subsequent collapse of blooms is associated with changes in dissolved oxygen that leads to fish kills).
- Blackwater is a naturally occurring process caused by nutrient-rich organic material, such as leaves and bark, washing into rivers during a flood. As this organic matter decays, tannins are released, giving the water a blackish appearance. The process can also release chemicals that make water more alkaline or acidic. When large amounts of organic matter are inundated with warm water, decomposition rates are high and this reduces dissolved oxygen levels, occasionally over hundreds of kilometres of river channel. However, this natural process is not always a threat and is important to the productivity of the river, providing nutrients to supply the food chain that aquatic life depend on.
- Low dissolved oxygen levels can occur in drought and flood conditions. Low dissolved oxygen levels suffocate and kill aquatic life (such as fish and shrimps) in large numbers. In drought, oxygen levels throughout the water column can quickly reduce when stratified water bodies with low-oxygen deeper layers rapidly mix with oxygenated surface layers due to sudden changes in climate conditions. In floods with large inputs of organic matter, the process responsible for blackwater can rapidly consume the oxygen in a river or lake.
- High turbidity is created by issues such as sediment flushed into rivers by erosion, following bushfires, or stirred up by carp. Turbidity reduces the penetration of sunlight, affecting plants and aquatic life.
- Temperature variations in rivers created by cold water released from dams, or summer heatwaves can be harmful to plants and aquatic life. Warm temperatures also encourage blue-green algae growth.

Drought conditions increase the threat of poor water quality, and under drought circumstances it is inevitable that poor water quality events will occur. It is expected that the delivery of environmental water and coordinated actions under the Water Quality and Salinity Management Plan will reduce the frequency or severity of poor water quality events and thereby reduce the impacts.

Salinity at key sites on the Murray River has shown a trend of decreasing over the past 30 years. However, the salinity levels at Burtundy on the Darling River show an increasing trend.

Evaluation assessment

Table 10 Approach to assessing outcomes for water quality

Indicator	Condition assessment	Assessment of contribution of the Basin Plan
Water quality	Not assessed: preliminary lines of evidence provided	Not assessed: preliminary lines of evidence provided

Basin Plan objectives for water quality

The objective in relation to water quality and salinity is to maintain appropriate water quality, including salinity levels, for environmental, social, cultural and economic activity in the Murray–Darling Basin (Ch. 5.04).

Chapter 9 of the Basin Plan (9.04) sets the further objective: that the quality of water is sufficient:

a. To protect and restore the ecosystems; and
b. To protect and restore the ecosystem functions of the ecosystem; and
c. To ensure that ecosystems are resilient to climate change and other risks and threats

How have we assessed water quality?

Table 11 Approach to assessing outcomes for water quality

Indictor	Analysis method		Location of data and analysis details
	Condition assessment	**Assessment of the contribution of the Basin Plan**	
Water quality	Not assessed: preliminary lines of evidence presented	Not assessed: Preliminary lines of evidence presented	N/A

Condition of water quality in the southern Basin

Preliminary lines of evidence

Implementation of the Water Quality and Salinity Management Plan is addressed as a separate theme of this evaluation. Key findings of that component of the evaluation include:

1. Salinity targets have been met at three measured sites on the Murray River since implementation of the Basin Plan. At Morgan, on the Murray River, salinity levels have shown a decreasing trend over the past 30 years.
2. The salinity target at the Darling River downstream of Menindee Lakes at Burtundy has been exceeded on a number of occasions with the number of days exceeding the target, showing an increasing trend. Over the five-year reporting period ending in June 2019, recorded salinity at the Burtundy site was above the target for 46% of the time.

Contribution of the Basin Plan to water quality in the southern Basin

Preliminary lines of evidence

Since the implementation of the Basin Plan, 41,583 ML of water has been delivered over 12 events in the southern Basin with the specific primary purpose of achieving water quality outcomes. The Edwards–Wakool River has received a number of flows specifically for water quality purposes, which have been monitored under the LTIM program. Over the four years of LTIM, the dissolved oxygen concentration was consistently higher during late summer and early autumn seasons at sites receiving environmental water compared to sites that did not receive environmental water (Watts et al. 2019).

There has been limited monitoring of water quality responses to environmental flow, however, monitoring in the Edwards–Wakool has highlighted the value of using watering actions to maintain baseflows for avoiding adverse water quality outcomes (Grace 2020). The hydrological component of this evaluation states that Commonwealth environmental water has made important contributions to improved base flow conditions in some southern Basin valleys, including the lower and central Murray, Edward-Wakool and Goulburn valleys. This has been particularly important in avoiding very severe baseflow conditions in these valleys. Subsequently, it is expected that water quality has benefited.

In addition to using flows to maintain water quality there are also a number of examples of where flows have been used to reduce the impacts of adverse water quality events. For example, in 2012–13 fish kills in the Lower Darling (due to low dissolved oxygen and moderate algal blooms) in resolved with releases from the Menindee Lakes. In 2015–16 widespread cyanobacteria outbreaks in the Murray were mitigated with dilution flows, fluctuations and exchanges of Murray and Lake Victoria water. In 2017–18, water was released from Lake Victoria to prevent downstream water quality issues relating to cyanobacteria outbreaks in the lake. Following hypoxic conditions and subsequent fish deaths in the Murrumbidgee in January 2019, environmental flows were released in the lower Murrumbidgee to provide refuge for fish and other aquatic organisms.

There have also been occasions where there was no capacity to deliver water to mitigate water quality issues. An example of this is the hypoxic conditions that occurred in the Lower Darling River in 2018–19, resulting in catastrophic fish deaths. Extremely low inflows, as a result of widespread drought, resulted in insufficient water availability to reduce the impact of this event. Other measures such as aerators and translocation of fish were used to reduce the impacts. This extreme event resulted in an independent report (Vertessy et al. 2019) and the subsequent development of an emergency response plan to ensure preparedness to reduce the impacts of detrimental water quality events on fish populations.

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Attachment 1: Hydrology analysis approach

In addition to the details below a technical paper on the hydrology analysis for this evaluation can be found on the MDBA website 2020 Evaluation: reports and data page.

What is the reference Baseline?

Schedule 7 of *the Basin Plan (2012)* outlines the targets to measure progress towards objectives. It states that there should be ’no loss of, or degradation in [flow regimes]’. However, there is no clear guidance in the legislation as to what reference conditions should be used to determine whether degradation has occurred.

