

# 2018–19 Basin-scale evaluation of Commonwealth environmental water – Hydrology

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## Final Report

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## **2018–19 Basin scale evaluation of Commonwealth environmental water – Hydrology**

Final Report prepared for the Commonwealth Environmental Water Office (CEWO) by La Trobe University

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# 1 Introduction

## 1.1 Background

The management of Commonwealth environmental water is one of the principle means by which the Australian Government seeks to achieve the *Murray–Darling Basin Plan 2012* (Basin Plan) environmental objectives. The Commonwealth Environmental Water Holder (CEWH) manages Commonwealth environmental water to achieve specified environmental outcomes as a result of the management of these water holdings. This report seeks to evaluate whether there is no loss of, or degradation in, the following:

- a) flow regimes, which include relevant flow components set out in the Basin Plan (Section 8.51(1)(b))
- b) hydrological connectivity between the river and floodplain and between hydrologically connected valleys.

This Hydrology evaluation underpins the evaluation of ecological outcomes for the other ecological indicators that are evaluated at the Basin scale (called ‘Basin Matters’: Fish, Vegetation Diversity, Ecosystem Diversity, Stream Metabolism and Water Quality, and Generic Diversity). This is a three-step process:

- 1. Identify flow outcomes to support evaluation of Commonwealth environmental water effects on flow regime.
- 2. Identify resultant hydraulic outcomes to enable evaluation of whether environmental flow management achieved the expected hydraulic and connectivity outcomes. This takes the form of inundation mapping across the Basin.
- 3. The hydraulic and connectivity outcomes are then used to evaluate the environmental outcomes and, over time, improve our understanding of environmental water requirements.

This evaluation of the effect of Commonwealth environmental water delivery on flow regime is a collaborative undertaking between the Commonwealth Environmental Water Office (CEWO) with the evaluation team working across the University of Melbourne and University of Canberra. The CEWO coordinates compilation of operational data to characterise Commonwealth environmental water delivery. The evaluation team undertake the analysis and interpretation of these data to evaluate Basin-scale hydrological outcomes.

## 1.2 Context

This report provides an evaluation of the contribution of Commonwealth environmental water to flow regimes and hydrological connectivity across the Basin. The evaluation focuses on the 2018–19 watering year, and also evaluation of the cumulative multi-year outcomes achieved over the period 1 July 2014 to 30 June 2019 in the valleys of the Basin where Commonwealth environmental water was delivered.

This evaluation is one component of the broader LTIM Project for the CEWO, which seeks to evaluate the ecological outcomes of the management of Commonwealth environmental water and its contribution to the environmental objectives of the Basin Plan. Hydrological outcomes inform the broader evaluation of biodiversity, ecosystem function and resilience at the Basin scale. The report does refer to specific outcomes within individual valleys but only where these contribute important information to the Basin-wide outcomes. A systematic account of outcomes at the valley scale can be viewed in the Report Cards – Annex A.

The hydrological analysis methods and underpinning datasets have been improved throughout the five-year Long-Term Intervention Monitoring (LTIM) Project as anticipated in the initial

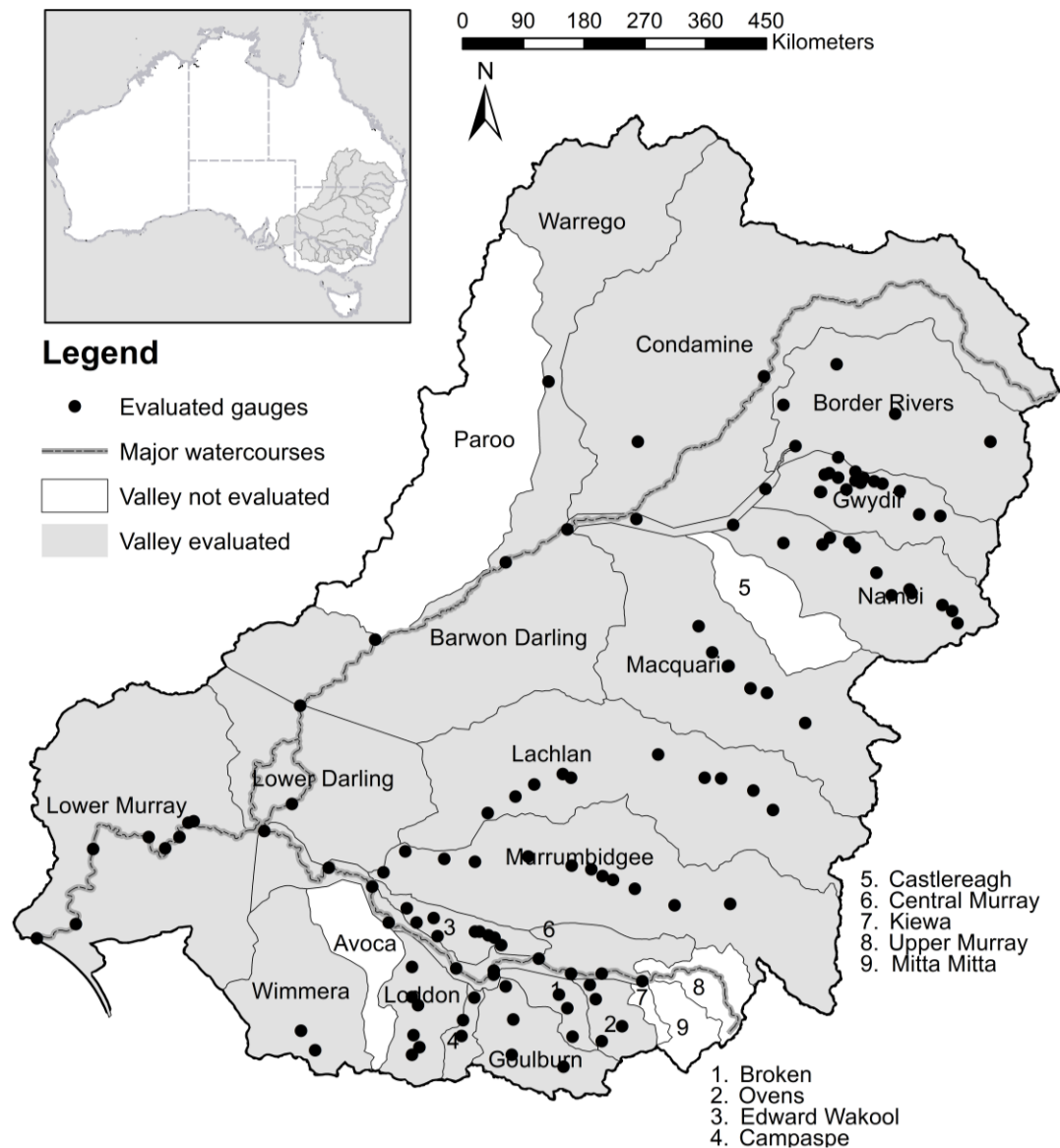
program plan. For this five-year report, the results across all five years have been updated using best available information and methods. For this reason, these five-year results supersede results provided in our earlier reports, where they differ.

## 2 Features of this Evaluation

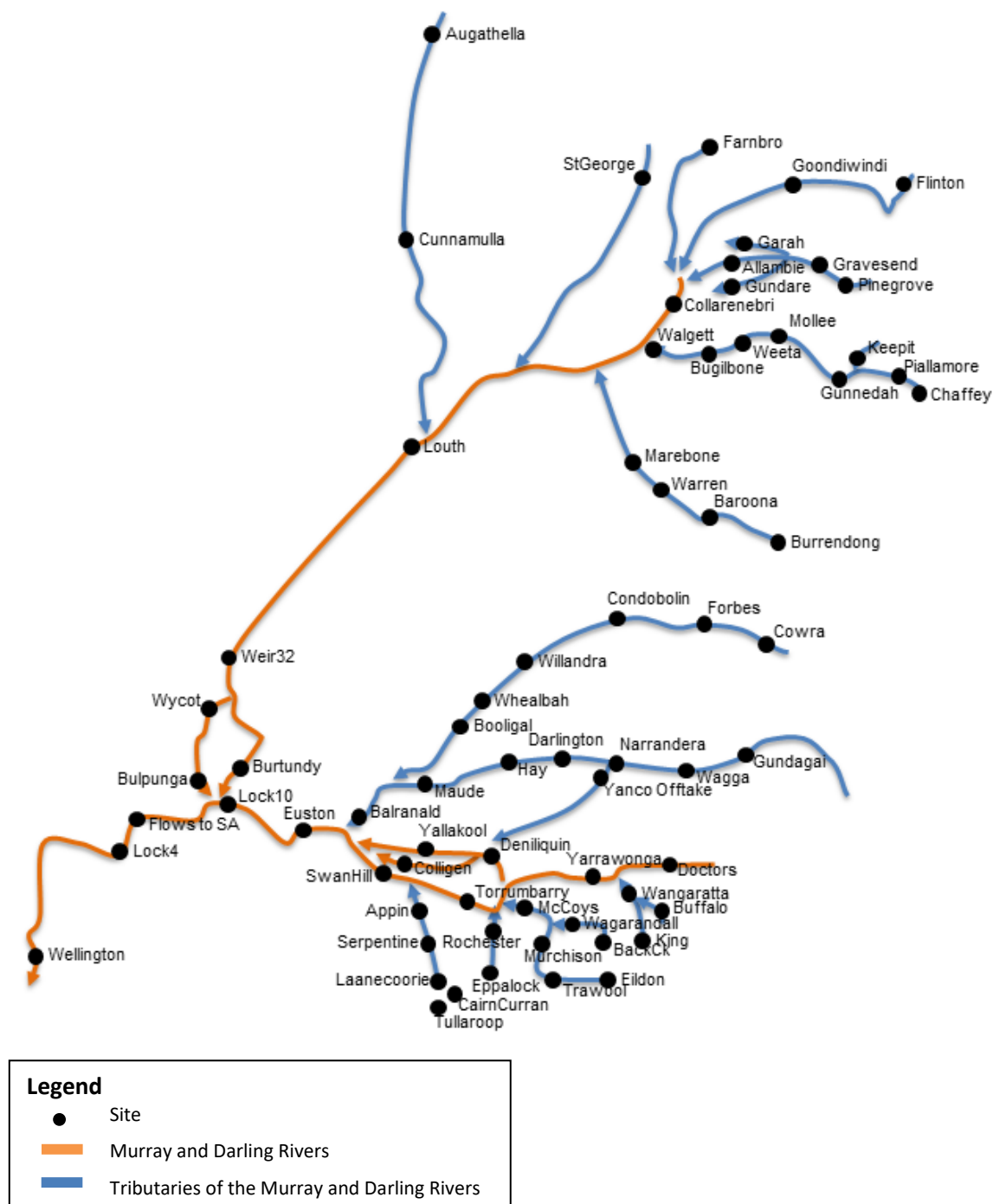
### 2.1 Scale of evaluation

This report describes the hydrological outcomes from the delivery of Commonwealth environmental water at the site, valley and Basin scales. The valleys used for the LTIM Project Basin-scale hydrological assessment are adapted from a modified version of the Murray–Darling Basin Sustainable Rivers Audit valley boundaries (Figure 1). These valley boundaries were the most closely aligned with regions targeted for environmental flow delivery. Note that the regulated portion of the River Murray is divided at Lake Victoria into the Central Murray valley, extending from Hume Dam to Lock 10 (upstream of Lake Victoria); and the Lower Murray valley, extending from Lake Victoria to the upstream extent of the Lower Lakes. Although the Basin includes a total of 25 valleys (Figure 1), valley-based reporting is provided for 17 valleys (Figure 1) where environmental water was delivered. Hydrological outputs are also synthesised at the Basin scale in this report.

We also report on conditions at 72 sites (Figure 2) to represent variation in hydrological outcomes throughout the Basin. The 72 sites are a sample of a larger set of sites used for the valley and Basin evaluations. Detailed information for the full set of sites including the time-series of environmental water delivery, is provided in the valley Report cards (Annex A). Although, Commonwealth environmental water was delivered in the Wimmera River in 2018-19, we do not include this valley in our 72 site assessment due to the intermittent nature of environmental flow delivery in this valley.



**Figure 1.** Valleys assessed in the 2018–19 hydrological evaluation of Commonwealth environmental water.

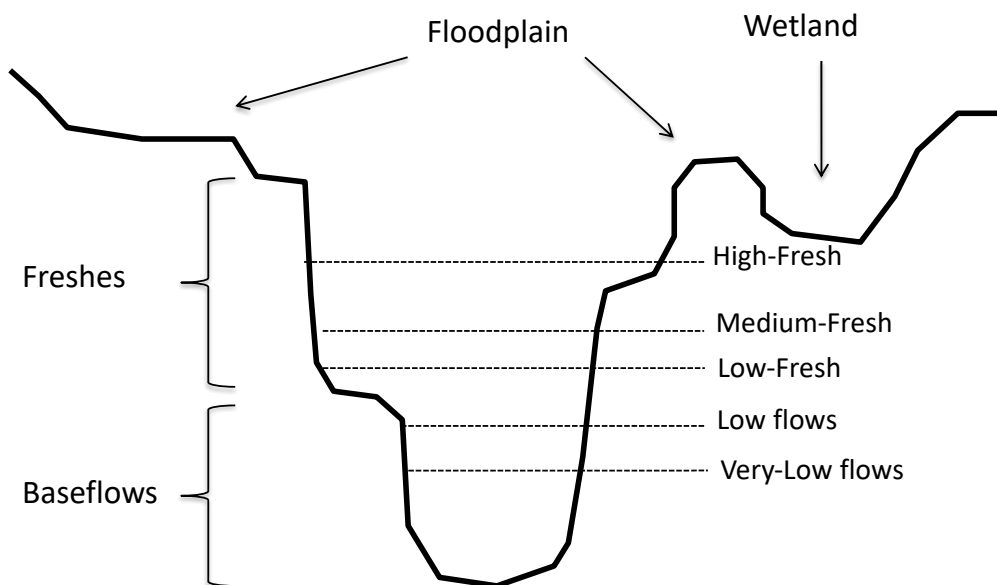


**Figure 2.** Key sites for presenting hydrological outcomes in this report.

## 2.2 Hydrological features considered in this report

The hydrological evaluation in this report examines the contribution of Commonwealth environmental water to four features of the Basin's hydrology: base flows; freshes; lateral hydrological connectivity with the floodplain; and longitudinal hydrological connectivity downstream through the Basin. Here we provide a brief introduction to these features. The detail of the evaluation methods is provided in Appendix I.

In the case of base flows and freshes, we use scores to indicate improvements in the flow regimes with environmental water delivery. The scores are calculated using two base flow thresholds and three fresh thresholds (Figure 3). In the case of base flows, we are concerned with the duration of flows below these thresholds and for freshes, we are concerned with the occurrence of flows above these thresholds. We consider flow magnitude relative to these flow thresholds because: (a) they have an environmental significance; and (b) it allows comparison of flows regimes across rivers of different size.



**Figure 3.** Conceptual diagram indicating water levels corresponding to the flow freshes and base flows used in this evaluation.

#### *Base flows*

Environmental water is delivered across the Basin to maintain base flows. We report two base flow scores to evaluate the contribution of these flows to the flow regime. Low base flow scores indicate excessive duration of low-flow conditions relative to conditions prior to water resource development. The score varies between 0 and 100%. A low score indicates dry conditions with low-flow conditions persisting much longer than would have occurred prior to development. A score of 100% indicates base flow conditions that are similar to pre-development. We use scores related to two baseflow thresholds:

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

#### *Freshes*

Three fresh scores relate to the occurrence of freshes. A score of zero indicates that very few or no freshes have occurred. A score of 100% indicates that freshes have occurred at a frequency typically targeted by environmental flow programs.

The three fresh scores relate to freshes that exceed three flow thresholds within the river channel. A **low-fresh** is defined as flow spell that raise 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. A **medium-fresh** is defined as a flow spell that raise 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. A **high-fresh** is defined as a flow spell that raise 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 unimpacted flow regime, often multiple times.

#### *Lateral Hydrological Connectivity*

Environmental water is used to fill wetlands and other habitats across the floodplains of the Basin using a variety of delivery methods. The movement of water between the channel and floodplain is described as lateral hydrological connectivity. We evaluate this contribution of environmental water based on the area of floodplain that has been inundated.

#### *Longitudinal Hydrological Connectivity*

The low reaches of each river valley and the entire Basin are particularly vulnerable to upstream water withdrawals with flows declining to severely low levels and even ceasing in some cases. It is hoped that protection of environmental water entitlements in these valleys increases flow volumes passing down to these lower reaches. We evaluate improvements in longitudinal hydrological connectivity by reporting the increase in end-of-valleys flows as a result of Commonwealth environmental water.

