Ecological needs of low flows in the Barwon-Darling

Technical Report

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Murray-Darling Basin Authority

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The Murray–Darling Basin Authority acknowledges and pays respect to the Traditional Owners, and their Nations, of the Murray–Darling Basin, who have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. The MDBA understands the need for recognition of Traditional Owner knowledge and cultural values in natural resource management associated with the Basin.

The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of the Northern Basin Aboriginal Nations Board:

…As the First Nations peoples (Traditional Owners) we are the knowledge holders, connected to Country and with the cultural authority to share our knowledge. We offer perspectives to balance and challenge other voices and viewpoints. We aspire to owning and managing water to protect our totemic obligations, to carry out our way of life, and to teach our younger generations to maintain our connections and heritage through our law and customs. When Country is happy, our spirits are happy.

Cover image: Small in-channel flow at Bourke Weir on 19 January 2004 (about 900 ML/d)

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Executive Summary

In November 2016 the MDBA released the findings from the Northern Basin Review, recommending a reduction in the total volume of water to be recovered for the environment across the Northern Basin. As a result of the Northern Basin Review's extensive research and community consultation, the MDBA recommended that the 390 GL recovery volume set in 2012 be reduced to 320 GL, contingent upon commitments from governments to implement a range of 'toolkit measures'.

The purpose of the toolkit measures is to improve water management practices. The Authority believes that implementing these measures will provide improved environmental outcomes and lessen the social and economic impacts compared with the original 390 GL Basin Plan recovery settings.

One of these measures specifies the need for the protection of smaller but ecologically significant flows across the Northern Basin. Smaller flows are critical for both communities and the environment, particularly in dry-times. The Authority believes that the protection of the most ecologically significant small flows is critical to achieve the desired outcomes of the Basin Plan, particularly in the Barwon-Darling. This sentiment was reiterated by stakeholders from their lived experience of living and working on the river. Protecting environmental water and restoring ecologically important small flows was also identified as a policy priority to be addressed by Basin governments by the recent MDBA Compliance review and Ken Matthews Review (Matthews, 2017) commissioned by the NSW government.

This report provides a synthesis of environmental water requirements associated with ecologically important small flows 'low flow and small fresh events' in the Barwon-Darling between Mungindi and Wilcannia.

For the purpose of this analysis, 'low flow and small fresh events' have been defined to be those representing flow events with a peak of between 350-2,000 ML/d across the Barwon-Darling river system. This flow range is consistent with the ecological significance as described in previous studies (Thoms et al. 1996, MDBA 2011 and NSW DPI 2015). To place this definition into context, commence to pump thresholds for licences, specified in the Barwon-Darling Water Sharing Plan (2012), are generally within this flow range, and these flows may not be considered low for purposes other than environmental.

The MDBA has previously assessed the environmental water requirements of the Barwon-Darling river system, and developed a suite of site-specific flow indicators, as part of the Northern Basin Review (MDBA, 2016a). These indicators focused on ecologically important larger in-channel and overbank aspects of the flow regime to assist with determining the long-term average amount of water required by the environment as an input to setting Sustainable Diversion Limits.

The analysis presented in this report complements the previous assessment. The Northern Basin Review focused on larger flow events (>6,000 ML/d) that are important for informing the total quantum of water to be recovered for the environment and describe the types of flows that are ecologically important during average to wetter conditions. The synthesis of existing information on 'low flow and small fresh events' within this document has two objectives. Firstly, to describe

the types of flows that are ecologically important during drier conditions. Secondly, to inform consideration of mechanisms to better protect environmental flows as part of managing water within the Sustainable Diversion Limit.

It is acknowledged that the management of unregulated flows in the Barwon-Darling river system must occur at a reach scale and through management of individual flow events in order to optimise outcomes across all users, including the environment. Under existing management arrangements, commence to pump thresholds are largely within the range of the environmental water requirements for ecologically important small flows. It is therefore important to ensure the rules around water sharing, and approaches to managing environmental water, are based on a good understanding of the ecological needs associated with that flow window.

In addition, ecologically important small flows are the types of events that the Commonwealth Environmental Water Holder currently has capacity to deliver and actively manage with the portfolio of water recovered for the environment (as has been demonstrated on several occasions in recent years — see Appendix B). Protection of this water is important to ensure it meets is intended purpose and flows through the river system.

The ecological needs for small flows in the Barwon-Darling river system include:

- Maintaining populations of native fish and other aquatic biota (like mussels) by replenishing refuge pools and maintaining aquatic habitats; providing opportunities for movement between habitats; and supporting key ecosystem functions (including cycling of nutrients and provision of carbon for productive food webs);
- Supporting regular breeding and recruitment of fish and other invertebrates with short life cycles to maintain populations and genetic diversity.
- Maintaining water quality through regular flushing of refuge pools to mitigate against issues such as algal blooms and salinity spikes.
- Providing longitudinal connectivity through the Barwon-Darling river system and its tributaries to support the ecological needs above, maintain in-channel and riparian vegetation condition, and provide natural cues for flow responsive fish and other aquatic biota.

Ecologically important small flows also provide water for downstream communities to ensure reliable and good quality water for critical human water needs (such as town water and stock and domestic uses), and water to support cultural and recreational values.