In 2014 the Basin-wide environmental watering strategy (BWEWS) (MDBA, 2014) used the Basin Plan modelling as a baseline and to anticipate long-term Basin Plan changes against this modelling; however, experience from the 2017 Evaluation (MDBA, 2017) indicated that using a long-term model baseline was only partially effective for evaluating the Basin Plan, and the model had significant limitations in performance relating to certain parts of the flow regime.

As part of the 2020 Evaluation the MDBA has explored the use of an observed baseline—that is, to compare the pre- and post-2012 flows. For the observed baseline a cut-off of 1994 was selected, based on the Ministerial Council’s decision to introduce a Cap to limit growth in diversions to 1993–94 levels of development.

- The observed baseline runs for a period of 18 years from 1994–95 to 2011–12 and uses observed state gauge data.
- The model baseline uses a 98-year climate sequence and represents the 2008–09 levels of development.

The modelled baseline has the advantage of a much longer and more diverse climatic sequence that is a better representation of the diversity of conditions the Basin Plan is designed around. However, this model baseline does not represent historical flows.

The MDBA has used the model baseline in some circumstances and the observed baseline in others. The over-arching driver for this approach is to use the best available data that can best inform ongoing Basin Plan implementation. Analysis of model performance at different locations and in different parts of the flow regime found poor model performance outweighed the shorter climate sequence for cease-to-flow and terminal wetland indicators. Hence the relevant baselines are:

- ***Cease-to-flow***—observed baseline
- ***Baseflows***—observed baseline
- ***Terminal wetlands***—observed baseline
- ***Flow thresholds***—model baseline
- ***Transmissions***—model baseline.

Where model performance is not a significant issue, results against both baselines are produced as the information is still potentially pertinent to the Basin Plan Evaluation.

- Analysis against the overserved baseline tells us how/if things have changed in the ’real world’, i.e. what is the actual difference between the period before and after implementation of the Basin Plan. This provides a set of conclusions around flow changes and the associated tangible on-ground outcomes.
- Analysis against the baseline model tells us how the post Basin Plan years compare to the representation of 2008–09 levels of development that many Basin Plan settings (i.e. the SDL) were set against. This comparison can be used to guide long-term policy and planning settings.

Baseflows

Rationale: Baseflows (or low, in-channel flows) are an important component of the flow regime, maintaining aquatic habitat for fish, plants and invertebrates. Baseflows comprise long-term seasonal flows which provide drought refuge during dry periods and contribute to nutrient dilution during wet periods or after a flood event. These flows are generally maintained by seepage from groundwater, but also by low surface flows.

Indicator: A comparison of baseflows relevant to the natural or unaffected flow regime.

Target: The relevant target for the assessment period (ending June 2019) is that there is no degradation in the flow regime (and hence no degradation to baseflows against Pre-Basin Plan conditions). The target for 2024 is that baseflows are kept to at least 60% of the natural level.

Baseline/reference condition: While the desirable baseline would be a comparison of baseflow conditions pre and post implementation of the Basin Plan, modelling that was able to adequately characterise baseflows prior to the implementation of the Plan was not available. What has been completed is an evaluation of the provision on baseflows post Basin Plan and the contribution of the Basin Plan to baseflows in the southern Basin.

Condition analysis: This metric measures the Base Flow Index (BFI), the ratio of Baseflow/Stream Flow. As the baseflow has already undergone division by site specific streamflow, it was not measured as a function of catchment inflows. Baseflow was calculate as defined by Ladson, A. R., Brown, R. Neal, B. and Nathan, R. (2013) in *A standard approach to baseflow separation using the Lyne and Hollick filter*. An increase in BFI does not indicate a higher volume of baseflow, rather a higher proportion of baseflow relative to flow. For this reason, it is more common to see (counter-intuitively) high BFIs under dry conditions.

BP contribution analysis: LTIM Hydrology Basin Matter Reporting was used to assess the contribution of environmental water to baseflows (Stewardson and Guarino 2020). This analysis considers baseflows in two categories:

1. The very-low flow baseflow score, which relates to the duration of exceptionally low flows at the lower end of the range that would have normally occurred prior to water resource development.

2. The low flow baseflow score, which relates to the duration of flows below a level that might typically be used as a minimum environmental flow to maintain low flow habitats.

Freshes

Rationale: In-channel fresh events are small-to-medium flow events which inundate benches or small anabranches but stay in the river channel. They are generally relatively short in duration (i.e. a few days to a month) that typically occur in most years, and under natural conditions would occur multiple times within a year. These events replenish soil water for riparian vegetation, maintain in-stream habitats and cycle nutrients between parts of the river channel. They also inundate snags and woody debris, which form important habitat for invertebrates. Additionally, the rise in water level associated with freshes can induce reproductive behaviours in native fish.

Indicator: The indicator assessed for freshes is the number of days above the fresh flow threshold per water year.

Target: The relevant target for the assessment period (ending June 2019) is that there is no degradation in the flow regime (and hence no degradation to freshes against Pre-Basin Plan conditions). The BWS target for 2024 was based on fresh flows in the southern Basin increasing by 12% to 61%, depending on the catchment.

Baseline/Reference condition: The baseline is the pre-Basin Plan conditions. For this indicator, this has been represented by the baseline model run scenario (845), representing conditions as at 2009 and the pre-Basin Plan observed data (from 1994).

Condition analysis: Seven southern Basin sites (Murray, Loddon, Campaspe, Goulburn-Broken, Lower Darling, Murrumbidgee and Lachlan) were selected to complete the analysis of freshes. These gauge locations were chosen due to having good data availability (both observed and modelled) and having flow threshold information available. For both the observed and modelled flow data the number of days above the flow threshold for each year was calculated. For the modelled data runs this was carried out on data from the 1895 to 2009 water years. The observed data was assessed for the pre-Basin Plan period 1994 to 2012 and over the post-Basin Plan period of the 2012 to 2018 water years. The number of freshes observed each year was divided by the annual inflow at the catchment scale. This was used as a proxy for climatic condition when comparing the post-Basin Plan years to the pre-Basin Plan years. Both a t-test and a 2-sample ks-test was undertaken for each site to assess if there was a change in the mean or distribution respectively of the pre and post Basin Plan populations.