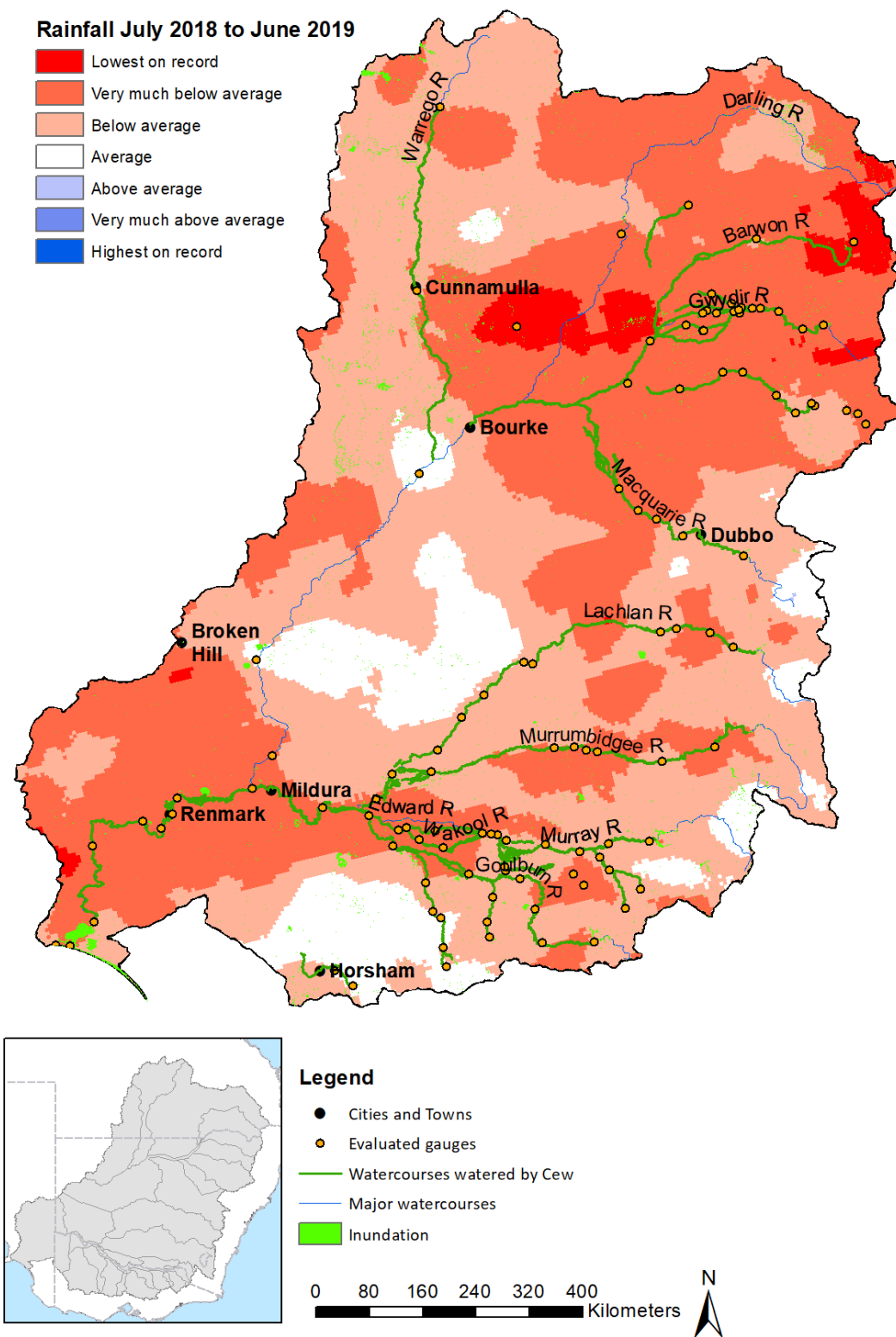
The Lower Lakes, Coorong and Murray Mouth are a unique feature of the Basin and dependent on longitudinal hydrological connectivity from upstream for the supply of freshwater. We include a close examination of the contribution of Commonwealth environmental water to the hydrology and related processes of this system.

### **3 Context for the Year**

#### **3.1 Climate**

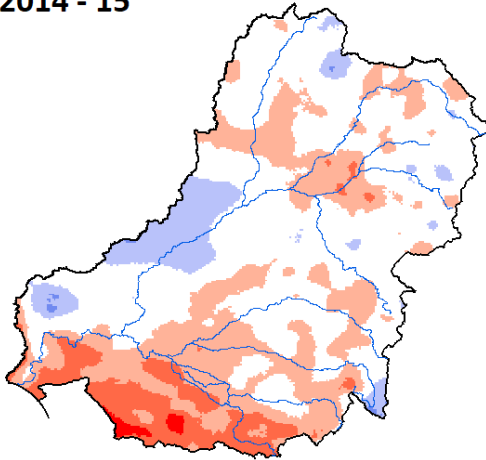
In 2018–19, the Wimmera was the only valley that experienced average rainfall conditions, whilst in the remaining valleys, where Commonwealth environmental watering occurred, rainfall was classified as “below” or “very much below” average conditions (Figure 4). The Campaspe, Goulburn, Loddon, Lower Darling, Lachlan, Macquarie, Ovens and Warrego, all experienced below average rainfalls, while rainfall in the Central Murray, Border Rivers, Broken, Condamine, Balonne, Gwydir, Lower Murray, Murrumbidgee, Namoi and Edward Wakool valleys was very much below average.



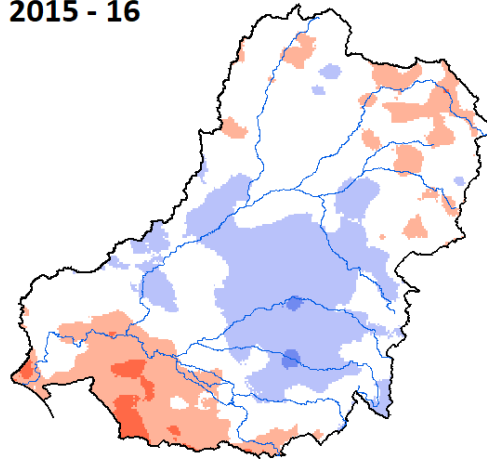


**Figure 4.** Gauges evaluated, areas inundated, streams watered by Commonwealth environmental water, and rainfall conditions during the 2018-19 watering year.

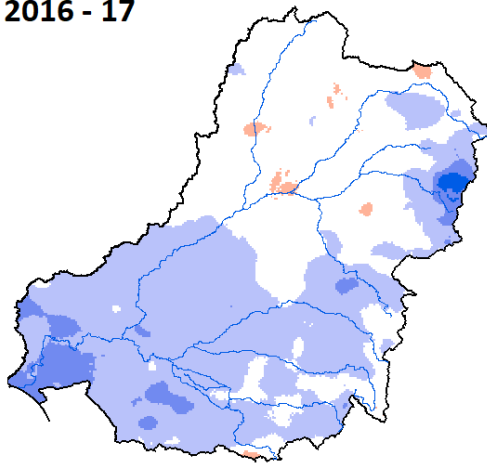
**2014 - 15**



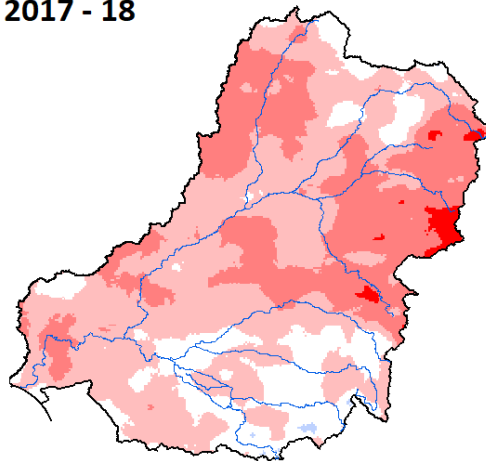
**2015 - 16**



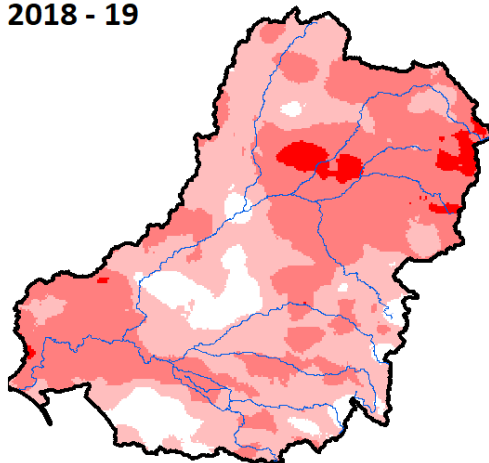
**2016 - 17**



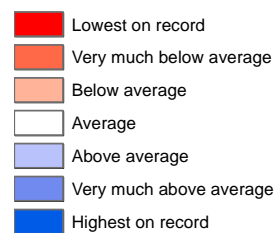
**2017 - 18**



**2018 - 19**



**Legend**



**Figure 5.** Annual rainfall conditions for period of LTIM monitoring.

Dry conditions have been common in the basin for the five-years from mid-2014 to mid-2019, the period of LTIM basin-scale reporting to date (Figure 5). The first two years saw particularly dry conditions in the southern basin. In the 2016-17 year, there were wetter conditions in the

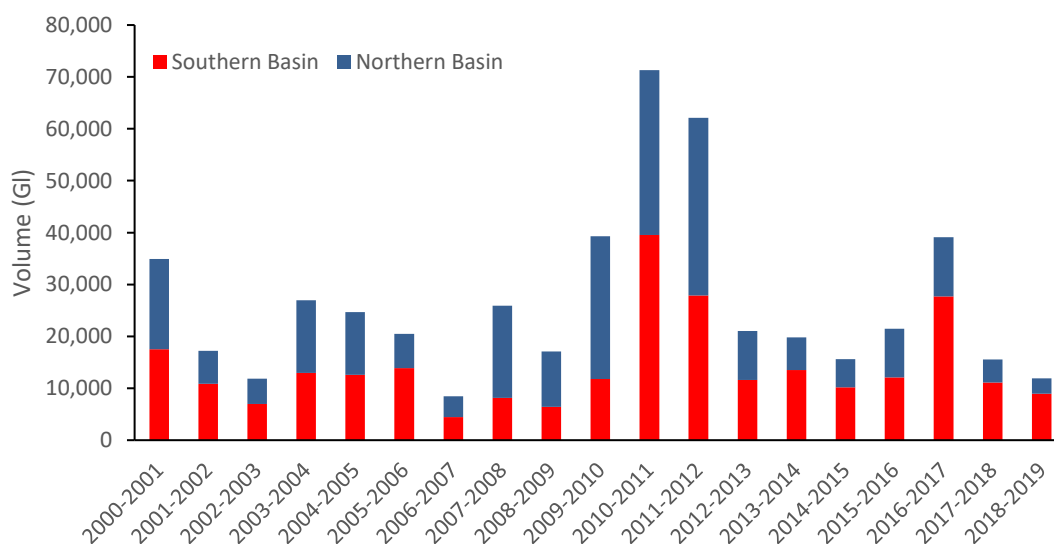
southern basin and along the headwaters of the NSW tributaries in the northern basin. However, conditions have returned to dry over the period 2017-19 across the whole basin.

### 3.2 Surface water inflows

In 2018–19 surface water inflows in the northern basin were lower than any other year since 2001 (Figure 6). The annual inflow totals for the northern basin were 21% of the long-term average since 2001. Extremely low inflows across the northern valleys reflect the widespread low rainfall conditions in the north.

In the southern basin, total inflows were slightly below the average for the period since 2001. However, this is still regarded as a low inflow compared with averages in the 20<sup>th</sup> century. The last 19 years has been a dry period for the southern basin with persistent low inflows during the millenium drought and only a brief respite for two years (2010-11 and 2011-12) before returning to dry conditions with some relief also in 2016-17..

In the northern basin, the five-year average inflows (since mid 2014) have been the lowest for any five year period since 2001 (Figure 6). This continues a six year period of very low inflows across the northern basin. In contrast, the southern basin inflows have been close to average for the period since 2001. The lowest inflow period in the southern basin since 2001, was at the end of the millenium drought (mid-2006 to mid-2009). Southern basin inflows have remained higher than these extreme lows since the drought broke.



**Figure 6.** Annual surface water inflows in the Murray-Darling Basin (Source: BoM National Water Account).

## 4 Environmental Water Delivery in 2018-19

### 4.1 Environmental watering actions

In the 2018–19 year, 853 gigalitres (GL) of Commonwealth environmental water was debited from the CEWH accounts, realising 131 watering actions across 17 valleys (Table 1). By using return flows, Commonwealth environmental water was used and reused for the 131 watering actions, improving flow regimes along approximately 14 379 km of waterway (Table 2 and Figure 4). Approximately 40% of the Commonwealth environmental watering actions in 2018-19 were delivered to support base flows (32 actions) and freshes (21 actions). Of the remaining 60% of Commonwealth environmental watering actions, 58% were wetland actions, and 2% contributed to overbank flows.

One fresh was delivered in each of the Gwydir, Namoi, Lachlan, Murrumbidgee, Loddon, lower Broken, Campaspe and Wimmera valleys. Whilst two freshes were delivered in the Border Rivers and Goulburn valleys. The Lower Murray experienced nine freshes through Commonwealth environmental water deliveries. Two actions were classified as overbank deliveries, and both of these occurred in the Central Murray.

**Table 1.** Summary of Commonwealth environmental watering actions in the Basin in the 2018-19.

Valley	Summary of environmental watering actions
Barwon Darling	<ul style="list-style-type: none"> <li>One fresh delivered via flows from the Border Rivers and Gwydir Valleys. This fresh has not been counted as water was not derived from the valleys entitlements.</li> </ul>
Border Rivers	<ul style="list-style-type: none"> <li>One baseflow delivered during autumn</li> <li>Two freshes delivered during spring and early summer</li> <li>Most watering actions were delivered for fish, connectivity, and resilience.</li> </ul>
Lower Broken	<ul style="list-style-type: none"> <li>Four baseflow delivered in every season of the year</li> <li>One fresh delivered in August</li> <li>Most watering actions were delivered for native fish and water quality</li> </ul>
Campaspe	<ul style="list-style-type: none"> <li>Two baseflows delivered over Spring, Summer and Autumn</li> <li>One fresh delivered during spring</li> <li>The watering actions were delivered for fish and vegetation</li> </ul>
Central Murray	<ul style="list-style-type: none"> <li>One base flow delivered over the entire year</li> <li>One winter fresh</li> <li>Two overbank flows delivered in Spring and early summer</li> <li>Most watering actions were delivered for fish and vegetation</li> </ul>
Condamine-Balonne	<ul style="list-style-type: none"> <li>One base flow delivered during spring, summer and autumn and winter for resilience</li> </ul>
Edward-Wakool	<ul style="list-style-type: none"> <li>Three baseflow / freshes delivered during winter, spring, summer and autumn</li> <li>One wetland delivered from spring through to summer</li> <li>Most watering actions were delivered for fish, vegetation, and water quality</li> </ul>
Goulburn	<ul style="list-style-type: none"> <li>Two base flows delivered during winter spring and autumn</li> <li>Two freshes delivered during winter and spring</li> <li>Most watering actions were delivered for other biota, fish and vegetation.</li> </ul>
Gwydir	<ul style="list-style-type: none"> <li>One base flow and one fresh delivered in autumn and winter</li> <li>Three wetland (two of which wetland/freshes) actions delivered during winter, spring and summer</li> <li>Watering actions were delivered for fish, vegetation, waterbirds and resilience</li> </ul>
Lachlan	<ul style="list-style-type: none"> <li>One baseflow delivered during spring</li> <li>One fresh delivered during spring</li> <li>Two wetlands actions delivered during autumn and winter</li> </ul>

Valley	Summary of environmental watering actions
	<ul style="list-style-type: none"> <li>• Most watering actions were delivered for fish, vegetation and ecosystem processes</li> </ul>
Loddon	<ul style="list-style-type: none"> <li>• One fresh delivered during the spring to support ecosystem processes</li> </ul>
Lower Darling	<ul style="list-style-type: none"> <li>• Commonwealth environmental water was not delivered in this valley during 2018-19</li> </ul>
Lower Murray	<ul style="list-style-type: none"> <li>• Three baseflows delivered throughout the year (as part of weir pool manipulations)</li> <li>• Nine freshes delivered during winter, spring and summer (as part of weir pool manipulations)</li> <li>• 54 wetlands delivered throughout the year</li> <li>• Most watering actions were delivered to support waterbirds, vegetation, frogs and fish</li> </ul>
Macquarie	<ul style="list-style-type: none"> <li>• Three baseflows delivered during winter and autumn</li> <li>• One wetland action delivered in spring and summer</li> <li>• Most watering actions delivered for frogs, resilience, waterbirds, biota and fish</li> </ul>
Murrumbidgee	<ul style="list-style-type: none"> <li>• 15 wetland actions delivered throughout the year</li> <li>• One fresh base flow delivered in summer and autumn</li> <li>• Most watering actions were delivered (almost equally) for water quality, biota and fish</li> </ul>
Namoi	<ul style="list-style-type: none"> <li>• One fresh delivered during spring</li> <li>• Action delivered primarily for water quality, resilience, connectivity and fish</li> </ul>
Ovens	<ul style="list-style-type: none"> <li>• One base flow delivered in autumn</li> <li>• Delivered for fish and connectivity</li> </ul>
Warrego	<ul style="list-style-type: none"> <li>• Five baseflows delivered during autumn</li> <li>• Most watering actions delivered to support fish and resilience</li> </ul>
Wimmera	<ul style="list-style-type: none"> <li>• One baseflow/ freshes delivered over spring, summer, autumn and winter</li> <li>• One fresh delivered during spring</li> <li>• These watering actions supported fish, vegetation, biota and water quality</li> </ul>

Over the course of the five-year LTIM program 541 independent watering actions were delivered. These actions targeted various flow component from low to high flows and both within and out of the channel. Between mid-2014 and mid-2019, 45% of all actions targeted delivery of water to wetlands, the most frequently targeted flow component. In addition, approximately 22% targeted base flows, 29% provided freshes, while 1% and 3% of actions targeted bankfull and overbank flow components, respectively.