What is this report about?

The report describes environmental flow requirements for ‘low flow and small fresh events’ in the Barwon-Darling river system based on a synthesis of existing information and literature. The description of flow requirements includes the flow event magnitude, duration, timing frequency and thresholds of concern for the period of time between events. The term environmental flow requirement has been used in this report to differentiate this work from the site-specific flow indicators developed previously as part of the Northern Basin Review. However, it should be noted that both are expression of environmental water needs for the Barwon-Darling River with the distinction being their focus on different parts of the flow regime.

Thirteen environmental flow requirements have been described for different points along the river, including at Walgett, Brewarrina, Bourke, Louth and Wilcannia (see table below). This approach provides spatial coverage of environmental water needs along the length of the river in recognition of reach based differences in hydrology, geomorphology and ecology. Furthermore, irrigation extractions occur along the entire length of the Barwon River and in the upper sections of the Darling River around Bourke. Hence, an understanding of the needs for all reaches is important from a management perspective given they experience varying levels of flow alteration due to consumptive use. Description of flow requirements at Wilcannia is considered especially important as the last gauge on the Darling River and hence it represents the full impact of upstream development and can be used to assess longitudinal connectivity for the entire river system.

The performance of the environmental flow requirements has been assessed against the modelled without development flow regime and observed gauged flows for between 1990-91 and 2016-17. The analysis of observed flows is important as the current hydrological model for the Barwon-Darling (the Barwon-Darling IQQM developed by the NSW government) is known to have issues with providing an accurate representation of such flow events, especially for low flows (CSIRO, 2008; Bewsher, 2016). When flows fall below about 400-500 ML/d at Bourke, there is a divergence between the observed and Baseline model flow exceedance curves, indicating the model has difficulty predicting these flows. This is not to say that the model does not provide valuable information, rather, that it is important to supplement the model with other sources of information.

List of Environmental Flow Requirements for the Barwon-Darling river system.

Ecological rationale	Threshold	Duration (days)	Timing	Target frequency (% of years with an event)	Threshold of concern for spells b/w events (days)
CEWO Northern Unregulated Rivers Portfolio Management Plan (CEWO, 2017)					
Maintain native fish populations and in-channel ecosystem processes such as refuge pools and connectivity down the river. #set to match the without development maximum spell between events.	500 ML/d @ Walgett	7-20	Aug-May (1 to 3 events)	80-90	476#
	500 ML/d @ Bourke	7-20	Aug-May (1 to 2 events)	80-90	365
	350 ML/d @ Louth	7-14	Aug-May (1 to 2 events)	80-90	365
Enhance native fish spawning, and recruitment for reaches in the Barwon-Darling(especially small bodied fish)	500 ML/d @ Bourke	50	Sep-April	70-80	730
	1,500 ML/d @ Bourke	5	Sep-April	70-80	730
Golden Perch small pulse requirements (Stuart and Sharp, 2017)					
Regular opportunity for Golden perch to migrate and spawn in the Barwon-Darling and Border Rivers, with larval development in- channel and downstream transport.	3,000 ML/d @ Brewarrina	20	Any time (ideally when temp is above 18 degrees)	60-70	1460
Algal suppression/connectivity flow - Interim Northwest Unregulated Flow Plan - associated with the B-D water sharing plan (NSW, 2012)					
Flow pulse to the end of system during the hotter months to mitigate against stratification of pools and the development of algal blooms.	2,000 ML/d @ Wilcannia	5	Oct-April	80-90	730

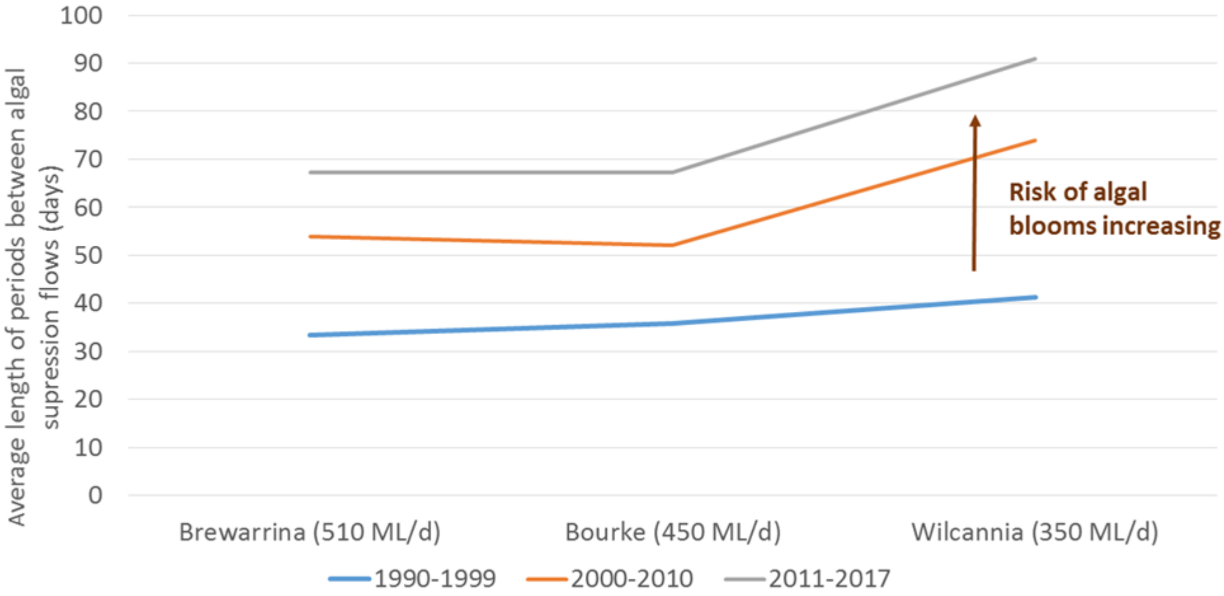
Ecological rationale	Threshold	Duration (days)	Timing	Target frequency (% of years with an event)	Threshold of concern for spells b/w events (days)
Management target for access to unregulated flows to be restricted to achieve event, unless flow occurred within the preceding months.					
Algal suppression thresholds (Mitrovic et al., 2006)					
Critical discharge to suppress stratification of pools and *Anabaena circinalis* (toxic blue-green algae) growth during the hotter months of the year. *would indicate there has not been an algal bloom mitigation flow between October to March.	510 ML/d @ Brewarrina	1	15 Oct-15 March	100	150*
	450 ML/d @ Bourke	1	15 Oct-15 March	100	150*
	350 ML/d @ Wilcannia	1	15 Oct-15 March	100	150*