BP contribution analysis**:** LTIM Hydrology Basin Matter Reporting was used to assess the contribution of environmental water to baseflows (Stewardson and Guarino 2020). This analysis considers freshes in three categories:

1. A low-fresh is defined as a flow spell that raises water levels at least one-eighth of the height of the bank above the low flow level. Such freshes would be a very frequent occurrence in both the dry and wet seasons under pre-development conditions.
2. A medium-fresh is defined as a flow spell that raises water levels at least one-quarter of the height of the bank above the low flow level. This threshold would be a frequent occurrence in the pre-development regime, maintaining moist soils.

3. A high-fresh is defined as a flow spell that raises water levels at least half of the height of the bank above the low flow level. Freshes of this magnitude would have occurred in most years in the unaffected or natural flow regime, often multiple times.

Transmission of flows

Rationale: The transmission of flows has been chosen as a metric for longitudinal connectivity in the southern Basin, as it indicates the percentage of flows making it through from the top to the bottom of the system. This is important as a measure of the connectivity along the length of the catchment, and also to providing connectivity with the Murray.

Indicator: The indicator assessed for transmission of flows is the transmission ratio measured as inflows vs outflows at an annual scale for each catchment.

Target: The relevant target for the assessment period (ending June 2019) is the Basin Plan Schedule 7 target that there is no loss of, or degradation in, the flow regime and in hydrologic connectivity between hydrologically connected valleys (and hence no degradation in transmission of flows against Pre-Basin Plan conditions).

Baseline/reference condition: The baseline is given by the indicator results for the Pre-Basin Plan conditions. For this indicator, this has been represented by the post-cap period of 1994 to2011 and the baseline model run (845).

Condition analysis: Outflow was compared to inflow for every water year from 1994 to 2018. Post Basin Plan years were compared to pre-Basin Plan years and statistically compared using both a t-test and 2 sample ks-test to determine any changes in the mean and distribution respectively.

BP contribution analysis**:** LTIM Hydrology Basin Matter Reporting (Stewardson and Guarino 2020) together with reporting from environmental water holders on water delivery (Basin Plan Matter 9.3 reporting).

Site-specific flow indicators

As part of the development of the Basin Plan and the setting of the SDLs, the MDBA developed the environmentally sustainable level of take ESLT method (MDBA, 2011) to combine the best available environmental, social and economic science with the MDBA's whole-of-Basin hydrologic modelling framework. In effect, the ESLT method allowed the MDBA to complete a series of hydrologic model scenarios exploring different Basin Plan options, and then to translate modelled flow into social-economic-environmental outcomes using a scientifically robust method. These results were a primary line of evidence underlying the Authority's 2012 decision around the Basin Plan settings.

Central to the ESLT method were the site-specific flow indicators (SFIs). The SFIs were the primary flow-to-ecology translation metrics that were used during the development of the Basin Plan and were then reapplied as part of the Northern Basin Review (MDBA, 2016) and the SDL adjustment mechanism.

The broad purpose of the SFIs was to provide measures of success for various Basin Plan model scenarios — that is, to allow the MDBA to infer the environmental outcomes that could be achieved through different Basin Plan options. They are strongest when used in relation to long-term flow datasets (i.e. multi-decadal) and for whole-of-Basin or catchment-scale studies. Applying SFIs at shorter time scales or at sub-catchment geographic scales requires careful interpretation.

As a first concept, it would appear sensible to compare the SFI results that have occurred since 2012 to those that were anticipated by Basin Plan modelling — that is, to address the query 'the Basin Plan was expected to achieve these outcomes, but has it delivered?' Processing the SFI results for observed flow conditions is straightforward, and the MDBA has completed this task every year since 2014 to assist with the setting of the Basin annual environmental watering priorities. However, comparing observed and modelled flow carries an array of difficulties and caveats that must be either removed (i.e. through refined analysis) or addressed (through careful interpretation). The MDBA has previously not compared the observed and modelled SFI results, primarily due to three complications:

1. <u>Climate</u> – Basin Plan modelling represents 114 years of modelling that captures a wide range of different historical climatic conditions, but the period since 2012 has been preferentially dry, including record low inflows to Menindee.
2. <u>Basin Plan implementation is ongoing</u> – Basin Plan modelling represents a fully implemented Basin Plan, including 2,750 GL of water recovery, pre-2012 river operating constraints (such as 25,000 ML/d downstream of Yarrawonga Weir), and complete coordination of environmental water releases across the southern connected system. In practice, water recovery has been ongoing (and is still not complete), operating constraints have become more stringent, and coordination of environmental water between the southern catchments has been progressively increasing.
3. Environmental water holder behaviour – Basin Plan modelling used the SFIs as a basis for the pattern of environmental water releases. In practice, SFIs have not been used by environmental water managers. They are long-term, Basin-scale planning metrics which have limited utility to guide site-scale day-to-day water release patterns. This assumption was made due to lack of better information¾the modelling was completed in 2010–11, at which point the Commonwealth Environmental Water Holder was relatively new and there was no established behavioural pattern on which to base the modelled releases.

The analysis presented in this report largely removes the first of these complications by adjusting for climate (using inflows as a proxy). It also partially removes the second set of issues by accounting for progressive environmental water recovery (displayed in Figure 24). However, the issues around constraints and the pattern/coordination of environmental water releases remain. These issues will push the modelled SFI results in a consistent direction (i.e. higher than can be achieved in practice).

Theoretically, all the issues listed could be removed through improved modelling that better captures the day-to-day complexities of the river system (both natural and development-related) and is updated annually. Modelling at this level of sophistication is still a work in progress and must be completed collaboratively between the MDBA and the Basin states governments.