However, a different picture emerges when the distribution of Commonwealth environmental water across the flow components is examined. Of the 7 805 Gl of Commonwealth environmental water delivered over five-years, 47% supported base flows, 38% supported freshes, 9% supported wetlands, 5% supported overbank deliveries and 1% supported bankfull flows.

We can also look at the spatial distribution of Commonwealth environmental water (delivered volumes) over the course of the five-year LTIM program. Of the 17 valleys that received Commonwealth environmental water, 45% of the delivered volume was attributed to actions in the Lower Murray, 14% in the Central Murray, 13% in the Goulburn and 10% in the Murrumbidgee. The remaining valleys received 4% or less of total delivered volume of Commonwealth environmental water.

## **4.2 Timing of environmental water delivery**

In 2018–19, most of the southern Basin’s environmental water entitlement (Commonwealth environmental water and other environmental water) was delivered (mainly via dam releases) during three periods: start July to end August, start September to mid-January, and the second half of June (Figure 7). The general seasonal pattern of water delivery was similar to previous years although volumes of environmental water delivery were much lower reflecting lower allocations and a focus on delivering baseflows. In the northern Basin, environmental water was delivered as very large pulses during the winter, spring and autumn. Although, 2018-19 was similar to previous years where environmental water was concentrated in late winter and spring, the magnitude and duration of the pulses were greater particularly in the Macquarie, Border Rivers and Gwydir system.

Looking across the five-year LTIM project, Commonwealth environmental water and other environmental water entitlement holders generally delivered water with the same seasonal patterns. Given the strong coordination between environmental water entitlement holders to deliver joint water actions in many cases, any differences in timing will more likely be a result of this coordination rather than differences in strategies.

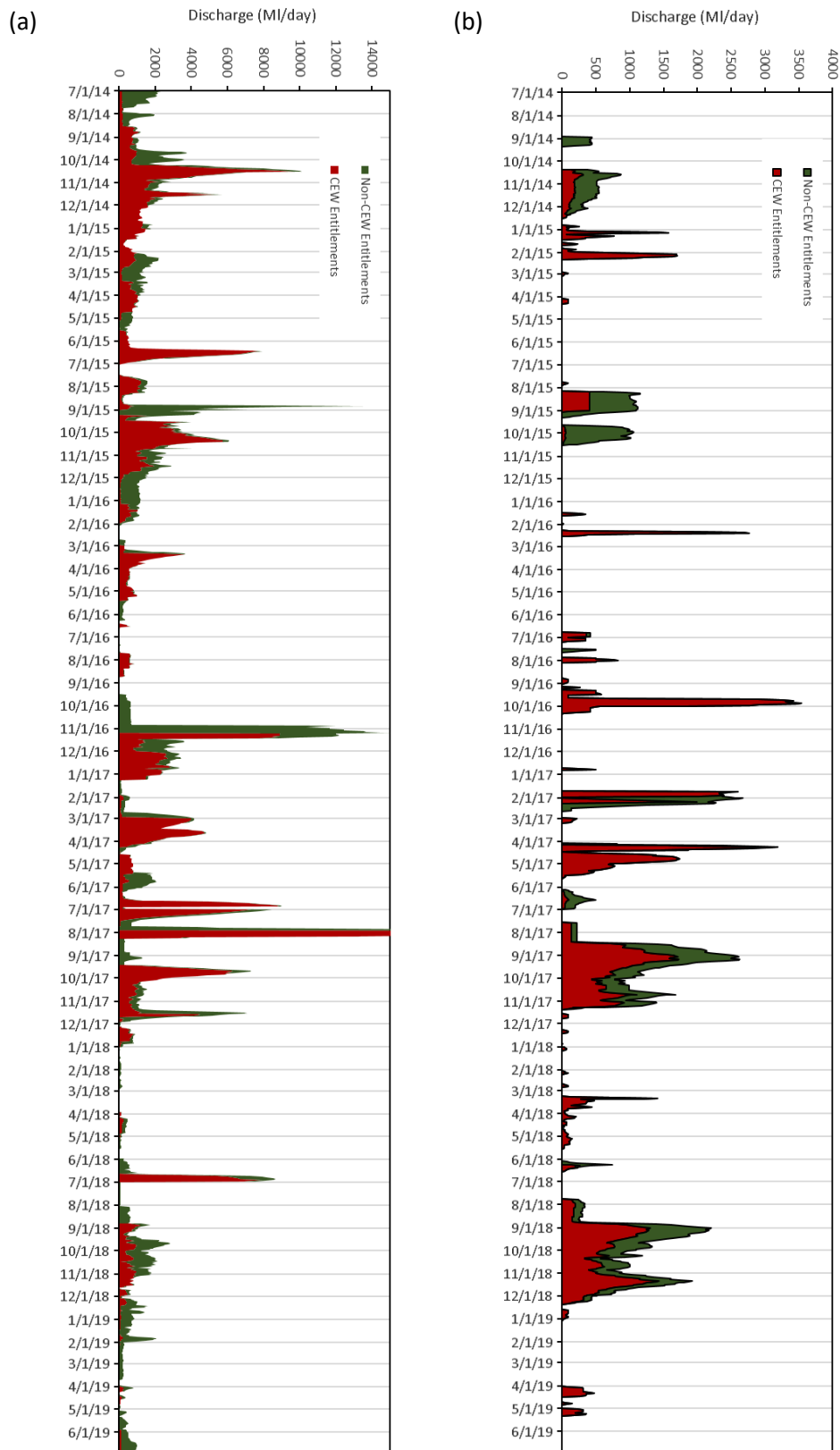


Figure 7. Aggregate environmental water volumes delivered by all environmental water entitlement holders in the (a) southern Basin; and (b) northern Basin tributaries.

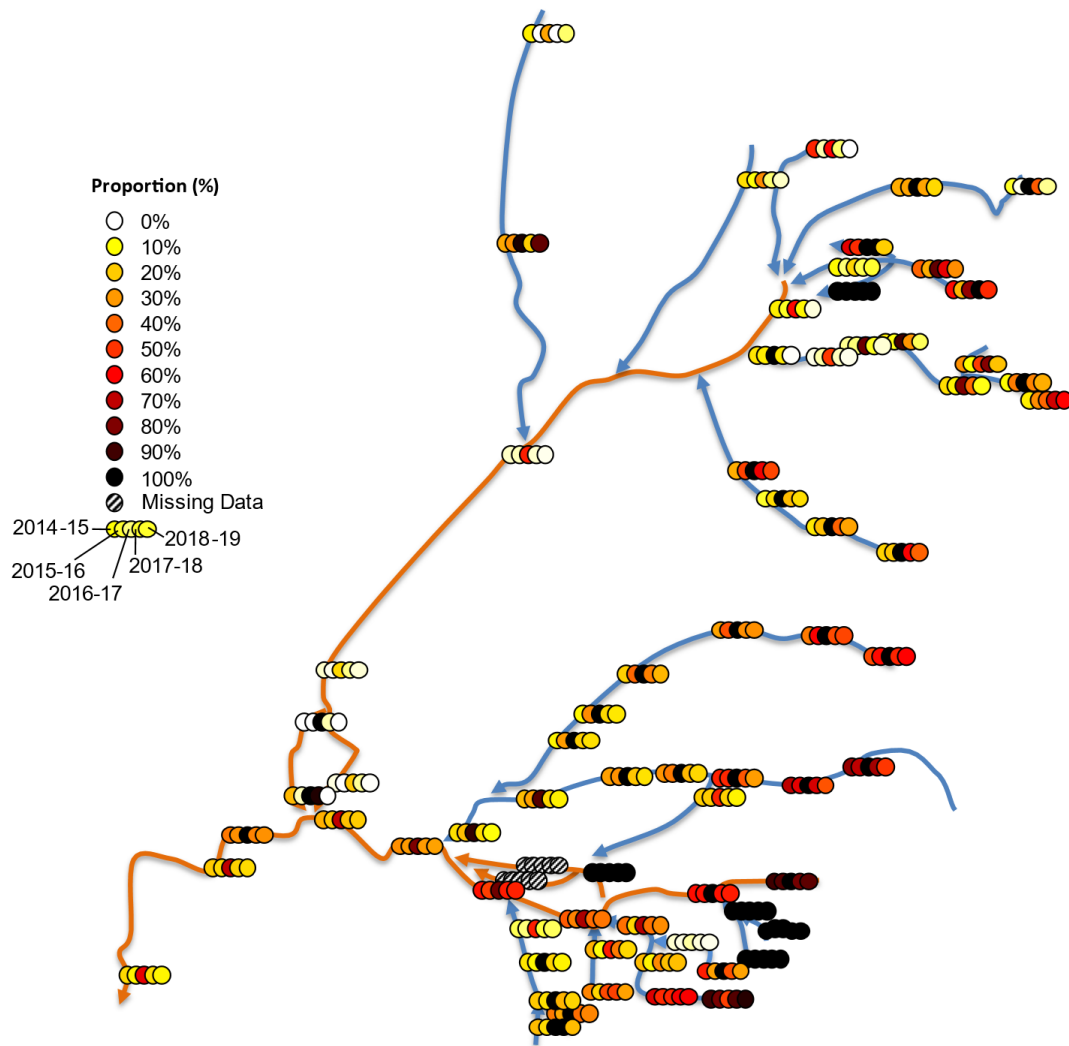
## 5 Streamflow volumes

### 5.1 Flow volumes throughout the Basin

In 2018–19, annual streamflow totals were below the average volumes expected under pre-water resource development conditions (Figure 8). Flow volumes were particularly low in the northern tributaries (Condamine-Balonne and Border Rivers) and throughout the Barwon-Darling River. Across the basin, flow volumes were higher at upstream sites but still well-below the average volumes under pre-development conditions, whilst volumes at sites further downstream were very low. The upper Murray River, Kiewa, Ovens and Goulburn all experienced close to average pre-development flow volumes in 2018-19. However, volumes further downstream in the Murray River are well below pre-development flows declining to very low flow volumes in South Australia relative to pre-development levels.

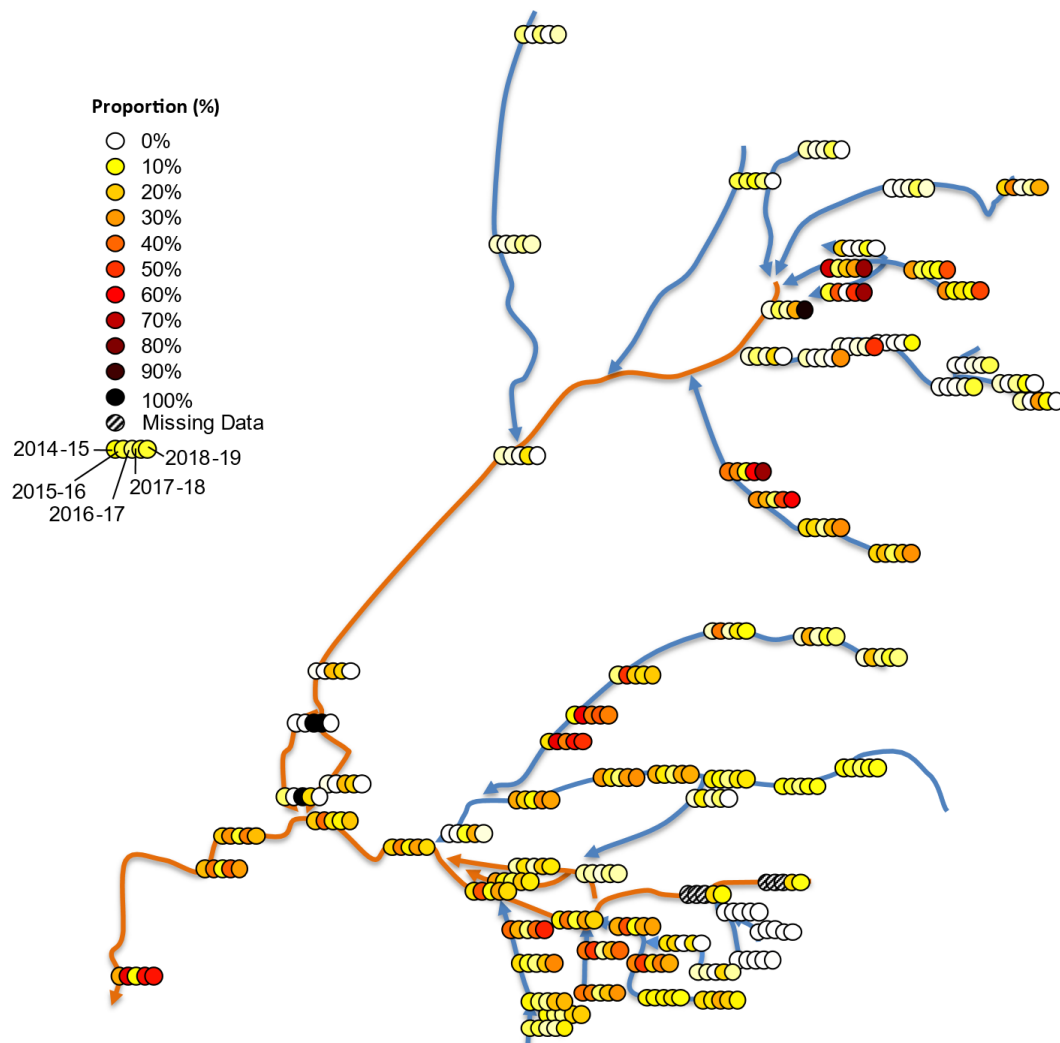
Looking across the five years of the LTIM project, most sites in Queensland and throughout the Barwon-Darling River experienced mostly low flow volumes. However, most of these valleys had at least one year (over the five year monitoring period) of flow volumes close to the average pre-development flow. The Goulburn, Campaspe and most sites in the Murray River downstream of the Ovens River confluence have been well below average pre-development flows throughout the monitoring period. Rivers in NSW experienced some respite from low flow volumes in 2016-17 but have otherwise remained low. In contrast to the rest of the basin, the upper Murray River has experienced flow volumes close to the average pre-development flow volumes in most years.





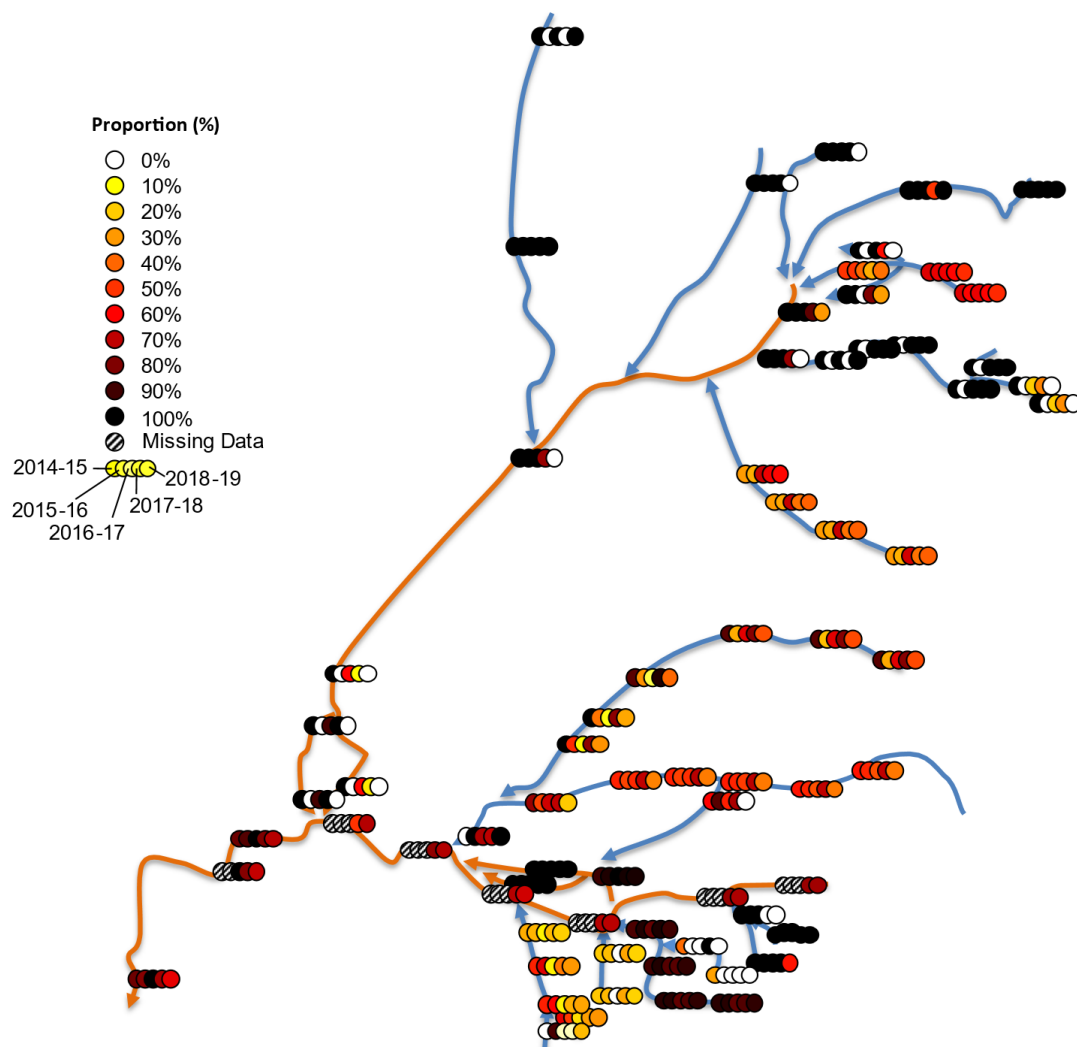
**Figure 8.** Annual flow volume as a percentage of mean pre-development annual flow volume.