What are the key findings?

Analysis of observed flows shows that the environmental flow requirements have mixed performance against the identified frequency and dry spell targets (Table 6, Table 7). The desired frequency and/or dry spell is exceeded for many of the flow requirements across multiples reaches of the Barwon-Darling river system. There are much longer periods of no to very low flows which go beyond the threshold of concern identified for most environmental flow requirement events, especially for the smaller in-channel freshes and baseflows.

Some of the trends and impacts of the longer low or no-flow periods include:

- The maximum dry spell between flow low events is approximately doubled in length for many of the flow requirements described when comparing observed flows to the without development flow regime. In extreme cases, the maximum dry spell is greater than 10 times longer which is likely to place ecosystems under severe stress.
- Periods of low or no flow have increased for gauges downstream of Bourke post 2000 as compared to pre-2000.
- Algal bloom risks is increased through the system with the risk highest at Wilcannia (compared to Bourke and Brewarrina) and increasing for the period after 2010 (see figure below). The flow thresholds important for mixing pools to mitigate algal bloom risk are also associated with other positive outcomes, such as connectivity for fish movement between habitats.
- Salinity spikes (salinity going over 5,000 µS/cm) observed during periods of low flow for the reach between Bourke and Tilpa, as a result of saline groundwater inflows. This salinity is known to exceed the tolerance for many plants and invertebrates.
- Longer periods between opportunities for fish to move between habitats and breed, especially for smaller fish that generally live for less than five years.



In order to sustain the ecological health of the Barwon-Darling River, there is a need to minimise the duration of longer very low and no-flow periods that are inconsistent with the natural hydrology of the Barwon-Darling river system. The aquatic biota have evolved to the boom and bust variability of the river but, extended dry periods beyond those that would have occurred naturally, test the resilience of the ecosystem.

It is recommended that alternative water sharing arrangements and rules should be investigated to implement event based management that limits no and very low flow periods from exceeding 60-80 days at Bourke and 120-150 days at Wilcannia, especially in spring-summer. Investigation of management strategies should not be limited to the main Barwon-Darling channel. As the development of upstream catchments has an effect on flows in the Barwon-Darling, examination of the management rules in these areas could improve outcomes for the Barwon-Darling and provide a better understanding of system-wide linkages between catchments.

This is based on multiple lines of information including: the maximum no-flow periods in the without development model; minimising salinity issues for the reach between Bourke and Tilpa, providing flows in the hotter months to supress algal blooms; providing fish with regular opportunities to access habitats and complete life-cycle stages; and providing water downstream for critical human water needs. For example, the weir at Wilcannia retains only ~120 days of town water supply following the start of a no-flow period after which time there is a reliance on groundwater.

The volume of water required to provide longitudinal connectivity along the length of the Barwon-Darling River is dependent on a range of factors with the dryness of the preceding period, source of tributary inflow and level of take by consumptive users' primary drivers. Analysis of observed flow events shows there is a very high likelihood of system scale longitudinal connectivity, through to Wilcannia, with an event volume of at least 20 GL at Bourke. This flow event would generally take the shape of a magnitude of 500 ML/d for at least 14 days, with 20 days providing more certainty. This flow would also be sufficient to mix and freshen pools and improve water quality. The volume needed would reduce under wetter antecedent conditions, and where a sequence of smaller events collectively build the volume required for connectivity.

How does this work relate to the Long-term environmental Watering Plan?

The NSW Office of Environment and Heritage is currently developing the Long-term Environmental Watering Plan (LTWP) for the Barwon-Darling river system. The LTWP is due to be completed in 2019. Ultimately, this plan will set the environmental objectives and water requirements used during the NSW Government's development of the water resource plan and for guiding decisions by environmental water holders regarding use of environmental water.