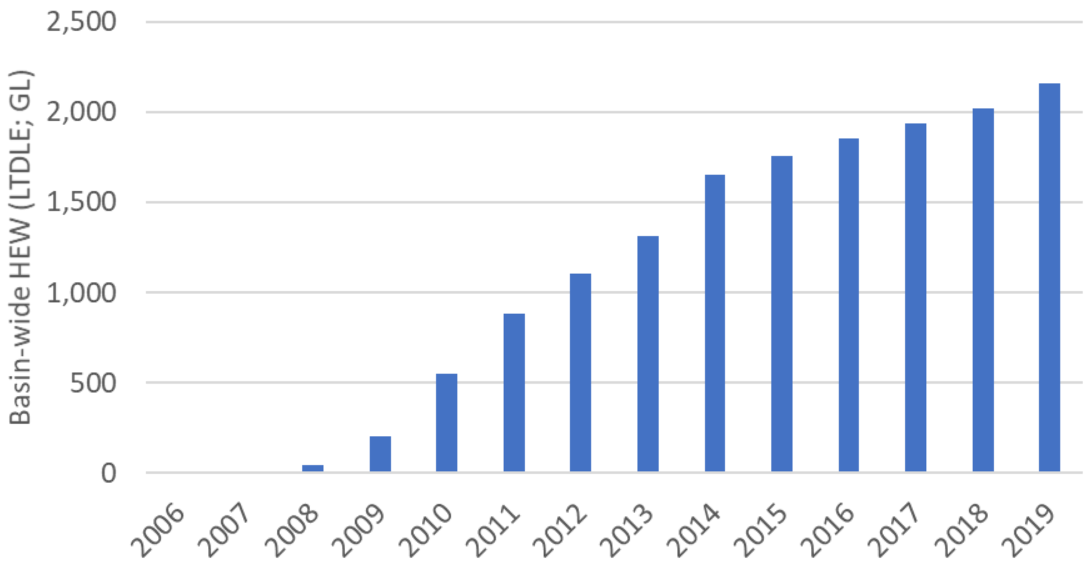


Figure 24 Progressive recovery of water for the environment—contracted surface water recovery in the Murray–Darling Basin at the conclusion of each calendar year (volumes in long-term diversion limit equivalent GL)

Analysis

This SFI analysis completed for the 2020 Evaluation has been designed to answer the following questions:

1. What are the SFI results for observed flow conditions since 2012?
2. Given the climate and water availability since 2012, what are the SFI results we would have expected to see under different scenarios? The scenarios examined for this question are the three primary scenarios from Basin Plan development (MDBA 2012):
    a. without development
    b. baseline (i.e. pre-Basin Plan)
    c. fully implemented Basin Plan (i.e. complete 2,750 GL water recovery and constraints as represented in the 2012 MDBA modelling).
3. Given that environmental water has been ongoing since 2012 and is not yet complete, what SFI results would we have expected to see? This question recognises the progressive implementation of the Basin Plan.
4. How do the observed SFI results compare to those that would have been anticipated under different scenarios? This analysis pulls together the results from questions 1, 2 and 3.
5. Given that there is seven years of data to draw on, what is the uncertainty in these results?

The approach adopted for this analysis has been to extrapolate SFI trends using existing Basin Plan model scenarios (Figure 25). That is, the analysis does not rely on new modelling or new data, but instead applies new analysis to existing data. Two sets of interpolation functions have been developed that relate SFI outcomes to climate (using inflows as a proxy) and to held environmental water respectively. Hence, for a given annual inflow volume, or annual held environmental water volume, the functions will provide a probability that a specific SFI will have been achieved. These functions operate at the catchment-scale, consistent with the overall hydrological method adopted for the 2020 evaluation. The approach is displayed in Figure 26.

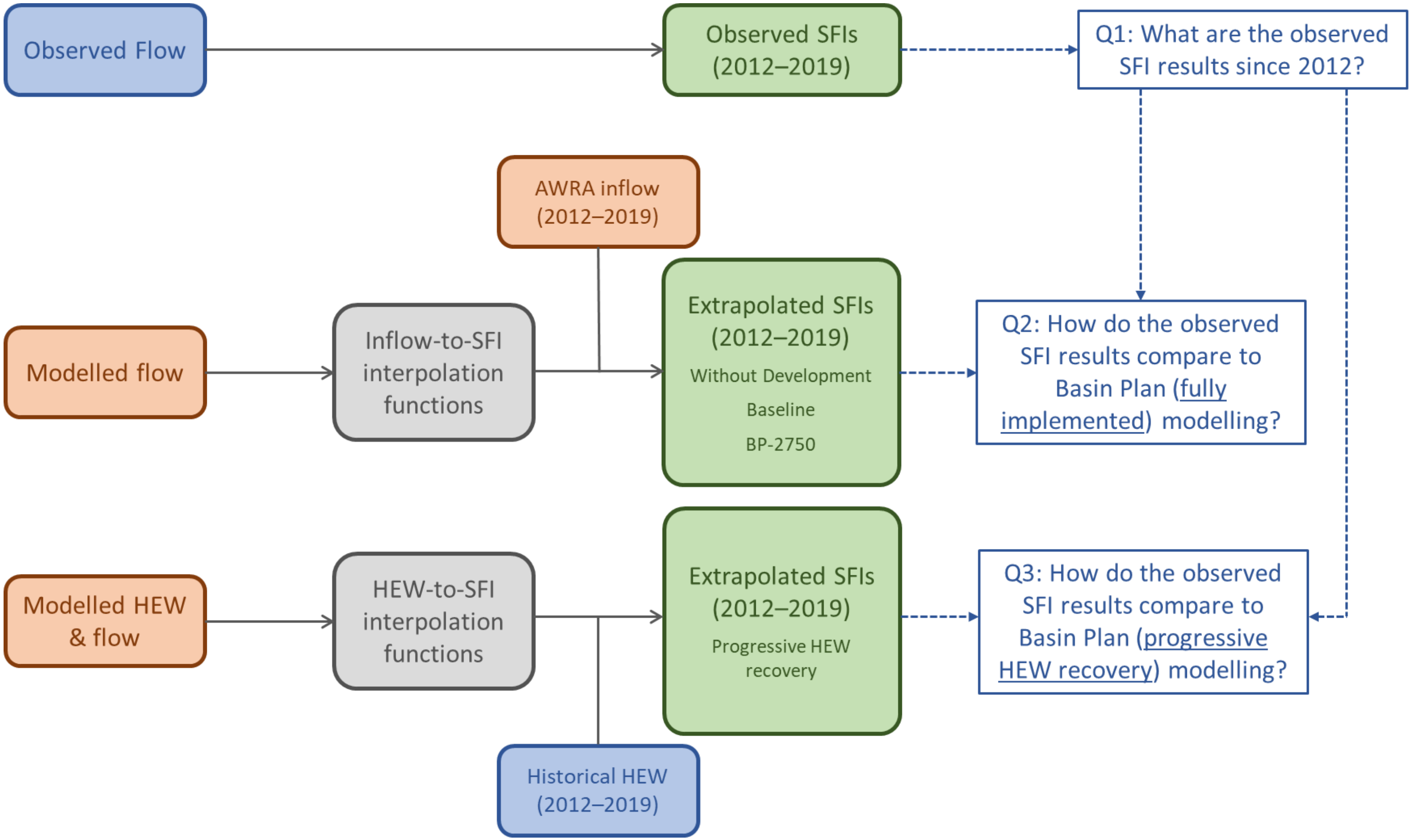


Figure 25 Analytical method used to extrapolate anticipated SFI results (2012–2019) under different scenarios. Blue boxes represent observed data, orange boxes represent modelled data.