Over the five years of monitoring, it is very rare for environmental water entitlements to contribute more than 80% of the annual flow volume (Figure 9). However, the influence of environmental water, is evident across all valleys except the Warrego, Condamine-Balonne, Ovens, some sites in the Border Rivers and upper Murray River where proportions are less than 10%. There is a general downstream gradient of increasing influence of environmental water in the Lachlan, Goulburn, Murray, Gwydir, Macquarie and Murray Rivers. In some years, environmental water is around 50% of the total volume or greater at sites in the lower reaches of the Gwydir, lower Macquarie, lower Lachlan, Loddon, Darling Anabranch and lower Murray. The difference between northern and southern tributaries is largely a function of the larger entitlements held and delivered in the south and the diversity of strategies available for water use in the southern Basin. Coordinating environmental water delivery in northern tributaries, as well as shepherding through the downstream valleys is needed to enhance the hydrological regime in the lower reaches of the northern Basin and particularly the Upper Darling.



**Figure 9.** Percent of annual flow that is sourced from an environmental entitlement.

Since 2014, Commonwealth environmental water has comprised almost 100% of the environmental flows in the Warrego, Condamine-Balonne, Barwon-Darling, Border Rivers, Namoi, Goulburn, Ovens and Edward-Wakool (Figure 10). In the other valleys, Commonwealth environmental water is a significant portion, at least in some years.



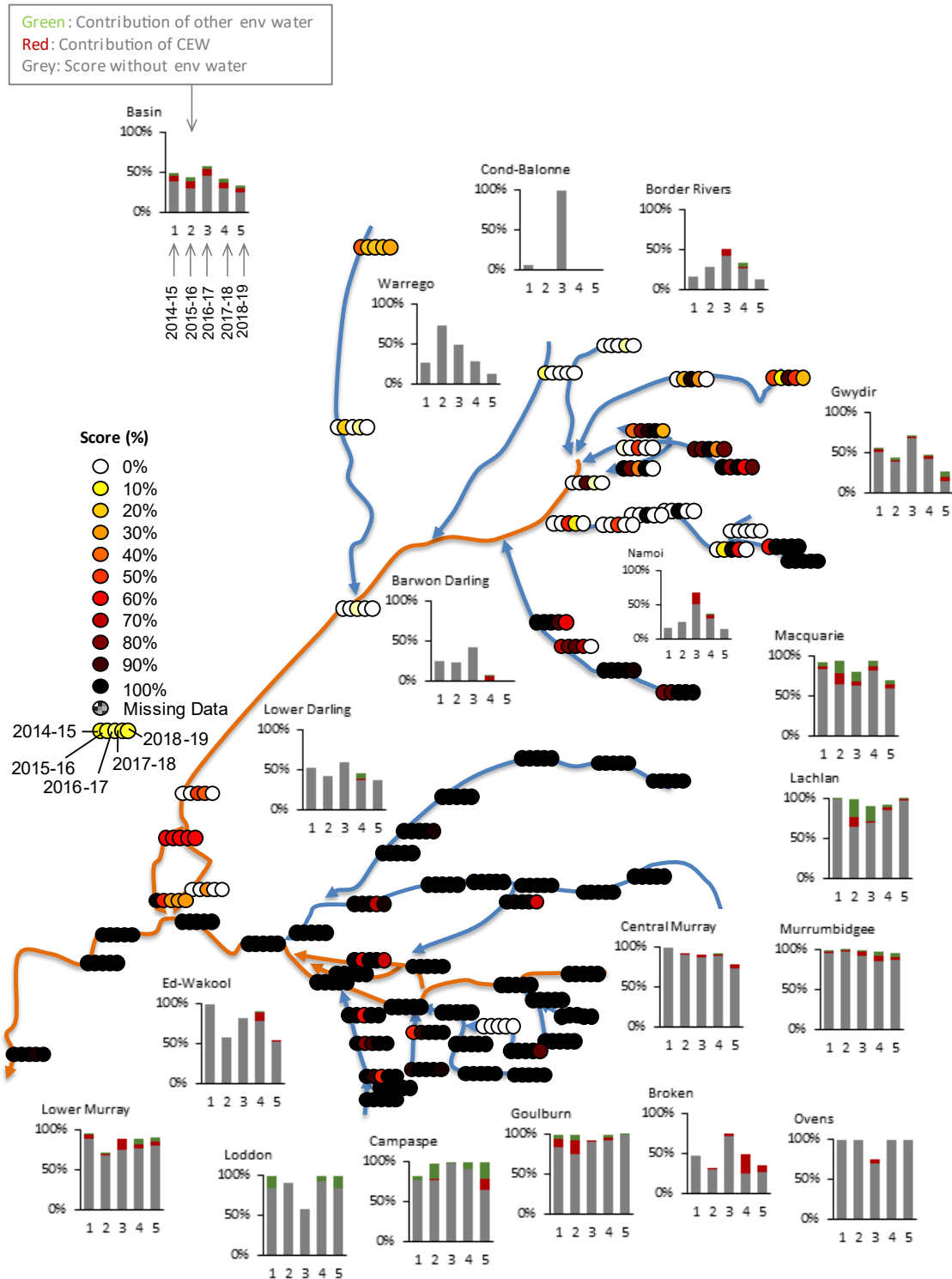
**Figure 10.** Percent of environmental water that is provided by Commonwealth environmental water.

## 6 Base flows

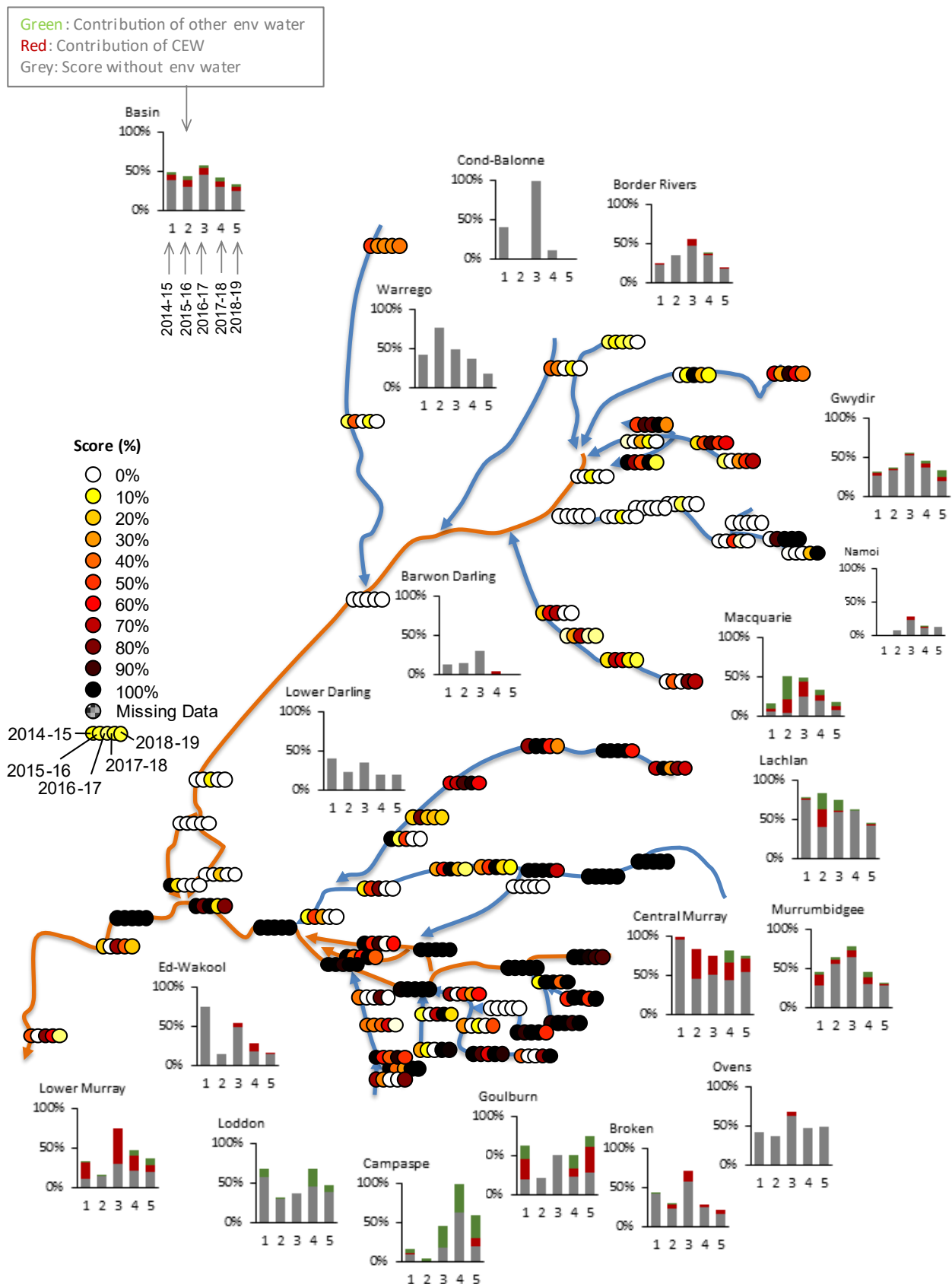
In this evaluation, we consider the contribution of environmental water to maintaining base flows focusing on periods where flow drops below either the “very low” or “low” flow thresholds. In 2018–19, excessive periods below the very-low flow threshold occurred at most sites in the northern Basin including throughout the Barwon-Darling. In contrast, excessive periods of very-low flows were largely avoided throughout the southern Basin. 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, Murrumbidgee, Macquarie and Namoi. In relation to very-low flow periods, conditions have remained more or less stable over the five-year monitoring period for many of the valleys although, declining conditions have occurred in the Macquarie valleys in 2018-19 after three years when low flow conditions were maintained at a good level.

Whilst very-low flows were generally avoided, excessive periods below the low-flow threshold were wide-spread throughout the basin in 2018-19. (Figure 11). Extended periods of low flows were particularly severe in the northern Basin including the Barwon-Darling, Macquarie and Namoi. Increased periods of low flow also occurred in the lower reaches of most southern basin rivers including the Murray River itself. The only exceptions were the Ovens and Campaspe valleys where excessive periods of low flow were largely avoided. Periods of low flows have generally got more severe in the northern basin over the five-year monitoring period. In the southern Basin, 2018-19 saw a decline in low-flow metrics in the Lachlan, Murrumbidgee, and both 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. The Barwon-Darling has experienced persistent severe low-flow conditions throughout the five-year monitoring period.

Commonwealth environmental water has made important contributions to improved base flow conditions in some valleys including lower and central Murray, Edward-Wakool, Goulburn, and Macquarie (Figure 12). The contribution in the lower Murray, Macquarie and Goulburn Rivers is particularly important in avoiding very severe base flow conditions in these valleys. Commonwealth environmental water has had a negligible effect on base flow regime in the unregulated rivers of the northern basin.



**Figure 11.** Annual very low base flow score from 0% (extremely dry) to 100% (average conditions).



**Figure 12.** Annual low flow base flow score from 0% (extremely dry) to 100% (average conditions).

## 7 Freshes

Freshes are generally understood to support a range of important ecological functions. We use three flow thresholds to define the onset of a fresh referred to as low-fresh; medium-fresh and high-fresh (Figure 3).

In 2018–19, low and medium freshes were infrequent in the Queensland valleys and largely absent in the Barwon-Darling (Figure 13 and Figure 14). This is like previous years although a high frequency of freshes did occur across these valleys in the 2016-17 year. There was minimal contribution of environmental flows to freshes in these valleys.

The frequency of freshes was generally low in the Namoi and Border Rivers for 2018-19 but considered adequate in the Gwydir and Macquarie. This is similar to previous years although conditions have declined in the lower Namoi and Border Rivers.

Across the southern basin (with the exception of the Broken), low freshes have been delivered with large contributions of Commonwealth environmental water from the Murray and Goulburn valleys. Moderate and high freshes are lacking in many valleys of the southern basin including the Edward-Wakool, Loddon, and Broken valleys (Figure 14 and Figure 15). These higher magnitude flow freshes would normally be an important part of the flow regime supporting a health ecosystem.