This report is expected to provide early support to the LTWP development. It is also expected that the environmental flow requirements described in the LTWP will be consistent with those described in this document as the same scientific literature base and site-specific eco-hydrology information is largely being used. The LTWP will be the enduring plan for managing environmental water in the Barwon-Darling river system at the regional scale. The environmental water requirements in the LTWP will supersede the requirements in this report once available.

What other work is being done to look at the protection of environmental flows?

The MDBA has undertaken hydrological analysis to investigate the historical behaviour of low flows (≤ 2000 ML/d) along the Barwon-Darling river system between 1990 and 2017 (MDBA, 2017b). The aim was to assess any observable changes to flow behaviour over this time period. The work produced a comprehensive catalogue of more than two thousand individual flow events and provides a robust dataset with which to undertake the hydrological investigation.

Both the hydrology report and this report provide lines of evidence as part of a larger ongoing work program to improve the protection of individual low flows for environmental outcomes, while still ensuring other water users along the river have access to flows including basic rights and improved water quality.

This work will inform the considerations of the Taskforce established by NSW government to address the Toolkit Measures, and the subsequent recommendations of the Matthews Report into water management and compliance. The Taskforce will provide recommendations to the NSW Minister on the most effective way to protect environmental water in the short and longer term within 90 days.

The Darling River at Louth, May 2016 (river peaked at 1,000 ML/d on 9 May (met 350 ML/d for 5 days but the flow was less than the specified 7-14 day duration for the environmental flow requirement).

Introduction

This report is a synthesis of existing information and literature describing the environmental water requirements for low flows in the Barwon-Darling river system between Mungindi and Wilcannia (see Figure 1). For the purpose of this report, low flows have been defined as events that are typically between 350-2,000 ML/d across the Barwon-Darling river system. To place this definition of low flows into context, commence to pump thresholds for licences, specified within the Barwon-Darling Water Sharing Plan, are generally below within this flow range.

The entire flow regime is important when describing the environmental water requirements for a river or catchment. The Barwon-Darling river system is unregulated and highly variable, including events that pulse through the river, separated by periods of low to no-flow and sporadic flooding. Each flow component (no-flow, small freshes, large freshes, bank-full and overbank) is important for the ecosystem to function. These components collectively make up the flow regime that the ecology has adapted to and relies upon.

The MDBA has previously assessed the environmental water requirements of the Barwon-Darling river system and developed a suite of site-specific flow indicators, as part of the Northern Basin Review (MDBA, 2016a). These site-specific flow indicators describe the types of flows that are ecologically important during average to wetter conditions and their focus on larger in-channel and overbank aspects of the flow regime (>6,000 ML/d) was deliberate to assist with determining the long-term average amount of water required by the environment as an input to setting Sustainable Diversion Limits.

This work complements, and is consistent with, the previous assessment. The synthesis of existing information on low flows within this document has two objectives. Firstly, to describe the types of flows that are ecologically important during drier conditions. Secondly, to inform consideration of mechanisms to better protect environmental flows as part of managing water within the Sustainable Diversion Limit.

Low flow events are also what the Commonwealth Environmental Water Holder currently has capacity to deliver and actively manage with the portfolio of water recovered for the environment. This has been demonstrated on a number of occasions in recent years, with the Gwydir River release in spring 2014 a good example (see Case study at Appendix B). Protection of Commonwealth environmental water is important to ensure it meets is intended purpose and flows through the river system.

The purpose of this work is to synthesise the available scientific literature to describe environmental flow requirements that represent the ecological needs for low flows in the Barwon-Darling. These requirements have been assessed using modelled and observed flow data to understand how they perform and understand trends over time that can be used to inform water management.