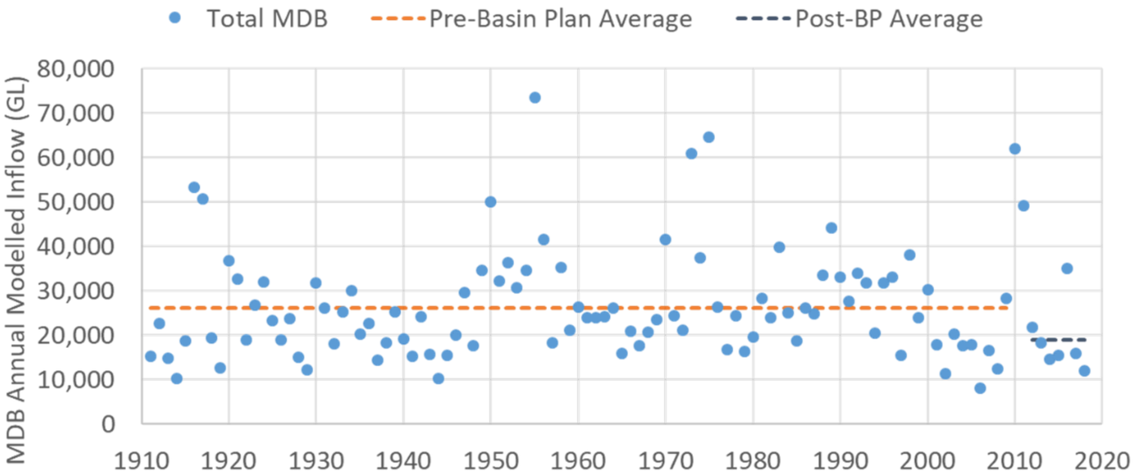
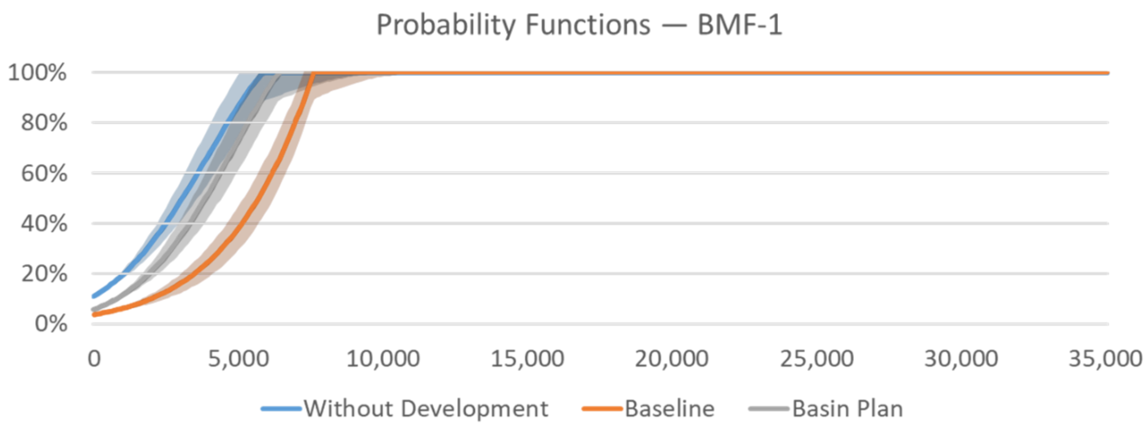


Figure 26 Basin-wide modelled inflows (from the AWRA model; BoM) for the period since 1910. Inflows since 2012 have been around 25% less than the long-term average, consisting of only one above-average year (in 2016).

Scaling the SFI results was achieved by developing probability functions from the Basin Plan modelling. Two sets of functions were developed – to provide a probabilistic relationship between annual upstream inflows volume and SFI achievement, and between annual HEW allocation and SFI achievement. Bootstrap resampling was used to measure the uncertainty in each probability function. Two examples are provided in Figure 27. An example of the output probabilities for each year is given in Table 12.



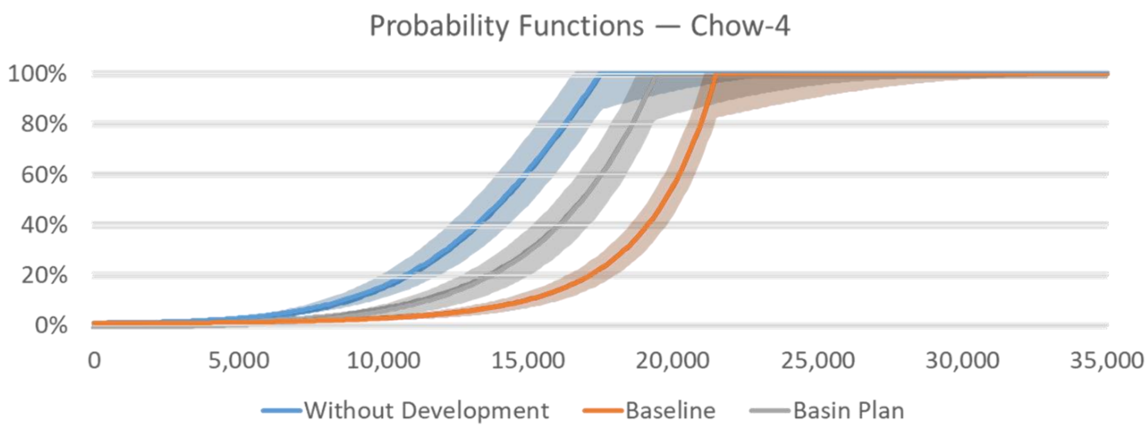


Figure 27 Probability functions for the 12,500 ML/d (for 70 days) SFI downstream of Yarrawonga Weir (Barmah–Millewa Forest) and the 60,000 ML/d (for 60 days) SFI at the South Australia border (Riverland-Chowilla floodplain)