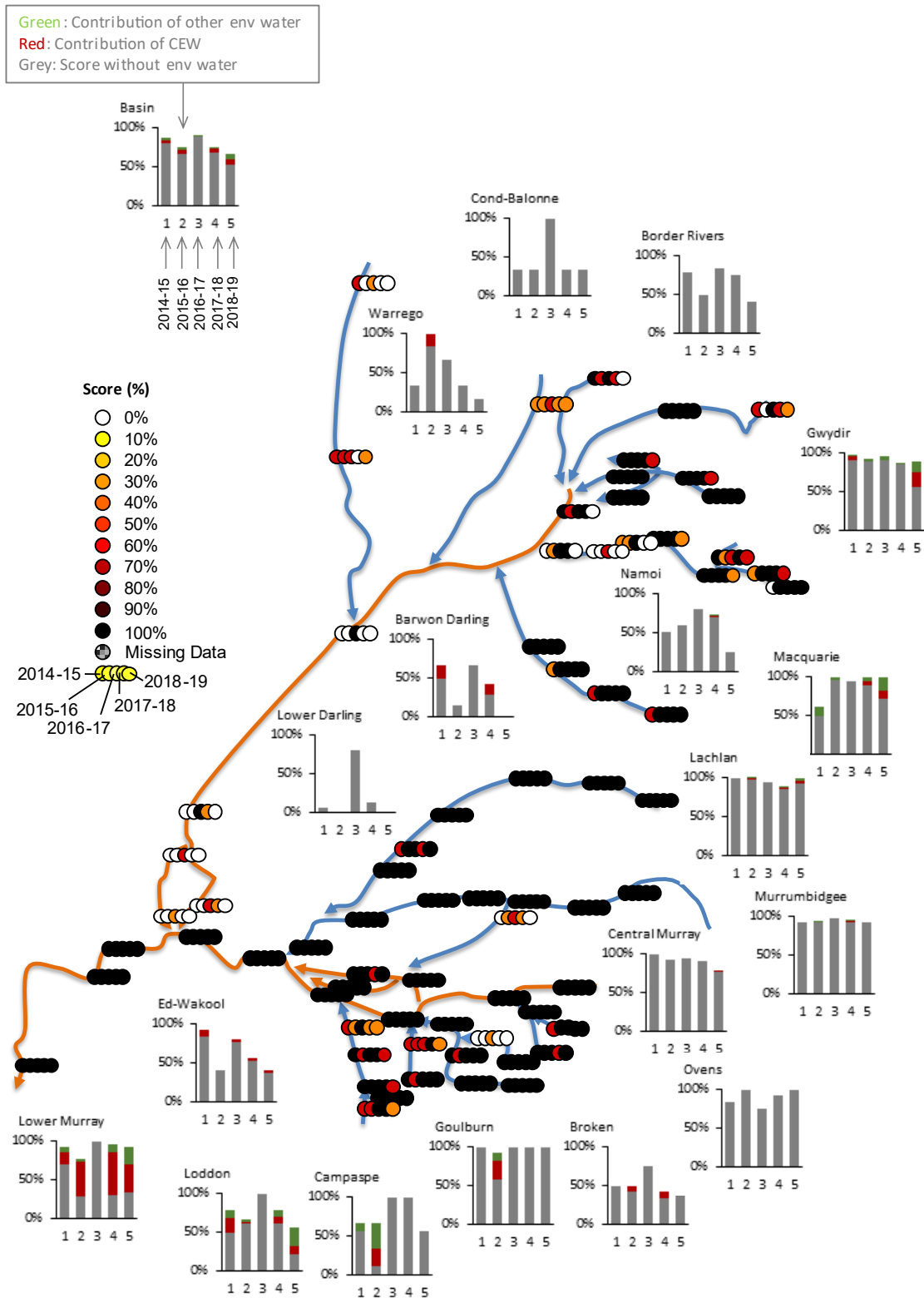
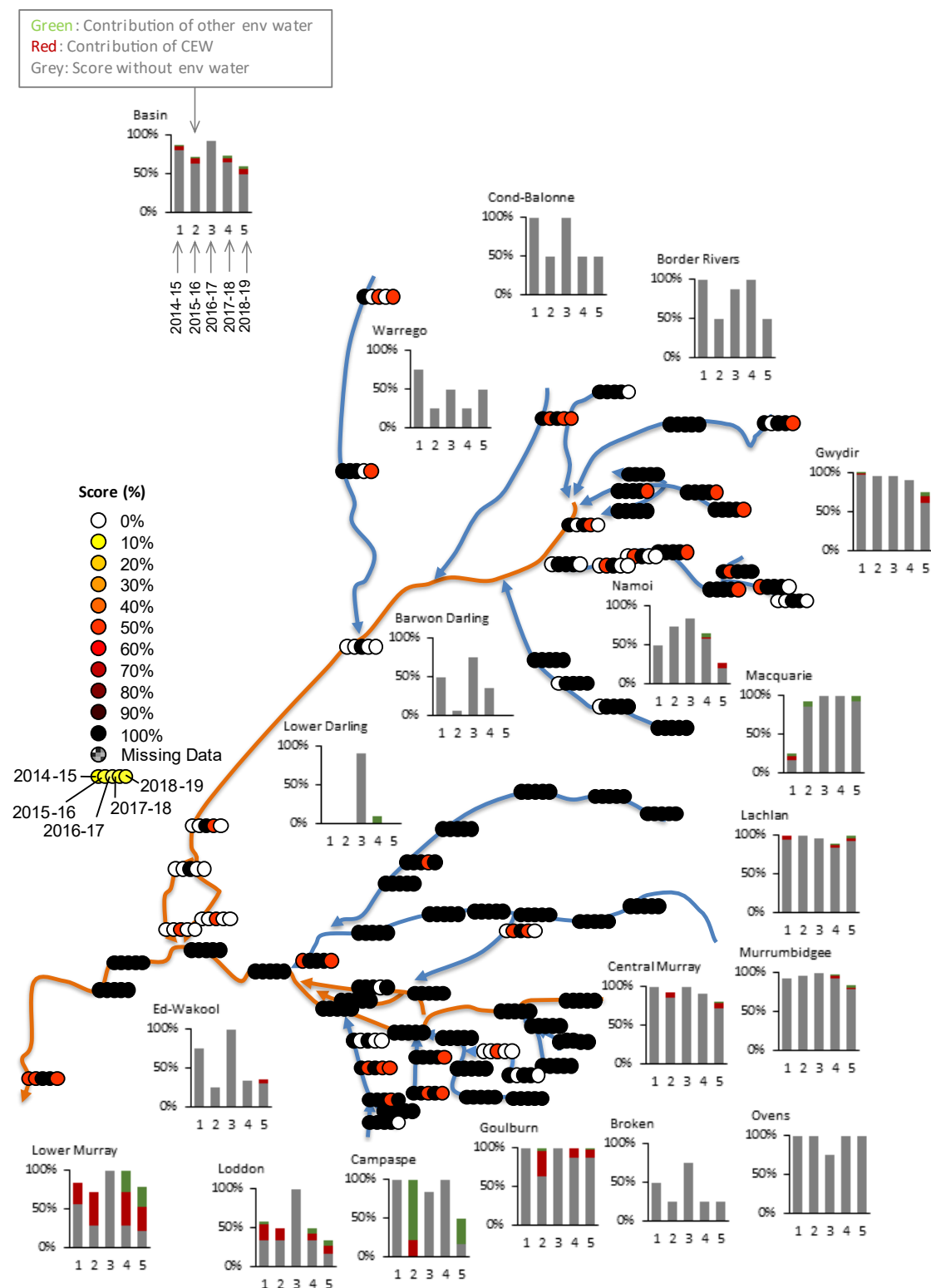
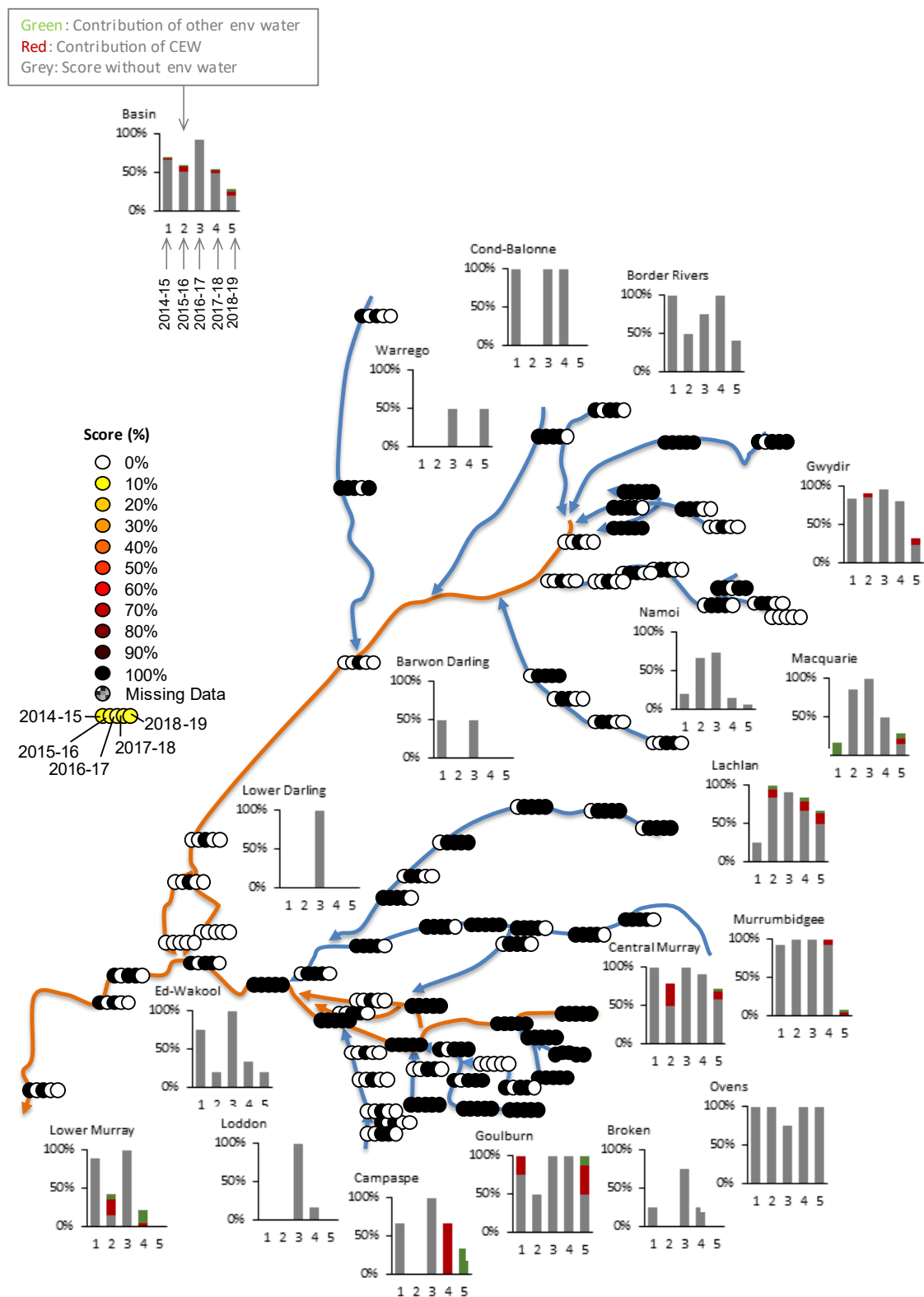


Figure 13. Annual low-fresh score from 0% (extremely dry) to 100% (average conditions).





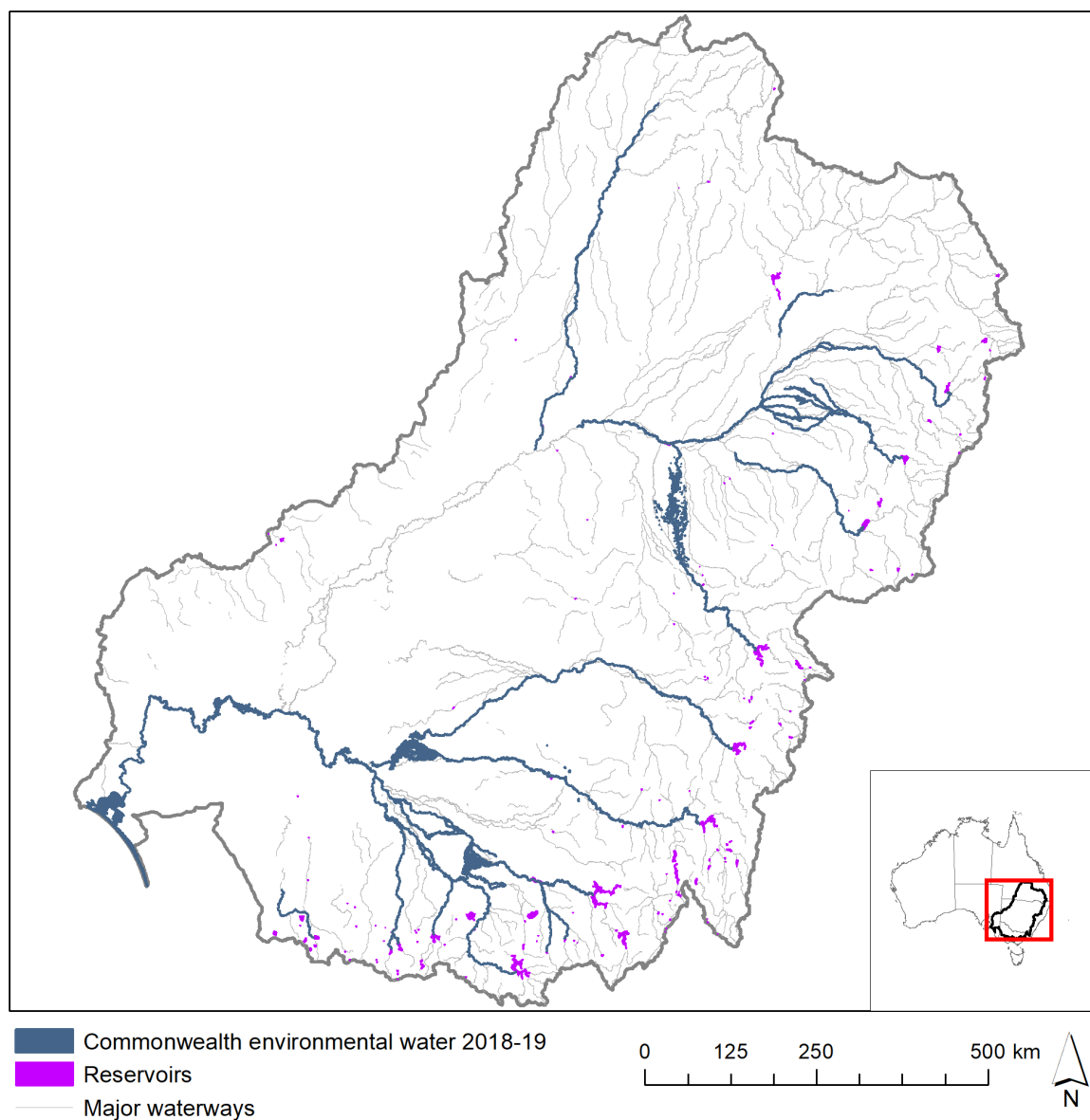
**Figure 14.** Annual medium fresh score from 0% (extremely dry) to 100% (normal conditions).



**Figure 15.** Annual high fresh score from 0% (extremely dry) to 100% (average conditions).

## 8 Lateral Connectivity

In 2018–19 wetland and floodplain inundation occurred in many parts of the Basin (Figure 16). Commonwealth environmental water made a substantial contribution to improved lateral connectivity, including 219 612 ha of lakes and wetland and 26 568 ha of floodplain inundation (Figure 16 and Table 2). In the Macquarie, Gwydir and Lachlan water was delivered onto the floodplain in the lower reaches where river channel size contracts and water spills out of the channel at moderate flow magnitudes. Commonwealth environmental water contributed to watering approximately 35 445 ha of the Macquarie Marshes in combination with NSW environmental water. Smaller but significant areas were watered in the lower Gwydir and Lachlan, inundating approximately 11 150 ha of lake and wetland habitat and 4 421 ha of floodplain area. As in previous years, regulating structures and pumps were also used to deliver water into wetland along the Murray and Murrumbidgee with a total area of inundation close to 49 088 ha of lake and wetland habitat and 4 934 ha of floodplain area



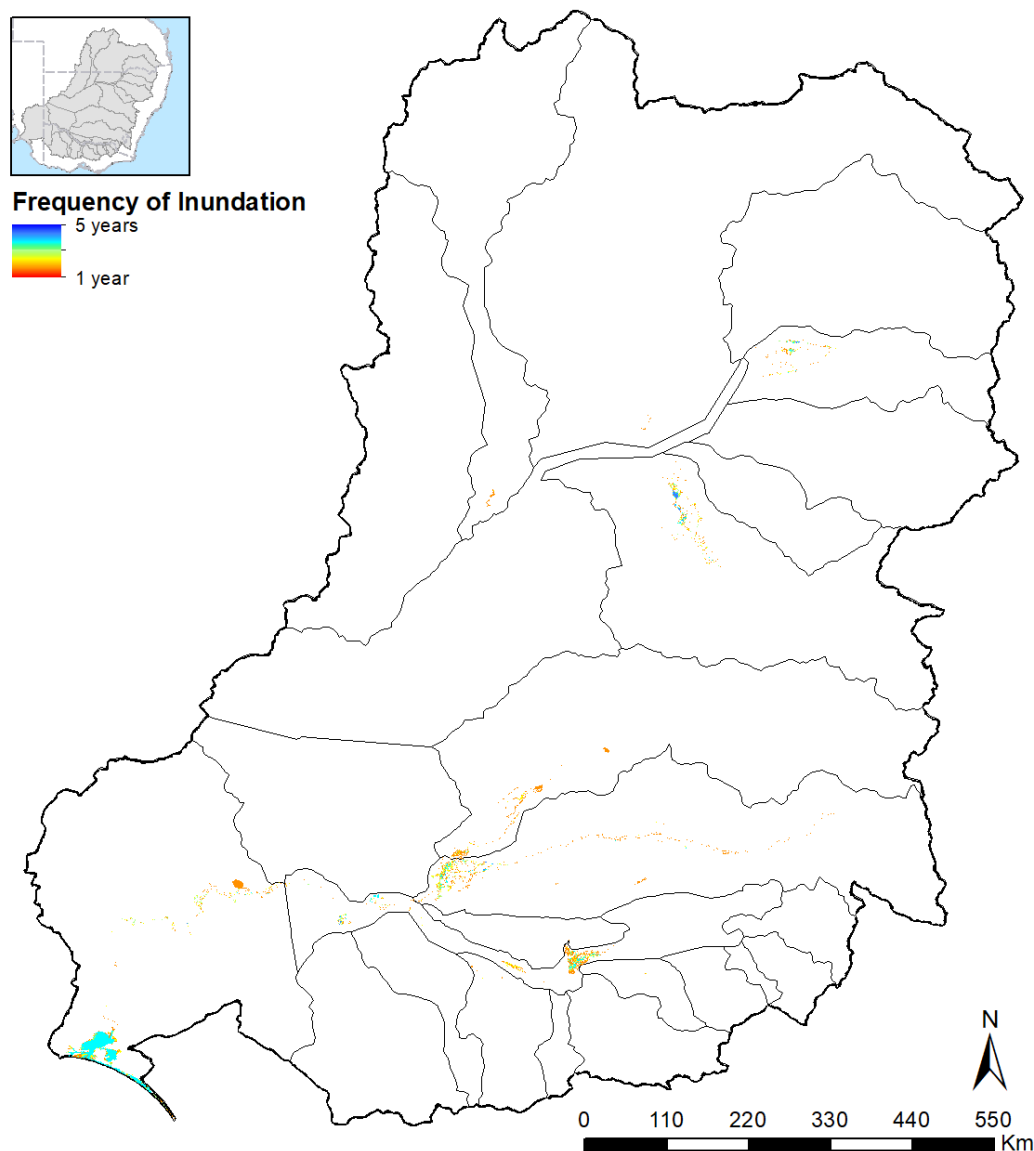
**Figure 16.** Inundation of floodplains as a result of Commonwealth environmental water contributions.

**Table 2.** Watercourses, wetlands and floodplains influenced by Commonwealth environmental water in 2018–19.

Catchment name	LTIM Selected Area	Lakes and wetland area influenced (ha)	Floodplain area inundated (ha)	Length of waterways influenced (km)
Avoca		-	-	-
Barwon Darling		-	-	833
Border Rivers		-	-	819
Broken		-	-	172
Campaspe		-	-	117
Castlereagh		-	-	-
Central Murray		30 606	4135	2196
Condamine Balonne		-	-	-
Edward–Wakool	Edward–Wakool river system	3	33	970
Goulburn	Goulburn River	-	-	395
Gwydir	Gwydir river system	7096	3238	1132
Kiewa		-	-	-
Lachlan	Lachlan river system	4054	1183	1363
Loddon		-	-	365
Lower Darling		-	-	-
Lower Murray*	Lower Murray River*	7270	766	1123
Lower Murray (CLLMM)		Estuarine: 23 802 Freshwater: 103 335	22	-
Macquarie		32237	3208	1054
Mitta Mitta		-	-	-
Murrumbidgee	Murrumbidgee river system	11 209	13 983	1626
Namoi		-	-	506
Ovens		-	-	320
Paroo		-	-	-
Upper Murray		-	-	-
Warrego	Junction of the Warrego and Darling rivers	-	-	1208
Wimmera		-	-	180
<b>Total</b>		<b>219 612</b>	<b>26 568</b>	<b>14 379</b>

\* excludes the Coorong, Lakes Alexandrina and Albert and the Murray Mouth.

# includes the Peel River.



**Figure 17.** Prevalence of inundation of over the entire LTIM project as a result of Commonwealth environmental water contributions.