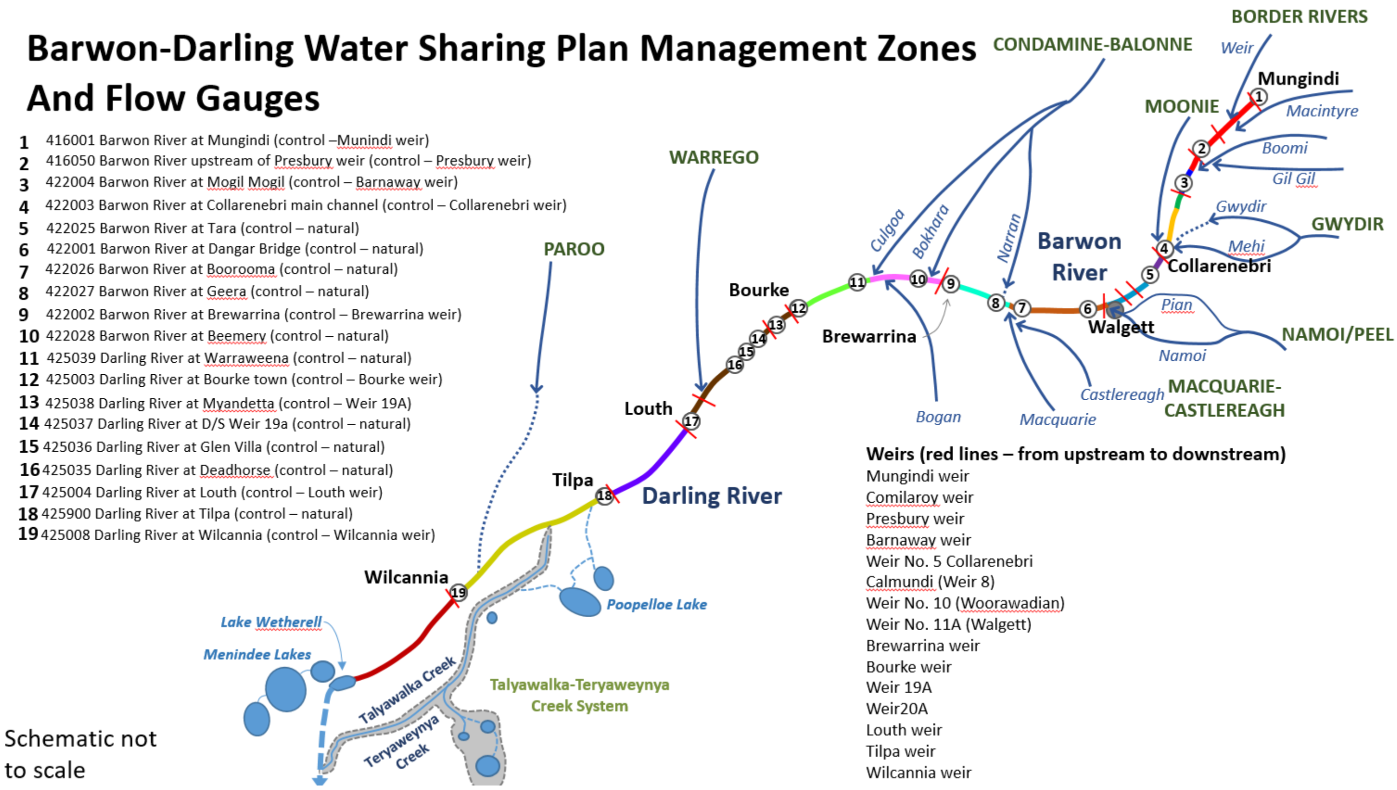


Figure 1: The Barwon-Darling system showing tributaries, key reaches (coloured sections), their associated upstream and downstream gauges and the location of the 15 weirs along the river.

Barwon-Darling Context

The Barwon–Darling river system, in north-western New South Wales, takes in the Barwon River from upstream of Mungindi at the confluence of the Macintyre and Weir rivers, to where the Barwon meets the Culgoa River. At this point the river channel becomes the Darling River and the Barwon–Darling system extends downstream to the Menindee Lakes.

The catchment only generates about 2.8% of the flow in the Basin, however much more water flows through the system, 99% of which is generated in upstream catchments. The Barwon–Darling is unregulated, except for the low-level weirs near townships, but many of the tributaries of the system are highly regulated.

The Barwon River flows south-west through a relatively narrow floodplain with a tightly meandering channel and a highly-variable flow pattern and capacity. Capacity is increased downstream of Collarenebri, after the Little Weir, Boomi, Moonie, Gwydir and Mehi rivers have joined the Barwon.

After Collarenebri, the Barwon River continues south-west, and is joined by more creeks and rivers. Beyond Walgett the river turns in a westerly direction and flows unrestricted across alluvial plains. It becomes less sinuous but there are many anabranches and effluent channels which split and re-join the major channel.

The Darling River flows south-west within a deeply incised channel towards Wilcannia. Below Wilcannia the Darling reaches the Menindee Lakes, at the artificial storage of Lake Wetherell. Beyond this point the catchment is the Lower Darling.

The highly variable flows in the Barwon–Darling are driven by tributaries carrying water from the many catchments in northern New South Wales and southern Queensland, including the Paroo, Warrego, Condamine–Balonne rivers and Moonie in the north and west, and the Border Rivers, Gwydir, Namoi, Macquarie–Castlereagh and Bogan Rivers to the east and south. Some of these waterways only reach the Barwon–Darling after major floods.

The Barwon River starts at an elevation of about 200 m, at the confluence of the Macintyre and Weir rivers, and flows about 700 km over a low gradient to an elevation of 110 m at its confluence with the Culgoa River. From this point, the Darling River flows another 900 km to the Menindee Lakes, at which point the elevation is less than 100 m.

The Barwon–Darling region has a semi-arid climate and rainfall is low throughout the year, but peaks in summer, with an annual average of 330 mm.

Environmental importance of the Barwon-Darling

The Barwon–Darling corridor connects the rivers, lakes and wetlands in the northern Basin; and then provides a connection to the southern Basin through the Lower Darling River. The river provides refuge habitat during dry periods and travel pathways for aquatic biota between rivers, especially for fish that are known to move long distances such as golden perch (MDBA, 2014). There are many billabongs and lagoons along the Barwon–Darling, as well as lakes and wetlands on the floodplains, which provide major bird refuges and breeding sites.

The Barwon–Darling is recognised for supporting populations of native fish, which are excellent indicators of the health of rives and their catchments. It is an ecologically significant area, featuring wetlands including the Wongalara, Woytchugga and Poopelloe lakes, the Acres Billabong and several deflation basin wetlands (MDBA, 2016a). There is also the nationally important wetland area Talyawalka Anabranch and Teryawynia Creek, near the southern boundary of the Barwon–Darling region, located between Wilcannia and Menindee on the Darling Riverine Plains.