Table 12 Annual SFI probabilities (under baseline modelled conditions) for the SFIs at Barmah-Millewa Forest

Site	SFI Identifier	SFI	Baseline									
			2009 – 2010	2010 – 2011	2011 – 2012	2012 – 2013	2013 – 2014	2014 – 2015	2015 – 2016	2016 – 2017	2017 – 2018	2018 – 2019
Barmah–Millewa Forest	BMF-1	12.5 GL/d for 70 days	4%	98%	83%	25%	25%	7%	9%	86%	14%	4%
	BMF-2	16 GL/d for 98 days	1%	93%	69%	13%	13%	3%	4%	73%	6%	1%
	BMF-3	25 GL/d for 42 days	1%	94%	69%	12%	12%	2%	3%	73%	6%	1%
	BMF-4	35 GL/d for 30 days	1%	92%	64%	8%	8%	1%	2%	68%	3%	0%
	BMF-5	50 GL/d for 21 days	1%	87%	55%	7%	7%	1%	2%	59%	3%	0%
	BMF-6	60 GL/d for 14 days	1%	81%	49%	7%	7%	2%	2%	53%	3%	1%
	BMF-7	15 GL/d for 150 days	1%	61%	33%	6%	6%	2%	2%	36%	3%	1%

Based on these functions and the annual inflow volumes for the 2012–19 period, a Monte Carlo simulation was completed to provide the expected SFI results (with associated uncertainties) under the three model scenarios.

Question 1—Observed SFI outcomes

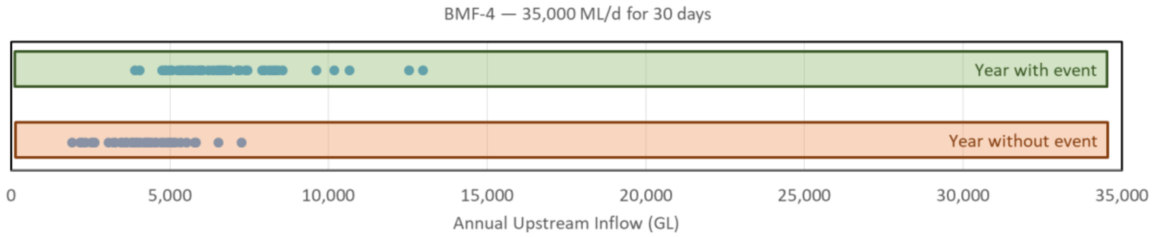
As described above, the MDBA regularly processes SFI results against observed flow data to inform the setting of the annual priorities for environmental watering. Complete SFI results for the Basin are available on the [MDBA 2020 Evaluation dashboard](). Table 13 shows the River Murray SFIs results since 2012 and the annual SFI frequencies since 1950 and 2012.

Table 13 SFI results for the River Murray since 2012

Catchment	Site	SFI	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	Frequency (1950–2019)	Frequency (2012–2019)
MURRAY	Barmah–Millewa Forest	12.5 GL/d for 70 days	1	1	0	0	1	0	1	54%	57%
		16 GL/d for 98 days	1	0	0	0	1	0	0	32%	29%
		25 GL/d for 42 days	1	0	0	0	1	0	0	38%	29%
		35 GL/d for 30 days	0	0	0	0	1	0	0	35%	14%
		50 GL/d for 21 days	0	0	0	0	1	0	0	25%	14%
		60 GL/d for 14 days	0	0	0	0	1	0	0	22%	14%
		15 GL/d for 150 days	0	0	0	0	0	0	0	9%	0%
	Gunbower–Koondrook–Perricoota	16 GL/d for 90 days	1	0	0	0	1	0	0	32%	29%
		20 GL/d for 60 days	1	0	0	0	1	0	0	42%	29%
		30 GL/d for 60 days	0	0	0	0	0	0	0	26%	0%
		40 GL/d for 60 days	0	0	0	0	0	0	0	13%	0%
		20 GL/d for 150 days	0	0	0	0	0	0	0	7%	0%
	Edward-Wakool	1.5 ML/d for 180 days	0	0	0	0	0	0	0	62%	0%
		5 ML/d for 60 days	0	0	0	0	1	0	0	42%	14%
		5 ML/d for 120 days	0	0	0	0	0	0	0	28%	0%
		18 ML/d for 28 days	0	0	0	0	1	0	0	25%	14%
		30 ML/d for 21 days	0	0	0	0	1	0	0	23%	14%
	Hattah Lakes	40 GL/d for 60 days	0	0	0	0	1	0	0	30%	14%
		50 GL/d for 60 days	0	0	0	0	0	0	0	26%	0%
		70 GL/d for 30 days	0	0	0	0	0	0	0	25%	0%
		85 GL/d for 30 days	0	0	0	0	0	0	0	19%	0%
		120 GL/d for 14 days	0	0	0	0	0	0	0	12%	0%
		150 GL/d for 7 days	0	0	0	0	0	0	0	10%	0%
	Chowilla	20 GL/d for 60 days	1	0	0	0	1	0	0	43%	29%
		40 GL/d for 30 days	0	0	0	0	0	0	0	26%	0%
		40 GL/d for 90 days	0	0	0	0	0	0	0	14%	0%
		60 GL/d for 60 days	0	0	0	0	0	0	0	13%	0%
		80 GL/d for 30 days	0	0	0	0	0	0	0	9%	0%
		100 GL/d for 21 days	0	0	0	0	0	0	0	6%	0%
		125 GL/d for 7 days	1	0	0	0	1	0	0	48%	29%

Question 2 — Extrapolated SFIs from Basin Plan modelling

Basin Plan SFIs are satisfied when a specific pattern of flow (generally, threshold and duration) is achieved at a particular time of year. However, there is a strong correlation between annual inflow volume and the probability that SFI conditions will be satisfied. Figure 28 shows the distribution of successful and unsuccessful years for the 35,000 ML/d Barmah–Millewa SFI. As expected, the SFI is more likely to be achieved in years with higher inflows. Also, due to flow regulation (i.e. public storages) and extraction, SFI achievement is less common in the baseline scenario compared to the without Basin Plan development scenario.