Over the course of the LTIM project, Commonwealth environmental water contributed to watering more than 250 000 ha (excluding the Coorong and lower lakes) of wetlands, lakes and floodplains in 12 of the 17 valleys (Figure 17 and **Table 3**). The valleys influenced included the Central Murray, Border Rivers, Broken, Condamine Balonne, Gwydir, Lachlan, Lower Murray, Macquarie, Murrumbidgee, Warrego, Lower Darling and Edward Wakool.

In many sites there was repeated inundation in multiple years. The same 7 838 ha were in all five years across four valleys. 90% of this annually inundated area is in the Macquarie, and Murrumbidgee valleys and the rest was in the Gwydir and Lower Murray. Similarly, the same 16 060 ha were watered in four out of five years, with the Macquarie and Murrumbidgee again the dominant valleys.

The Macquarie valley had the largest area of annually watered floodplain areas. Approximately 5 616 ha of the Macquarie marshes inundated annually using Commonwealth environmental water. In the Murrumbidgee valley, 1 149 ha was inundated annually.

**Table 3.** Prevalence of annual inundation at the same place as a result of Commonwealth environmental water over the five-year LTIM project.

Valley	Prevalence	Hectares (Ha)				
		1 of 5	2 of 5	3 of 5	4 of 5	5 of 5
Gwydir	5 in 5	8 001	4 246	2 525	1 550	589
Lower Murray <sup>1</sup>	5 in 5	34 958	15 998	5 360	2 737	183
Macquarie	5 in 5	14 009	7 895	5 120	3 955	5 616
Murrumbidgee	5 in 5	39 595	12 056	10 974	5 563	1 449
Central Murray	4 in 5	13 495	10 317	7 678	1 899	0
Lachlan	4 in 5	22 920	4 735	1 021	356	0
Broken	2 in 5	112	53	0	0	0
Warrego	2 in 5	3 816	28	0	0	0
Lower Darling	2 in 5	185	48	0	0	0
Edward Wakool	2 in 5	73	27	0	0	0
Border Rivers	1 in 5	125	0	0	0	0
Condamine Balonne	1 in 5	1 490	0	0	0	0
<b>Total</b>		<b>138 779</b>	<b>55 403</b>	<b>32 678</b>	<b>16 060</b>	<b>7 837</b>

<sup>1</sup>Excludes the Coorong, and Lakes Albert & Alexandrina.

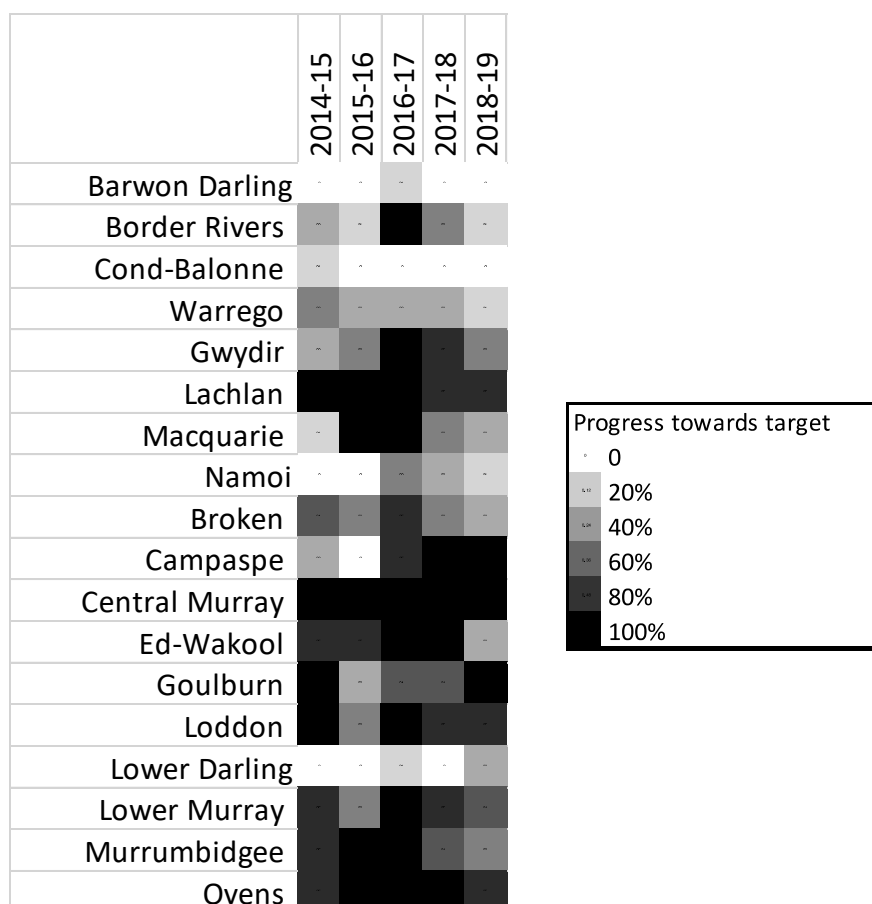
## 9 Basin wide watering strategy hydrological targets

### 9.1 Longitudinal connectivity

#### Increased baseflows

The Basin Watering Strategy (BWS) expects environmental watering will “keep base flows at least 60% of the natural level”. However, the strategy does not specify how “base flow level” is defined. Nor does it explain how the “natural level” is to be determined. Given no definitions are provided, we have chosen to use our base flow metrics for reporting on this outcome. This metric is relevant because it relates to the maintenance of base flows and compares observed base flows in each season with the natural duration of base flows. More specifically we use the valley-average values for both the very low-flow and low-flow thresholds. We assess performance against this outcome using the lower of these two metrics. We use a score of 0.6 as the threshold to indicate achievement of the BWS outcome. It is not possible to assess how well this replicates the intended BWS outcome because no definition is provided.

The results of this analysis are presented in Figure 18. There was only one valley, the central Murray, where the targeted outcome was achieved in every year. The Lachlan and Ovens achieved the target in three out of the five years. The Campaspe, Edward Wakool, Goulburn, Loddon, Macquarie and Murrumbidgee all achieved the target in two of the five years. The Border Rivers and Lower Murray achieved the target once, during the flood year of 2016-17. The low rainfalls across much of the basin during the period of monitoring has contributed to the low level of success in achieving the targeted base flows. It is also possible that our target threshold are not reflective the intended base flow level targeted by the BWS. We propose that the metric be reviewed for reporting in future years with advice from MDBA on the definition of this outcome in their BWS.



**Figure 18:** Progress towards target outcomes for base flows

### Increase in Flow Volumes

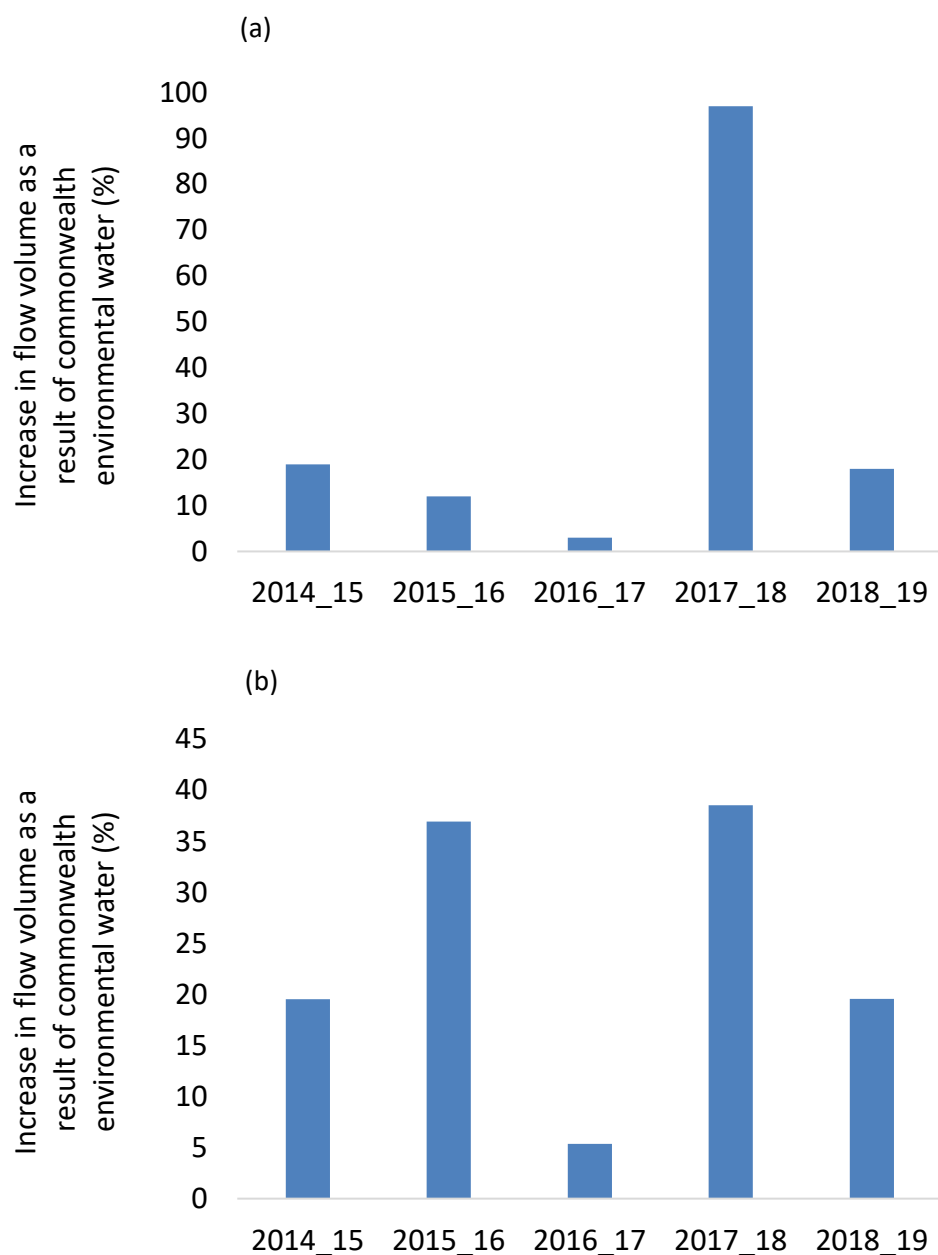
The BWS includes target outcomes related to increased flows into the Murray and Darling Rivers. The expected improvements are:

- a 10% overall increase in flows in the Barwon–Darling: from increased tributary contributions from the Condamine–Balonne, Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh catchments collectively
- 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

In relation to the first outcome, we consider contribution of Commonwealth environmental water at Louth, the first Barwon–Darling monitoring site downstream of all the northern tributaries that receives environmental water (Figure 19). The results indicate that this outcome was achieved in four years out of five years of monitoring, the year where this was not achieved was 2016–17, where inputs were estimated to be approximately 3%, but this was largely due to high flow year. The large addition of Commonwealth environmental in 2017–18 reflects the two large coordinated and protected flow actions (northern fish flow and northern connectivity), where Commonwealth environmental water and other environmental water was released from the Border Rivers and Gwydir valleys. Similarly, 2018–19 reflects contributions from high flows



conditions in the Warrego valley and the direction to by the Commonwealth not to divert water to the western floodplain near Toorale.



**Figure 19:** Increase in annual flow volume in (a) the Darling River at Louth and (b) in the Murray River at the SA Border, as a result of Commonwealth environmental water.

In relation to the second outcome, we consider contribution of Commonwealth environmental water to Murray River flows at South Australian border, a key accounting site and a short distance downstream of all the Murray River tributaries that receive environmental water (Figure 19). Contributions for Commonwealth environmental water hit target levels in 2015-16 and 2017-18 but were below the target levels in the other three years. Over the five years of monitoring, Commonwealth environmental water contributed a total of 16% additional flow of the total flow volume at the SA border, which is close to half of the target volume.

## 9.2 Lateral connectivity

### Increased Freshes

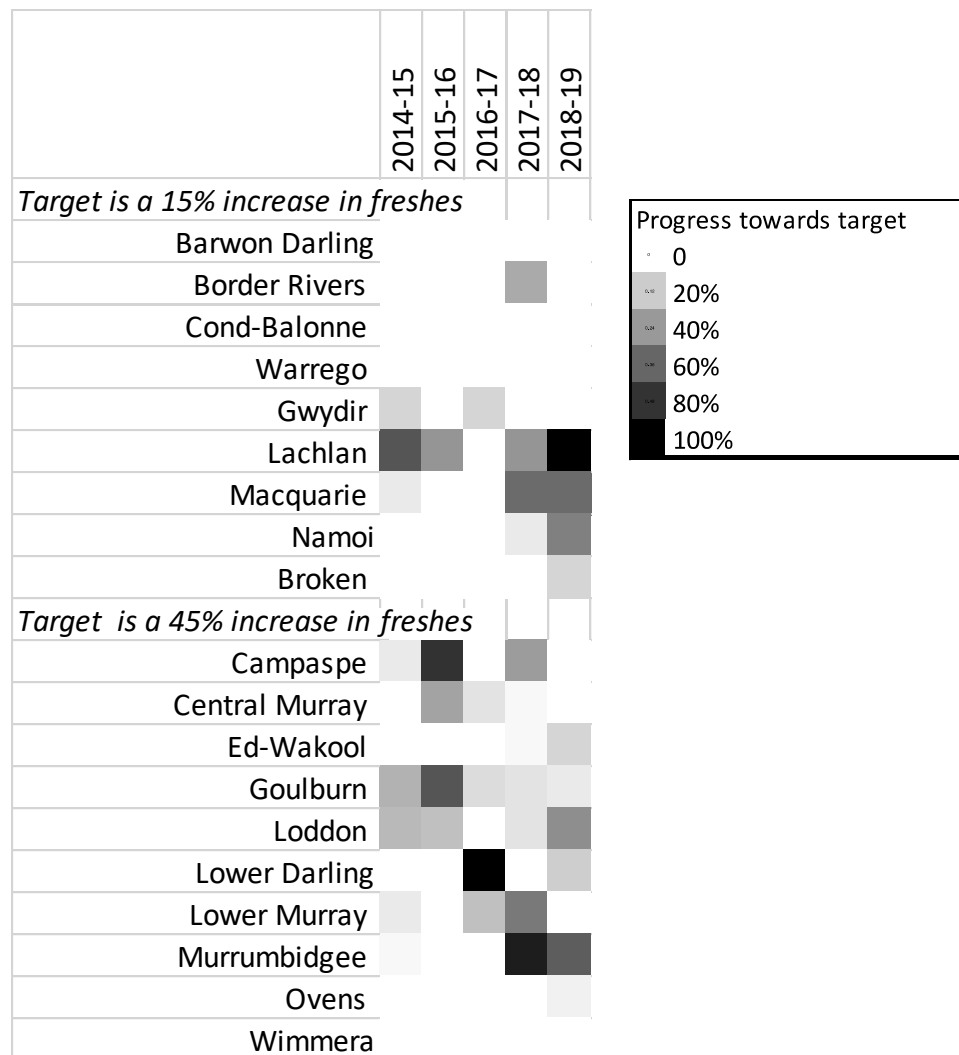
The BWS includes outcomes related to freshes as an indicator of longitudinal connectivity. The expected outcomes are:

- a 30% to 60% increase in the frequency of freshes, bank-full and lowland floodplain flows in the Murray, Murrumbidgee, Goulburn–Broken and Condamine–Balonne catchments; and
- a 10% to 20% increase of freshes and bank-full events in the Border Rivers, Gwydir, Namoi, Macquarie–Castlereagh, Barwon–Darling, Lachlan, Campaspe, Loddon and Wimmera catchments.

We use the middle of the intended outcome range for assessing the contribution of Commonwealth environmental water towards this target. The BWS also specifies maintenance of current levels of connectivity in the Paroo, Moonie, Nebine, Ovens and Warrego catchments as an expected outcome. However, this is not included in this assessment. Maintenance of flows requires restriction of water resource developments and does not relate to delivery of additional environmental water.

For these outcomes we use the low, medium and high fresh score to assess achievement of this outcome since this score relates to the frequency of fresh events. We have not considered the frequency of overbank events in this assessment since it is very rare for environmental flows to contribute to channel filling events. We considered increment in score as a result of Commonwealth environmental water as our measure of increased occurrence of freshes. We used the average of this increment across the low, medium and high fresh metrics for reporting on this outcome.

The results indicate that Commonwealth environmental water has made some progress towards this intended outcome in some valleys and years (Figure 20). The target is only fully achieved for isolated years in the Lachlan, Campaspe, Lower Darling and Murrumbidgee Valleys.



**Figure 20:** Progress towards target outcomes for increased freshes as a result of Commonwealth environmental water.

### 9.3 The Coorong, Lower Lakes and Murray Mouth

The BWS includes targets related to the Coorong, Lower Lakes and Murray Mouth (CLLMM) as an indicator of end-of-basin flows. The evaluations against each of the end-of-basin flows are documented progressively.

The Coorong, Lower Lakes and Murray mouth flow volume target focuses on;

- The barrage flows are greater than 2000 GI/year on a three-year rolling average basis for 95% of the time, with a two year minimum of 600 GI at any time.

To assess the contribution of Commonwealth environmental towards achieving this target we used the barrage releases with and without Commonwealth environmental water. Table 4 shows the annual contribution of Commonwealth environmental water to the barrage releases together with the barrages flows both, with and without Commonwealth environmental water. The results indicate that Commonwealth environmental water has been fairly effective in ensuring that the two-year minimum flows did not fall below 600 GI in four out of five years.