A wide variety of ecosystems and a number of fish species are supported by the river channel and riparian habitats. Vulnerable or endangered species such as the olive perchlet, Murray cod, silver perch and freshwater catfish, have been recorded amongst the 15 native species of fish known to inhabit the Barwon-Darling (NSW DPI, 2015). The Darling River Endangered Ecological Community listing under NSW legislation acknowledges the threat posed to native fish and aquatic invertebrates along the length of the Barwon-Darling River from Mungindi to Wentworth. Increasing numbers of carp have had a significant impact on native fish, however there are healthy communities of turtles, mussels, shrimp and other aquatic species. Flora species found in the catchment include river red gum, black box, river cooba, coolibah and lignum, which have varying levels of water dependence.

In the Sustainable Rivers Audit 2 released in 2012, the study area of the Darling River valley included the narrow upper valley of the Barwon–Darling river system, through to the wide floodplain regions of the mid and lower Darling River (Davies et.al. 2012). The audit reported that the overall ecosystem health of the Darling valley was poor. The fish community had lost half of its native species richness, and was rated poor in the lower and middle zones and moderate in the upper zone; while the macroinvertebrates were rated poor overall. Riverine vegetation in the region is notable for being in near-reference condition across the zones, with each being rated in good condition. There was little evidence of the main vegetation groups being cleared or damaged, however there were some modifications noted near the main river channels. The physical form of the river system was rated in moderate condition, but there was accelerated floodplain sedimentation in the upper zone and channel enlargements in the lower zone, since European settlement. The overall rating of hydrology of the Darling was moderate, as flow volumes, seasonality and variability has changed markedly in the main-stem of the river system.

History of water sharing arrangements in the Barwon-Darling

Water sharing pre 2012 Water Sharing Plan

As an early response to the impact of development (through dams, weirs and diversions through the northern basin), the Interim Unregulated Flow Management Plan for the North West was released in 1992 (NSW, 2012). This plan coincided with the massive algal bloom in the Barwon-Darling in the summer of 1991 which covered over 1,000 km of the river (Donnelly et al. 1997).

The primary objective of the interim plan was to better manage unregulated flows to provide water quality and fish passage outcomes for the Barwon-Darling (NSW, 2012). The interim plan established: target flows at key locations along the Barwon-Darling, priorities for river health and riparian flows, and a framework for sharing unregulated flows between irrigators.

Although the interim plan has been in place since 1992, difficulties with flow forecast across such a large geographical area with varying antecedent conditions has limited the application of the rules to protect flows to achieve the triggers in the plan (NSW, 2012).

The rules within the interim plan should be reviewed to ensure they can be implemented in a robust and transparent manner, under the water sharing plan. This includes considering better defining how periods of restrictions are applied, considering if the river operator is better placed to make decisions on temporary restrictions, considering if new or different rules are needed based on the latest information, and considering extending the restrictions to include A Class licences.

It was recognised in the mid-1990s that there had been a decrease in the annual and daily volumes of flow along the Barwon-Darling river system as a result of development in the Northern Basin. Impacts for the Barwon-Darling included increased rates of flood recession and erosion (related to pumping), decreases in the frequency of small flow pulses and marked changes in the frequency of large freshes and flooding flows (Thoms et al. 1996).

A panel of independent scientists were convened to assess the environmental condition of the Barwon-Darling between Mungindi and Menindee in 1995 and observed evidence of habitat degradation (Thoms et al. 1996). The panel considered the degradation to be particularly severe in the reaches between Collarenebri to Walgett and Bourke to Louth and less severe between Louth and Wilcannia and Brewarrina and Bourke. In all cases, in-channel habitat availability and access to important food sources was found to have declined due to hydrological changes.

As part of the scientific panel's deliberations, it was identified that water management actions were needed to protect critical elements of low flows important for in-stream ecosystem health. The panel considered these critical low flows to be ≤ 2,000 ML/d across the Barwon-Darling.

In response, the NSW government developed flow rules between 1998 and 2000 to address the river health needs in the Barwon-Darling, with a principle of not having an impact on water users exceeding 10% of their average annual diversions (NSW, 2012).

The Barwon-Darling environmental flow rules were based on the independent scientific panel's assessment into the impact of tributary and Barwon-Darling development on flows and water dependent environmental assets and ecosystem processes (Thoms et al. 1996).

The panel recommended that flows equal to or less than 10% of the river channel capacity were essential to maintain the river environment. Estimates based on cross sectional area and flow data indicate that this equates to flow in the 50th to 60th percentile range of without development flows throughout the river. It was proposed to increase pumping thresholds to the 60 percentile for B class and the 50 percentile for C class licences, thus meeting this recommendation while preserving the distinction between these classes.

It should be noted that A Class commence to pump thresholds fall well short of the base environmental flow (that is the 60th percentile). However, it was assumed that the effect of this class has a comparatively negligible impact on the river system because the volume and pattern of use of A Class licences was relatively small at this particular time (1998) and in the absence of subsequent rule changes.