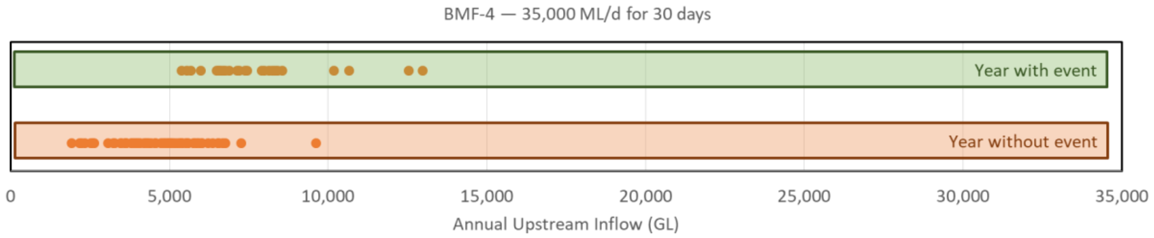


Figure 28 Distribution of years for the Barmah–Millewa 35,000 ML/d SFI against upstream annual inflow volume for without development (blue points) and baseline (orange points) conditions

Question 3—How do observed SFI results compare to Basin Plan modelling after accounting for the progress of water recovery?

A summary of the results is given in Table 14, noting that the description (increased, maintained or decreased) is based on post-2012 observed flows compared to the baseline model scenario. The findings are:

1. Freshes/bankfull flows have increased through most of the southern system.
2. Some floodplain outcomes (such as Barmah–Millewa Forest and in the Murrumbidgee) have been maintained or increased.
3. Other floodplain outcomes have decreased.

Table 14 Summarised outcomes based on SFI probabilistic analysis

Site	Comparison to Baseline			
	Fresh-to-Bankfull	Lower FP	Mid FP	High FP
Barmah–Millewa	Increased	Increased	Maintained	Maintained
GKP	Maintained	Maintained	Decreased	Decreased
Hattah	N/A	Decreased	Decreased	Maintained
Chowilla	Maintained	Decreased	Decreased	Maintained
Mid-Bidgee	N/A	Maintained	Decreased	Maintained
LowBidgee	N/A	Maintained	Maintained	Maintained
Balranald	Increased	N/A	N/A	N/A
Goulburn	Increased	Decreased	Decreased	Decreased

Note: The outcomes outlined in red have been identified to be strongly dependent on ongoing Basin Plan implementation activities, such as constraint relaxation, supplementing unregulated flows, and multi-catchment releases. Those outlined in grey were identified to be beyond flow regulating capacity.

Interpretation

The purpose of this analysis was to allow a more refined comparison between the observed SFI results and those that were provided by the 2012 Basin Plan modelling. This was achieved by scaling the Basin Plan modelling SFI results, based on inflows and ongoing HEW recovery since 2012.

The findings indicate that some of the lower-to-mid floodplain flows have gone backwards since 2012, despite ongoing Basin Plan implementation — notably, environmental water recovery and delivery.

Some of this is expected — during dry conditions the ability to deliver floodplain outcomes is very low and the focus is on maintaining critical habitats. Also, the only wet year in the post-2012 climate has thus far been 2016–17. This wet period commenced with relatively low storage levels and did not provide extended inflows (it was a short flow event), hence spills and subsequent downstream inundation would be towards the lower end of the anticipated outcomes.

In addition, those parts of the flow regime that have been categorised as ‘decreased’ are strongly dependent on ongoing Basin Plan implementation activities, such as the relaxation of constraints, supplementation of unregulated flows, and multi-catchment releases. Progress on these activities has been mixed:

1. Supplementing unregulated flows (i.e. pre-requisite policy measures) and multi-catchment releases have been progressively improving since 2012. Nevertheless, this progress does not mirror that represented in Basin Plan modelling — the scenarios provided the environmental water holder with weeks of foresight to order water against their entitlements, and these orders were given first preference over other entitlement holders by the modelled river operators. This level of environmental water coordination and prioritisation is unlikely to be achieved in practice (there would be significant third-party impacts). Accordingly, the red-box categories in **Error! Reference source not found.** are unlikely to meet the Basin Plan m odelling outcomes.

2. Constraints have not been relaxed compared to 2012. In fact, most constraints across the southern Basin have become more stringent compared to those that were in operation in the 2000s and represented in the Basin Plan modelling. As an example, the 22,000 ML/d Yarrawonga Weir releases that were included in the Basin Plan modelling are currently set at 15,000 ML/d in response to community concerns. This strongly restricts the ability of environmental water holders to deliver water to the floodplains.

Since the Millennium Drought, additional efficiencies in river operations have been introduced as part of standard adaptive management, reducing unmanaged flows through the southern system. The Basin Plan models from 2012 did not capture these management changes.

Furthermore, the SFI results in **Error! Reference source not found.** do not capture the floodplain b enefits that have been achieved through the combination of environmental water delivery and environmental works. This has allowed significant benefits to be achieved along parts of the floodplain. Overall, the large-scale floodplain benefits anticipated by the Basin Plan in 2012 have not yet been achieved, but environmental works are delivering benefits at specific sites.

Overall, the findings of this work indicate that, due to a wide array of factors, the floodplain outcomes anticipated in 2012 by Basin Plan modelling are not yet being achieved. Some of this relates to ongoing implementation activities (such as constraints relaxation, water recovery and the package of SDL adjustment measures). However, the climate since 2012 has also been a leading factor. With only a single wet year, measurable changes in rainfall seasonality, record high temperatures, and a record drought in the northern Basin (providing record low inflows to Menindee Lakes), it is likely that the hydrology of the Basin has been substantially impacted by climate change. This points to the need to adapt the Basin Plan and its subsidiary instruments in coming years in response to anticipated future climatic changes.

Attachment 2: Native fish analysis approach

Species richness

Rationale: The southern Basin supports 27 native species, of which 26 are listed as threatened species. Species richness, or the number of species, is one measure of diversity, with a decline in species richness an indicator of declining ecological health and biodiversity. Species richness, as a metric to evaluate directional trends in biodiversity under changing environmental conditions has its limitations, as it does not reflect how dominance and identity shift in fish communities over time (Hillebrand et al. 2017). In addition, there are sampling bias/effectiveness issues with most monitoring and assessment programs not recording all the species present due to the sampling/ site selection methods employed. This is particularly true for rare or cryptic species, unless dedicated surveys are undertaken. Despite this, species richness provides a useful means of evaluating temporal trends in species detections from which it can be determined if there has been any loss of native species in the Southern Basin since the implementation of the Basin Plan in 2012.

Indicator: Species richness based on presence or absence of native riverine fish species and consistent detection of key fish species over time.