Without Commonwealth environmental water this target would have only been achieved once, in the last five water years; the flood year of 2016-17.

Commonwealth environmental water was released through the barrages in every year of the monitoring program. The releases were significant ranging between 44% and 70% of the Commonwealths total delivered portfolio. Although, contributions of Commonwealth environmental water supported the Barrage BWS flow target of 200Gl in all years, this target was only achieved in the last 3 years of the program, and the achievement was largely due to the large unregulated flow event of 2016-17.

**Table 4.** Contribution of Commonwealth environmental water to Barrage releases in Gigalitres (Gl) with and without Commonwealth environmental water. Values in parentheses are the three-year rolling average.

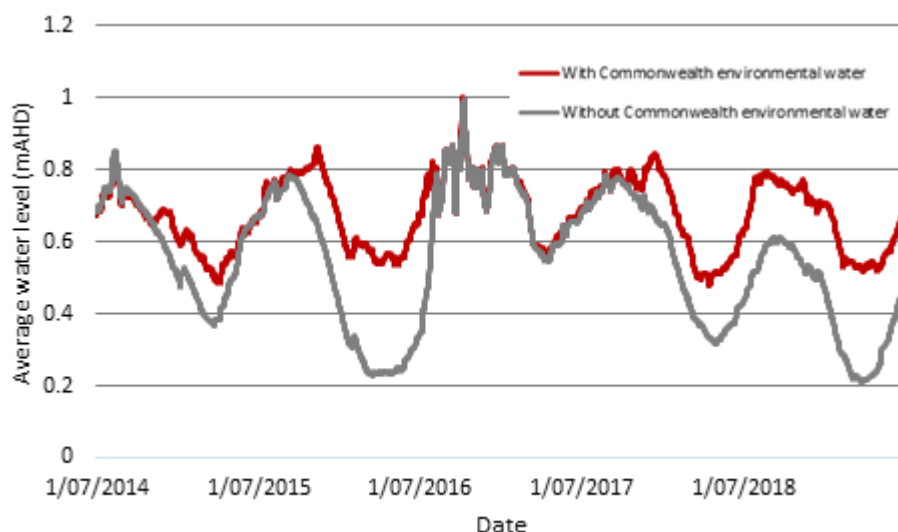
	2014-15	2015-16	2016-17	2017-18	2018-19
CEW contribution	453	736	811	755	377
Total barrage release with CEW	986 (NA)	736 (1073)	6558 (2760)	851 (2715)	377 (2595)
Total barrage release without CEW	533 (NA)	0 <sup>1</sup> (500)	5747 (2093)	96 (1948)	0 (1948)

<sup>1</sup>In the absence of Commonwealth environmental water, its likely that management would have intervened and averted zero flows over the barrages.

The water level target in the Coorong, Lower Lakes and Murray mouth focuses on;

- The water levels in the Lower Lakes are maintained above sea level (0m AHD) and 0.4 metres AHD, for 95% of the time, as far as practicable, to allow for barrage releases.

For this target we assess water level at Lake Alexandrina using the pre-buyback counterfactual model. Figure 21 shows the water level in Lake Alexandrina both with and without the addition of Commonwealth environmental water. Contributions of Commonwealth environmental water kept water levels from falling below the 0.4 m target threshold. Since 2014, the water levels in Lake Alexandrina have been above the 0.4 m target threshold for 100% of the time. Without Commonwealth environmental water, the model predicted that water levels in the Lower Lakes would have been less than 0.4 m for 471 days over the five-year monitoring period (26% of time).



**Figure 21** Contribution of Commonwealth environmental water towards maintaining water levels in the Lower Lakes above 0.4 m AHD.

The salinity target in the Coorong, Lower Lakes and Murray mouth focuses on;

- Salinity in the Coorong remains below critical thresholds for key flora and fauna including: salinity in the Coorong's south lagoon is less than 100 grams per litre 95% of the time.

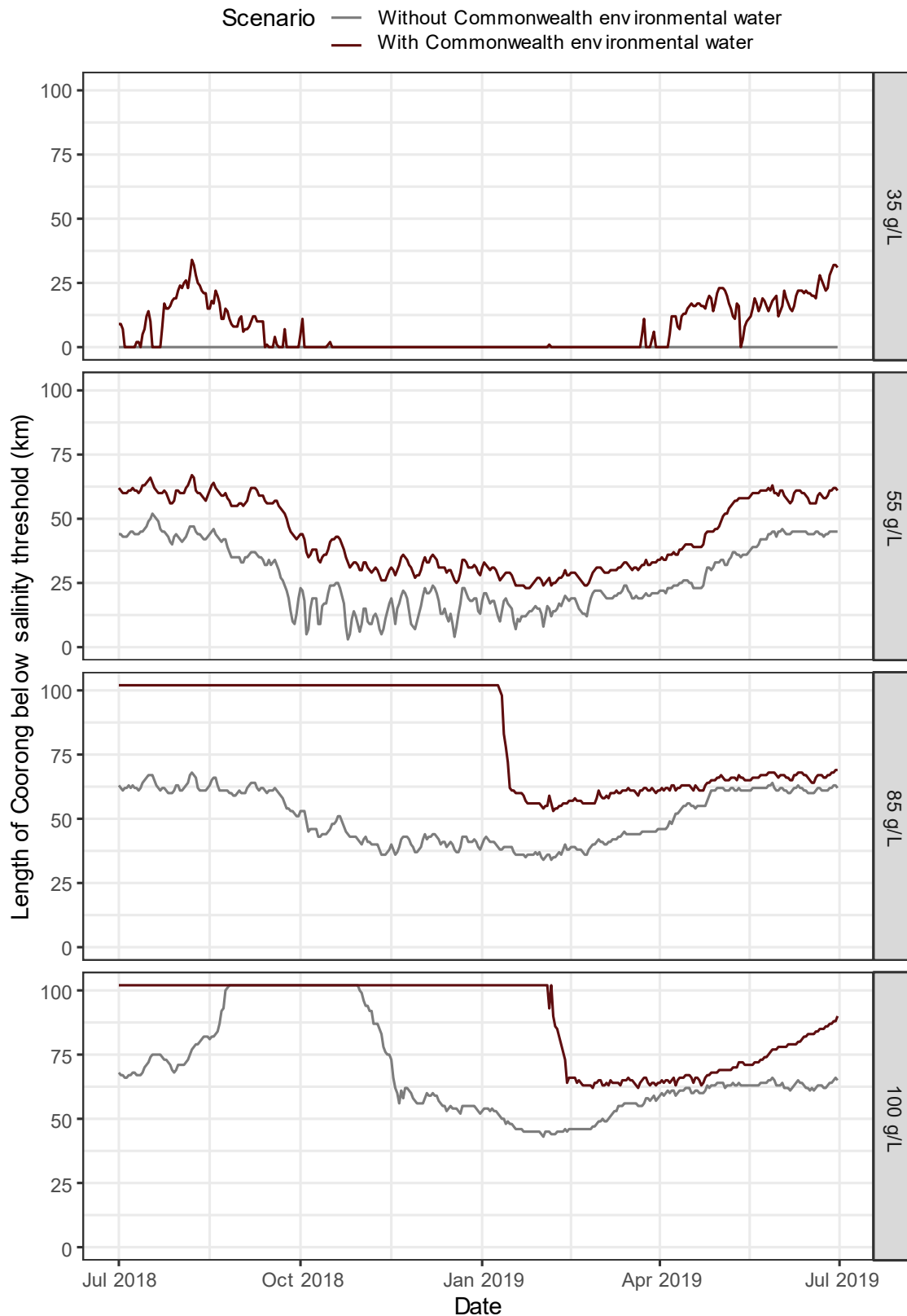
For this target, we report on the 2018-19 salinity in the Coorong using the Channel dynamics model developed by Webster (2010) and later improved by Jöhnk and Webster (2014).

The modelled salinity concentrations in the Coorong, both with and without Commonwealth environmental water, are reported in Table 5, Figure 22 and Figure 23. The addition of Commonwealth environmental water reduced the average, minimum and maximum salinity concentrations across all management units for the entire monitoring program, compared to the modelled scenario without Commonwealth environmental water (**Table 5**).

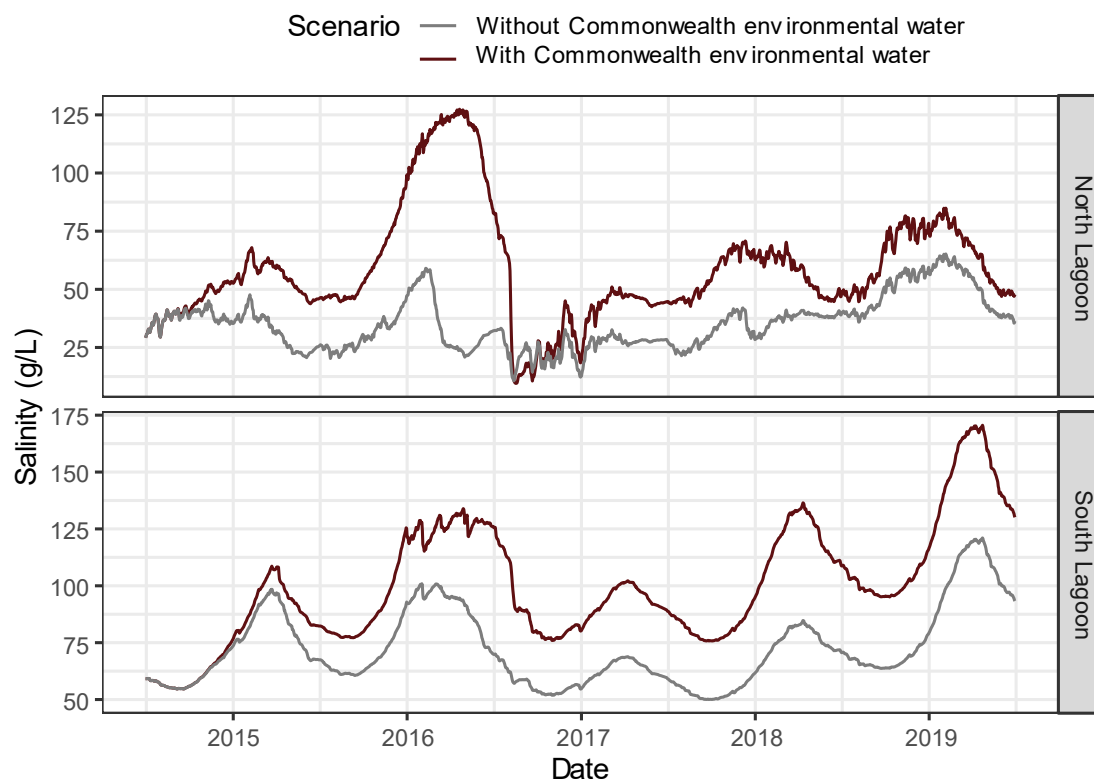
Looking across the entire LTIM project, the results show that the addition of Commonwealth environmental water kept salinity levels below the 100 gram per litre target threshold in the Coorong's Goolwa channel, south lagoon and north lagoon for 100%, 100% and 68% of the program respectively. However, without Commonwealth environmental water, salinity concentrations in the south lagoon would have deteriorated. The amount of time within the 100 gram per litre target would have reduced significantly to 26% of the year (a drop in 153 days). Salinity levels in the Goolwa channel and south lagoon remained unchanged with respect to this threshold.

**Table 5.** Modelled salinity concentrations, with and without the addition of Commonwealth environmental across the three management units of the Coorong Lower Lakes. Values are (mg/l) mean  $\pm$  standard deviation, parentheses show the minimum and maximum.

Scenario	Management unit	2018-19	2014-19
Without Cew	Goolwa Channel	25.0 $\pm$ 1.1 (23.2 – 27.0)	19.5 $\pm$ 8.1 (0.0 – 27.0)
With Cew	Goolwa Channel	6.8 $\pm$ 4.3 (0.0– 18.1)	10.4 $\pm$ 6.8 (0 – 24.2)
Without Cew	South lagoon	64.6 $\pm$ 12.5 (44.6 – 84.9)	50.4 $\pm$ 18.6 (0.3 – 99.9)
With Cew	South lagoon	49.9 $\pm$ 9.0 (35.4 - 65.2)	35.2 $\pm$ 11.2 (10.6 – 65.2)
Without Cew	North lagoon	125.1 $\pm$ 26.8 (95.1 – 170.6)	100.0 $\pm$ 26.0 (54.7 – 170.6)
With Cew	North lagoon	86.2 $\pm$ 20.6(50.0 – 121.0)	72.4 $\pm$ 16.9 (50.0 – 121.0)



**Figure 22.** Panel line chart showing the length of Coorong over the 2018 – 2019 water year across four ecologically relevant salinity targets. The simulated outputs are shown for the scenario with Commonwealth environmental water (red) and without Commonwealth environmental water (grey). The data points were derived from daily simulations for each 1km node along the 102 km Coorong transect.



**Figure 23.** Panel line chart showing the salinity concentrations within the North and South Lagoon of Coorong over the entire monitoring period 2014 – 2019. The simulated outputs are shown for the scenario with Commonwealth environmental water (red) and without Commonwealth environmental water (grey).



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## Appendix I: Details of Evaluation Methods

### Data sources for evaluating contribution to flow regimes

The contribution of Commonwealth environmental water to flow regimes in the Basin is primarily evaluated using streamflow for the 2018-19 watering year. Estimates of the contribution of Commonwealth environmental water were calculated at 126 streamflow sites across 17 valleys within Basin (Table A1). The evaluation of flow regimes is based on a comparison of streamflows recorded at these sites during the 2018-19 year (*actual case*) with streamflows that would have occurred in the absence of the Commonwealth environmental water program (*baseline case*).

**Table A1.** The contribution of Commonwealth environmental water was estimated at 126 streamflow sites across 17 valleys in 2018–19. The names of streamflow sites, the baseline modelling approach and number of sites within each valley is also reported.

No.	Valley name	Site count	Site name	Baseline modelling approach	Data owner or provider
1	Border Rivers	4	Goondiwindi, Farnbro, Flinton, Nindigully	Point derived	CEWO
2	Broken Creek	4	Rices Weir, Caseys Weir, Wagarandall, BackCk	Water accounting	GMW
3	Campaspe	3	Barnadown, Rochester, Eppalock	Water accounting	GMW
4	Central Murray	10	Doctors, Corowa, Barmah, Yarrawonga, Tocumwal, Torrumbarry, Wakool, Swan Hill, Euston, Lock 10	Water planning	MDBA
5	Condamine–Balonne	2	Roseleigh, St George	Point derived	CEWO
6	Edward–Wakool	10	Gee Gee Bridge, Deniliquin, Yallakool Offtake, Colligen Offtake, Tuppal, Niemur R at Barham Rd, Wakool R at Barham Rd, Niemur R at Mallan School, Wakool at offtake regulator, Wakool at Coonamit	Water accounting	Water NSW
7	Goulburn	4	Murchison, Trawool, Eildon, McCoys	Water accounting	GMW
8	Gwydir	19	Pallamallawa, Moree, Yarraman, Carole Offtake, Pinegrove, Gravesend, Boolooroo, Combadello, Tareelaroi, Mehi Offtake, Mallowa, Garah, Tyreel, Gingham Diversion, Brageen,	Water accounting	Water NSW

No.	Valley name	Site count	Site name	Baseline modelling approach	Data owner or provider
			Millewa, Allambie, Midkin, Gundare		
9	Lachlan	10	Cowra, Forbes, Condobolin, Jemalong, Willandra, Brewster, Nanami, Hillston, Whealbah, Booligal	Water accounting	Water NSW
10	Loddon	6	Laanecoorie, Cairn Curran, Loddon, Serpentine, Tullaroop, Appin South	Water accounting	GMW or provider
11	Lower Murray	8	SA Border <sup>1</sup> , Lock 6 <sup>1</sup> , Lock 5 <sup>1</sup> , Lock 4 <sup>1</sup> , Lock 3 <sup>1</sup> , Lock 1 <sup>1</sup> , Wellington <sup>1</sup> , Barrages <sup>2</sup>	<sup>1</sup> Water planning <sup>2</sup> Water accounting	MDBA <sup>1</sup> CEWO <sup>2</sup>
12	Lower Darling	2	Burtundy, Weir 32	Water accounting	Water NSW
13	Macquarie	6	Dubbo, Warren, GinGin, Burrendong, Marebone, Barooka	Water accounting	Water NSW
14	Murrumbidgee	12	Wagga, Gundagai, Narrandera, Yanco Offtake, Darlington, Beremba, Maude, Redbank, Carrathool, Gogelderie, Balranald, Hay	Water accounting	Water NSW
15	Namoi	11	Boggabri, Bugilbone, Carroll, Chaffey, Gunidgera, Gunnedah, Keepit, Mollee, Paradise, Piallmore, Weeta	Water accounting	Water NSW
16	Ovens	4	Buffalo, King, Peechelba, Wangaratta	Water accounting	GMW
17	Barwon–Darling	7	Bourke, Brewarrina, Louth, Collarenebri, Mungindi, Walgett, Wilcannia	Point derived	CEWO
18	Warrego	2	Augathella, Cunnamulla	Point derived	CEWO
19	Wimmera	2	Lonsdale, Lake Taylor	Water accounting	GWM
	<b>Total</b>	<b>126</b>			

Note: CEWO = Commonwealth Environmental Water Office; GMW = Goulburn–Murray Water; MDBA = Murray–Darling Basin Authority; SA DEW = South Australian Department of Environment and Water.