Commence to pump thresholds were finalised in 2000 when new gauges were installed and final thresholds were agreed for different reaches. More information on the process to establish commence to pump rules, and the rules, can be found in the Background Document to the Barwon-Darling Water Sharing Plan (NSW, 2012).

Barwon-Darling Water Sharing Plan, 2012

The Water Sharing Plan for the Barwon-Darling Unregulated and Alluvial Water Sources commenced on 4 October 2012. The Water Sharing Plan includes rules for protecting the environment, water extractions, managing licence holders' water accounts and water trading in the area. It contains the rules for the management of the surface water and groundwater sources.

The Water Sharing Plan was made under NSW law prior to the finalisation of the Basin Plan 2012 (Cth) (Basin Plan) in 2012, and was considered an interim water resource plan under section 242 of the Water Act 2007 (Cth) (Water Act). The interim status expired in October 2017.

In September 2017 the MDBA reviewed amendments made to the water sharing plan since it was first made in 2012 and advised the Department of Agriculture and Water Resources that, given there had been no substantive changes since the plan commenced under NSW law, the amended plan meet the 'no less consistent' test in the Water Act 2007 for it to be recognised as a transitional plan.

A transitional plan is not required to be fully consistent with the Basin Plan, however NSW must deliver the Barwon-Darling Water Resource Plan, incorporating its Basin Plan commitments, by 2019. The MDBA will assess the Water Resource Plan and make a recommendation to the Minister on whether it should be accredited.

A State Interagency Panel, State Groundwater Panel and the Barwon-Darling Interagency Regional Panel were involved in the development of the Water Sharing Plan. Activities in the development of the plan included: targeted consultation in November 2010, and a public exhibition for the draft plan (initially from 10-18 October 2011, and then extended until 18 December 2011).

The MDBA was consulted by NSW during the preparation of the Water Sharing Plan. The MDBA made no comment at that time because the Basin Plan was not in effect so there was no legislative basis on which comment could be provided. There were changes between the draft plan and what was included the final Water Sharing Plan that were not shared publically prior to commencement. Some of these are detailed below.

The key rule additions and/or changes between the draft and final Water Sharing Plan included:

- The final Water Sharing Plan (2012) removed the Total Daily Extraction Limits that were proposed in the draft plan, provided no ability for the Minister to impose restrictions on Class A Licence extractions for public interest purposes, provided unlimited carryover of account water at the end of each water year, provided power for the Minister to grant pumping exemptions for A and B Class licences when flows are imminent, provided opportunity for extraction of up to 300% of access entitlements, provided no detailed requirement for the protection of environmental water, introduced water trading arrangements and defined the commence to pump rules (as per the rules previously in place).

The most contentious aspect of the Water Sharing Plan was that the changes to the extraction rules meant that there was increased opportunities to legally extract water at low flows. Other potential implications of the rules under the Water Sharing Plan that were raised included: while the Minister has the power to impose extraction restrictions this is a discretionary power; if unchecked, the provisions for unlimited carryover and 300% take in any year could lead to breaching of the Cap/SDL; and as a result of enabling trade in the region there has been a concentration of licences.

Various submissions to the Northern Basin Review in 2016 and the advice of the Northern Basin Advisory Panel provided commentary about the consequences of operation of the rules in the Water Sharing Plan (MDBA, 2016b; NBAC, 2016).

Analysis of hydrological impacts

The development of water resources has modified flow regimes across the Murray-Darling Basin, including in the Barwon-Darling and its tributaries (MDBA, 2011; Sheldon et al. 2014).

Figure 2 shows a comparison between the observed flows at the Bourke gauge and modelled without development flows for a five year period in the 2000s (MDBA, 2016a). This example shows the hydrological changes in flow magnitude and variability following water resource development.

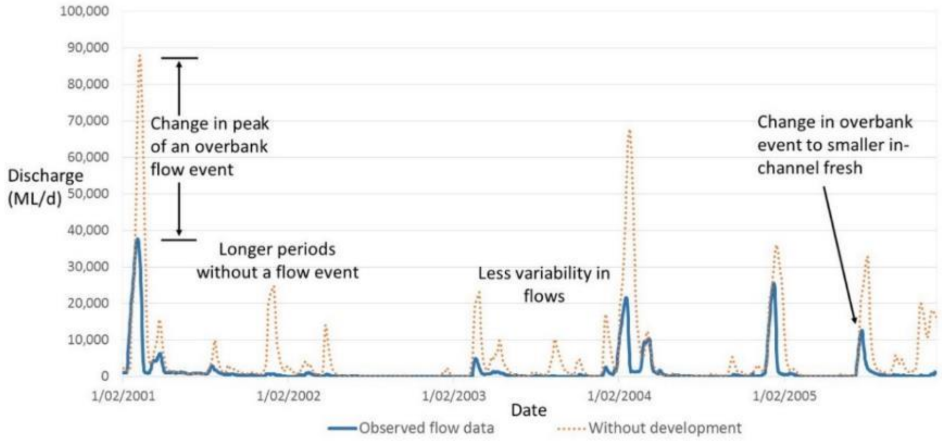


Figure 2: Comparison of observed and modelled without development flow data for a five year period at Bourke on the Darling River.