Target: No loss of fish species in the southern Basin and continued presence of key fish species, as identified in the BWS (2014). Key fish species were identified by an expert panel during the development of the BWS and comprise: silver perch, golden perch, Murray cod, trout cod, Macquarie perch, freshwater catfish, river blackfish, two-spined blackfish, southern pygmy perch, southern purple-spotted gudgeon.

Baseline/reference condition: A subset of the Sustainable Rivers Audit monitoring, selected to match the current MDBFS sites (see Text Box 1) from the period 2005 to 2011, was used to develop a pre-Basin Plan baseline.

Analysis: Data from the Murray Darling Basin Fish Survey (MDBFS) (See Text Box 1) was analysed for the presence of native fish in the southern Basin. In addition, a literature review of the existing published information was conducted to capture the presence of rare species that may be missed in the MDBFS sampling program.

Murray cod and golden perch populations

***Rationale**:* Evaluation of riverine key fish populations and recruitment are key elements for assessing the effectiveness of the Basin Plan in achieving biodiversity and ecosystem function outcomes. Assessing the length-frequency or life-stage frequency distributions are a useful metrics of population dynamics. Increases in the abundance of adult fish suggest that fish are breeding and successfully recruiting into the population, and that adults are surviving throughout the age classes. The overall proportion of adults, sub-adults and Young of Year (YOY) (i.e. life classes) can be used as indicators of the maintenance of a species population through time.

Population Indicator*:* The abundance and population (life classes) structure for two southern Basin riverine key fish species; Murray cod and golden perch. These were selected noting that there was insufficient information to complete the analysis for other riverine key fish species in the southern Basin using the MDBFS database.

Target*:* The target set for Murray cod and golden perch is that life class structure is maintained during the reporting period 2015-2019 compared to before implementation of the Basin Plan, 2005-2013.

Baseline/reference condition*:* The pre- Basin Plan baseline was derived from the SRA monitoring over the period 2005 to 2013.

Condition analysis*:* Data from the MDBFS (see Text Box 1) was analysed for Young of the Year, sub-adult and adult life classes of Murray cod and golden perch in the southern Basin. The length-frequency life class plots, based on the sizes used for the SRA, were used to infer the annual population and recruitment outcomes for each SRA and MDBFS sampling round. Basin-scale LTIM fish data was analysed for the total population abundance, the abundance of YOY and spawning outcomes (the probability of spawning and larval fish abundance). LTIM Basin-scale fish data consists of standardised sampling, collected from 2014–2019 at six selected areas across the Basin; including the Goulburn River, Edward–Wakool River system, Murrumbidgee River, Lachlan River and Lower Murray River System.

BP contribution analysis: Basin-scale LTIM fish data was analysed for the abundance of YOY and spawning outcomes (the probability of spawning and larval fish abundance). LTIM Basin-scale fish data consists of standardised sampling, collected from 2014–2019 at six selected areas across the Basin; including the Goulburn River, Edward-Wakool River system, Murrumbidgee River Lachlan River and Lower Murray River System. King et al. (2020) assesses the effects of flow and the contribution of Commonwealth environmental water during this five-year period on the outcomes for key riverine species and key fish metrics.

Basin-wide native fish survey

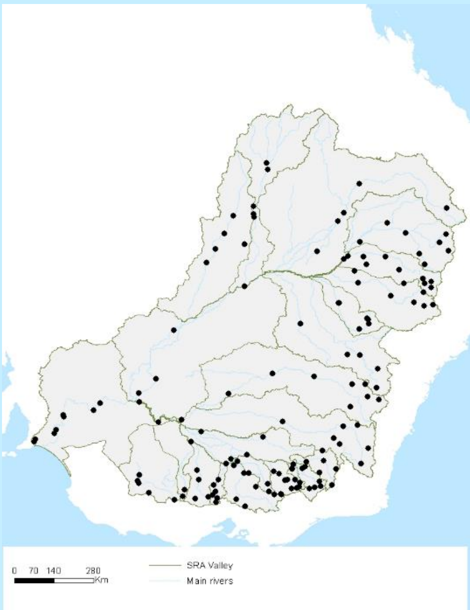
Basin-wide fish surveys were conducted using standard sampling protocols at 110 consistent sites (44 in the northern Basin and 66 in the southern Basin) over seven sampling periods (2004–07; 2007–10; 2010–13; 2014/15; 2015/16; 2017/18; 2018/19). The first three sampling events were conducted over three- year periods as part of the Sustainable Rivers Audit (Davies et al 2012), while the most recent sampling events were conducted annually between 1st November and 30th June.

The design of the Basin-wide fish survey uses a fixed-site sampling design to understand what changes occur over time in fish populations across valleys of the Murray–Darling Basin. From a statistical perspective the survey is focused on temporal rather than spatial variability. Under the survey for the Sustainable Rivers Audit (SRA), sites to be surveyed were randomly selected. Only those sites in the SRA that were resampled each sampling period (‘fixed’ sites) were included in the current Basin-wide survey. Despite the sites being fixed, there has been some variability in the sites used because of a variety of conditions that have limited the capacity to sample a particular site. As such, a sub-sample of 110 sites that have been consistently sampled each year is being used for this evaluation.

As with many monitoring programs, the Basin-wide survey has limitations. The probability of capturing a fish using electrofishing changes depending on the fish's characteristics as well as the environmental conditions at the site (Lyon et al. 2014). As such, it is recognised that in certain conditions some cohorts of fish may go undetected unless sufficient replication is applied (Lyons et al. 2014). The coarse and untargeted nature of the survey may also contribute to some species and/or size classes being underrepresented.

An analytical challenge is that the design of the survey is a form of cluster sampling, which means that the fish detected at any one site are not independent of each other (Nelson 2014).

This means that the Type I error rate of common statistical tests conducted on this data will be severely inflated and significant differences may be found where they are not truly present (Nelson 2014). These limitations mean that currently the data from the Basin-wide survey is not a good indicator of the entire biological population across the Basin. As such, the data from the survey is presented descriptively in this evaluation to develop an understanding of changes over time in a consistent data set, and is considered to be just one indicator of changes in native fish populations.



Location of survey sites of the Murray Darling basin Fish Survey

Office locations
Adelaide
Albury-Wodonga
Canberra
Goondiwindi
Griffith
Mildura
Murray Bridge
Toowoomba

mdba.gov.au 1800 230 067 engagement@mdba.gov.au