## Observations of streamflows

Recorded streamflows were available online at the respective jurisdictional websites (Table ). It was assumed that the minimum requirements set by the International Organization for Standardization (ISO) standard (ICS.17.120:20) for flow measurement in open channels had been met by the custodians of the streamflow sites, so we provided no further assessment of data quality other than checking for complete records. It is important to note, that in compiling our hydrological record we have used provisional data, and in some instances, ratings adjustments have occurred, post analysis. Similarly, our hydrological record has been aggregated to daily values, where the start and end date for the day differed, between sites and valleys. In most instances, our reported day was never midnight to midnight as reported on most jurisdictional websites.

**Table A2.** Websites used to source discharge data for 126 streamflow sites in the Murray–Darling Basin.

Jurisdiction	Water monitoring website
New South Wales	<a href="http://waterinfo.nsw.gov.au">http://waterinfo.nsw.gov.au</a>
South Australia	<a href="https://www.waterconnect.sa.gov.au">https://www.waterconnect.sa.gov.au</a>
Queensland	<a href="https://water-monitoring.information.qld.gov.au">https://water-monitoring.information.qld.gov.au</a>
Victoria	<a href="http://data.water.vic.gov.au/monitoring.htm">http://data.water.vic.gov.au/monitoring.htm</a>

## Baseline hydrology scenarios

The evaluation was based on a comparison of observed hydrology (i.e. daily streamflow time series for the 2018-19 watering year) with baseline hydrology represented by daily streamflows for the 2018-19 year in the absence of Commonwealth environmental water. In most cases, the baseline hydrology was estimated as actual flows minus flows delivered from an environmental water entitlement. However, in cases where the baseline was calculated using the water planning model method (described below), a further adjustment was made so that the baseline hydrology represented stream flows that would have occurred in the 2018-19 year if the Commonwealth water portfolio had never been procured (i.e. agricultural water entitlements resemble those before establishment of the Commonwealth environmental water program). This latter case allows evaluation of the combined consequences of the Commonwealth environmental water recovery and delivery program. In the future, we hope to work with data providers to extend the water planning model approach (see below) to more sites.

Baseline hydrology for the 2018-19 year was derived by several agencies using one of the following three approaches: water accounting model; water planning model; and point derivation.

1. *Water accounting model:* This approach is based on a mass balance of water in river reaches between streamflow sites with a fixed lag time to allow for travel times as well as estimates of losses and gains. Operators enter known factors, such as water orders and water taken, and use empirical data, such as actual unaccounted differences and meteorological data, to calculate saleable components of flow at nominated streamflow sites. Based on these data, the data provider estimates the Commonwealth environmental water and non–Commonwealth environmental water components of the observed time series. The baseline scenario is derived by subtracting the environmental water component from the observed hydrograph at the streamflow gauge. This approach is used by river operators (Goulburn–Murray Water (GMW), WaterNSW and MDBA) to provide baseline streamflow series in the

Victorian tributaries (Goulburn, Broken, Campaspe, Loddon, Ovens, Murray) and regulated valleys of New South Wales (NSW) (Murrumbidgee, Lachlan, Macquarie, Gwydir, Edward–Wakool, Murray) and the South Australian Murray.

This approach is used to provide the time series of environmental water provided by the CEWH and non–Commonwealth environmental water holders separately.

2. *Water planning model:* The method was developed by the MDBA and applied in the River Murray. In this method, two scenarios were modelled using the MSM-BigMod modelling suite; ‘modelled pre-buyback’ and ‘modelled actual’, for the period between July 2018 and June 2019. The initial conditions of the model were based on the 2014–15 model run. The difference between the two model runs measured the impact of environmental water recovery and use during 2018–19. The ‘modelled actual’ flow differs from the actual observed flow at streamflow gauges because of model error. To avoid artefacts associated with this error, we recalculated the ‘pre-buyback’ case by subtracting the difference (i.e. the modelled actual minus the modelled pre-buyback flows) from the actual observed flows. The resulting flow series is used as the baseline. In this model, the total environmental water entitlement is treated as a single component and there is no separate treatment of Commonwealth environmental water and non–Commonwealth environmental water.
3. *Point derivation:* This method was developed in-house by the CEWO and applies to the unregulated valleys of NSW and Queensland (Border Rivers, and Condamine–Balonne, Warrego and Upper Darling rivers). The CEWO monitors real-time river data to detect when access to Commonwealth unregulated entitlements is triggered. Gauge data, in conjunction with official announcements of water-harvesting access in unregulated valleys (Border Rivers and Lower Balonne and Warrego rivers), are used to estimate in-stream contributions. Volumes are accounted for in accordance with the licence (access) conditions of each entitlement in the same way that other water users manage their take (i.e. water is assumed to be used at all available opportunities when access conditions are triggered). This approach reflects the use pattern of most irrigators in unregulated systems and hence the volumes and pattern of flows that have been reinstated. The baseline scenario was derived by subtracting the Commonwealth environmental water component from the hydrograph.

Commonwealth environmental water delivery is often coordinated with delivery of water by other environmental water holders; hence, the evaluation considers the combined hydrological effect of all environmental water delivery. Where possible, we also indicate the contribution of the Commonwealth environmental water component to the total hydrological effect of all environmental water.

None of these methods comprehensively account for planned environmental water. The focus of this evaluation is on the contribution of Commonwealth environmental water–held environmental water allocations or other environmental water allocations delivered in coordination with this Commonwealth environmental water.

## **Data sources for evaluating contribution to hydrological connectivity**

### ***Floodplain inundation extent***

Floodplain and wetland inundation extents in this evaluation are reported as mapped area hectares (ha) in the ANAE and represent monitoring outputs from multiple providers using differing methods (Table A3). The areas reported represent cumulative inundation over the course of the year. An attempt to attribute inundation as Commonwealth environmental water, other environmental water (where the watering actions were separate to Commonwealth

actions) and other water (reflecting the inundation associated with natural events) was made. However, this attribution was not straightforward because the information required for attribution was not easily accessible nor determinable and on-ground validation was not comprehensive. Inundation was classified as: Other water (natural events, rainfall/runoff etc), Commonwealth environmental water (high or low certainty), other environmental water, large on farm storages where known and the Coorong Lower Lakes region. High certainty classifications refer to actions such as pumping or where site validation data was provided by environmental water managers whereas low certainty classifications represented inundation areas that included contributions from other environmental water and other water, making attribution difficult to disentangle. Attributing inundation Basin wide will remain this way until accurate, reliable and accessible inundation mapping is made available to support defensible and robust monitoring and evaluation.

### ***Watercourses watered***

The watercourses watered using Commonwealth environmental water were mapped using information provided via CEWO environmental water delivery personnel and other operational reports. In the regulated rivers where environmental water was ordered from a dam, the reaches downstream to the accounting point (in NSW) were marked as watered (i.e. reaches beyond the end of system were not included) whereas, in Victoria, the reaches watered were extended to the confluence with the River Murray. This distinction was justified on the basis that in Victoria, returning environmental flows are protected whereas in NSW they are not protected. In the unregulated rivers of the northern Basin, CEWO provided advice on the estimated extents of watercourses influenced by Commonwealth environmental water.

**Table A3.** Description of the method used to derive inundation across valleys where inundation was reported in the Murray–Darling Basin. Boundary definition and data confidence are reported.

Valley name	Method	Data owner	Boundary definition
Central Murray	Landsat and visual survey; MIKE hydro-dynamic model; DEM + water level	Mallee CMA; MDBA; GA	Wet area boundaries denote contributions from both Commonwealth environmental water and natural rainfall/runoff processes.
Gwydir	Landsat, Sentinel and visual survey	NSW OEH; Eco Logical; GA	Wet area boundaries denote contributions from both Commonwealth environmental water and natural rainfall/runoff processes.
Lachlan	Visual survey; NDVI; Landsat, Sentinel	NSW OEH; GA	Wet area boundaries denote contributions from both Commonwealth environmental water, other environmental water, other water and natural rainfall/runoff contributions.
Lower Darling	MIKE hydro-dynamic model; DEM + water level	MDBA; GA	Wet area boundaries denote contributions from both Commonwealth environmental water and natural rainfall/runoff processes.
Lower Murray	Landsat, Sentinel, and visual survey; MIKE hydrodynamic model; DEM + water level	NSFA; SA DEWNR; NRM Board; MDBA; CEWO; GA	Wet area boundaries denote contributions from both Commonwealth environmental water and natural rainfall/runoff processes.
Macquarie	Landsat, Sentinel and visual survey	NSW OEH; GA	Wet area boundaries estimate contributions from both Commonwealth environmental water and natural rainfall/runoff processes.
Murrumbidgee	Landsat, Sentinel; Tassel Cap and visual survey	NSW OEH; GA	Wet area boundaries denote contributions from Commonwealth environmental water, other environmental water and natural rainfall/runoff processes.
Warrego	Landsat and visual survey	NSW OEH; Eco Logical; GA	Wet area boundaries denote contributions from both Commonwealth environmental water and natural rainfall/runoff processes.

Note: DEM = digital elevation model; GBCMA = Goulburn Broken Catchment Management Authority (CMA); MDBA = Murray–Darling Basin Authority; NDVI = Normalised Difference Vegetation Index; NFSA = Nature Foundation South Australia; NRM = Natural Resource Management; NSW OEH = NSW Office of Environment and Heritage; SA DEWNR = South Australian Department of Environment, Water and Natural Resources; GA = Geoscience Australia (Digital Earth Australia).

## Evaluation of Basin-wide hydrological impacts

The hydrological evaluation is in two parts. The first part summarises the Basin-scale contribution of environmental water to general enhancements in flow regimes without reference to local watering targets. This is provided to fulfil two purposes:

1. To support an evaluation against the Basin Plan objectives as described in the Basin Plan Section 8.51(1)(b). The Basin Plan identifies seven flow components that must be considered in the determination of watering requirements of environmental assets and ecosystem functions. Only the relevant flow components are included in this evaluation (Table A4).
2. To provide the basis for evaluating ecological consequences of environmental watering at the Basin scale. In this part, we use hydrological measures related to standardised flow thresholds to indicate effects on base flows and freshes. It is important to note that this section is not for assessing the performance of environmental water delivery with respect to local hydrological targets (which is instead dealt with in the Section 4 of this report).

**Table A4.** Flow components included in the Basin Plan and those that are included in the of the Basin-scale evaluation.

Basin Plan flow components	Included in evaluation?
Cease to flow	No
Low flow season base flows	Yes
High flow season base flows	Yes
Low flow season freshes	Yes
High flow season freshes	Yes
Bankfull flows	No
Overbank flows	No

We provide a summary of the hydrological outcomes across the Basin using data for streamflow sites, selected based on data availability rather than randomly sampled. As such, it is not possible to make statistically based inferences concerning the mean and variance of outcomes across the Basin because statistical design does not support a random sample. Also, streamflow sites included in this evaluation were not specifically targeted to receive environmental water. This means any outcomes at these sites are an inadvertent result of actions designed to meet environmental targets elsewhere in the Basin. This is important as the Basin Plan sets principles on maximising environmental benefits, which are intended to ensure that the water achieves the best environmental outcomes (i.e. through considerations on multi-site watering en route to an intended priority asset or enhancing existing flow events).

### ***Flow thresholds***

The summary is based on the occurrence of low flows and freshes. We consider two components of low flows – very low and medium low; and three components for freshes – low, medium and high. These flow components are defined by five threshold discharges as follows:

- **Very low flows** are defined as flows that fall below the lowest flow in the unimpacted (defined below) monthly flow series or 2% of mean unimpacted flow, whichever is greater. This threshold corresponds to exceptionally low flows at the lower end of range that would normally occur in an unimpacted perennial river.



- **Medium low flows** are defined as flows that fall below the 95th percentile exceedance flow in the unimpacted monthly flow series or 10% of the mean unimpacted flow, whichever is greater. This flow threshold corresponds to a value that might typically be used as a minimum flow to maintain low flow habitats.
- **Low freshes** are defined as flow spells that raise water levels at least one-eighth of the height of the bank above the medium low flow level. This threshold corresponds to a slight increase in stage above base flow levels and would be a frequent occurrence in both the dry and wet seasons under unimpacted flow conditions.
- **Medium freshes** are defined as flow spells that raise water levels at least one-quarter of the height of the bank above the medium low flow level. This threshold corresponds to an increase in stage that wets the lower part of the bank and would be a frequent occurrence in an unimpacted regime maintaining moist soils and is an important component of a variable watering regime for this portion of the channel throughout the year.
- **High freshes** are defined as flow spells that raise water levels at least half of the height of the bank above the medium low flow level. Freshes of this magnitude would have occurred in most years in the unimpacted flow regime, and it would be common for freshes to exceed this threshold several times per year.

The unimpacted flow is the expected flow series without development conditions under an historical climate. Unimpacted monthly flow series were provided by the MDBA for sites across the Basin. These were not always the same sites as used in this evaluation of Commonwealth environmental water delivery. In most of these cases, the nearest appropriate unimpacted flow data site was chosen. There were a small number of sites where unimpacted flow series were modelled using the various water planning models across the Basin during the development of the Basin Plan. The bankfull discharge was estimated either as the 5th percentile exceedance in the monthly unimpacted flow ( $\times 1.5$  as a rough estimate of peak daily flow based on the mean monthly value) or from channel dimensions available for sites across the Basin (these were data collected for the Sustainable Rivers Audit II – Physical Form Theme). Dimensions were taken from the site closest to each of our hydrological evaluation sites, and on the same river channel. Bankfull discharge was estimated from these dimensions using equation M15 in Stewardson *et al.* (2005). We generally used the larger of these two bankfull estimates but made some exceptions based on individual site considerations. The estimates of discharge corresponding to the low, median and high fresh water levels (defined above) were based on widely accepted at-a-station hydraulic geometry equations (Stewardson *et al.* 2005).

### ***Flow regime score***

We calculated a flow regime ‘score’ corresponding to each of the five flow thresholds (Stewardson and Guarino 2018). The score is a number equal to or between zero and one. The purpose of this score is to provide a summary of the flow regime and identify contributions of environmental water to protection and restoration of flow regimes across the Basin. In the case of the two low flow thresholds, the score relates to the maintenance of flows above the very low and medium low flow thresholds in each calendar season. Under unimpacted conditions, there would have been a broad range of base flow regimes across the Basin, including some intermittent rivers. To allow for this, the score was calculated based on a comparison of 2018-19 low flows with unimpacted low flows. The score measures the duration of flows exceeding our two low flow thresholds in each calendar season relative to the normal duration in the unimpacted state. If the average unimpacted base flow durations were maintained in 2018-19, then the site received the maximum score of ‘1’. A reduction in the duration compared with unimpacted duration, in any of the four seasons, reduced the score. If we applied this score to an unimpacted regime, we could expect that, in dry years, we would get a lower score than in average and wet years. The score is not an environmental flow objective, rather an indication of

the dryness of the low flow regime in 2016–17 and the components of the flow regime that are significantly affected by environmental watering actions.

Similarly, a score was calculated for each of the three thresholds corresponding to low, medium and high freshes. However, we did not attempt to adjust these scores based on a comparison with the unimpacted flow regime. Instead, the score relates to the occurrence (or not) of flow freshes exceeding these fresh thresholds. For the low fresh threshold, the duration of flows above this threshold within a calendar season must have exceeded 3 days for a 'fresh' to be considered to have occurred. The maximum score (of '1') was achieved for the low fresh if a fresh occurred in three of the calendar seasons. For the medium fresh, the maximum score was achieved if a fresh occurred in at least two calendar seasons. For the high fresh, the maximum score was achieved if a fresh exceeded this threshold at some time over the year.

In Annex A, we report scores for each site but simplify the results by combining the two low flow scores into a single base flow score and the three scores for the flow fresh thresholds into a single freshes score. The freshes score (reported in the Annex A) weights the low, medium and high fresh scores according to the percentage weights 50:30:20, respectively.

*We emphasise that these scores are not an evaluation of individual watering actions and their associated objectives. The scores are used to summarise the flow regime at sites across the Basin and support an evaluation of the overall effect of the management of Commonwealth environmental water on flow regimes at the Basin scale. For this reason, a number of the sites included in the analysis were not actually targeted with environmental watering actions.*

### ***Attribution of Commonwealth environmental water***

Commonwealth environmental water delivery is often coordinated with delivery of other environmental water to achieve a combined outcome. In such cases, it makes little sense to consider the contribution of the Commonwealth environmental water in isolation. For consistency, we have evaluated the aggregate hydrological outcome of all held environmental water.

The total contributions of all environmental water cannot be fully attributable to the Commonwealth environmental water in situations where there is coordinated delivery with other environmental water holders. To address this issue, we have developed a simple procedure for sharing score increases between Commonwealth environmental water and other environmental water:

1. Calculate the total improvement in score with all environmental water entitlements (i.e. compare the score for the observed and baseline flow regimes).
2. Calculate the improvement that would have been achieved if Commonwealth environmental water was delivered on its own.
3. Calculate the improvement if the non-Commonwealth environmental water had been delivered on its own.
4. Apportion the total improvement (from 1 above) to Commonwealth environmental water and non-Commonwealth environmental water based on the ratio of improvements achieved in 2 and 3 above.