The impact of extraction, both in-situ and from upstream tributaries, on low flows in the Barwon-Darling is of highest significance for the first flow after a dry period as this event is critically important for the environment to break the dry spell. This is important to maintain habitats and refresh pools, improve water quality, provide conditions for fish and other animals to access key habitats and water riparian vegetation. This flow event is also important for the critical human water needs of the downstream communities that depend on the river.

However, there is acute pressure from competing demands, as irrigators also need access to water, under their licence rules, to support the businesses. In addition, the first flow of the year is often in spring/summer in the Barwon-Darling which aligns with the cotton growing season.

It is because of this vying for the finite volumes of available water during low flows that rules are required for the protection of environmental water to support the ecology and the downstream communities of the river system, in a way that still enables irrigators to access water.

To inform water management and the planning process, hydrologic models developed by Basin States are used to predict flow patterns under a variety of climatic conditions and policy settings. During Basin Plan development, the MDBA used these models to predict flows for the period 1895 – 2009 under different water sharing scenarios. Two key model scenarios have been developed; a without development scenario which represents pre-development conditions and a baseline scenario representing water sharing arrangements as they existed as at 30 June 2009.

Figure 3 shows the flow duration curve at Bourke for the without development and baseline scenario, as well as for gauged flows for the periods 1990/91 to 2016/17 and 1972/73 to 2016/17. The 1972/73 to 2016/17 period is the full history of near-continuous observed flow data available at Bourke. The difference between without development and the other lines shows the impact of development on different parts of the flow regime. This shows a very evident impact of water resource development across all elements of the flow regime, particularly for flow events of ≤ 2,000 ML/d and 80th percentile flows that is a commonly used metric to define base-flows.

Issues with the Barwon-Darling hydrology model providing an accurate representation of flow events, especially for low flows have been documented previously (CSIRO, 2008; Bewsher, 2016). At the about the 70th percentile flow there is a divergence between the observed and the

Baseline model flow exceedance curves, indicating that the model has trouble predicting low flows. This percentile represents a flow threshold of about 400 to 500 ML/d at Bourke.

Overall, the model is extremely valuable for exploring long-term water sharing options, and the associated impact on long-term flow behaviour, but it contains weaknesses in the representation of low flows — the is partly a result of the purpose of the model (i.e. a water resource model), but is also due to the uncertainty in observed data at the low end of the flow regime. This emphasises the need to supplement the model with other sources of information.

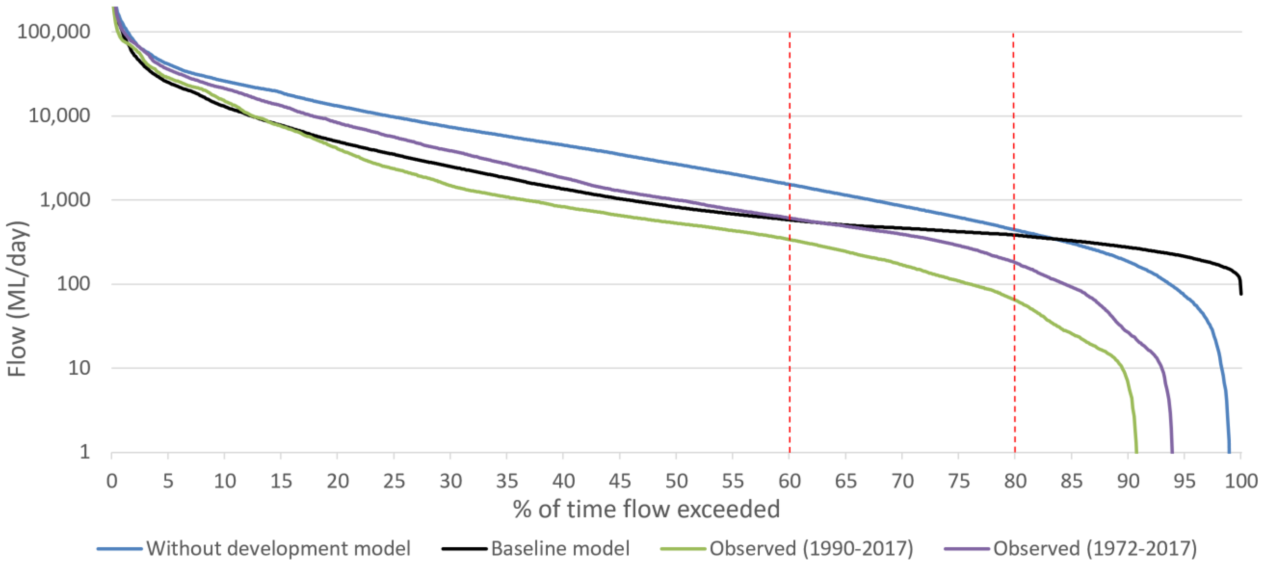


Figure 3: Flow duration curves at Bourke for the modelled without development and baseline scenarios (1895-2009), and observed flows for 1990-2017 and 1972-2017. The red lines represent B class pump threshold (60th percentile) and baseflows (80th percentile)

Connection to the Basin Plan environmental water planning framework

Since the making of the Basin Plan in 2012, the basin-wide environmental watering strategy has been developed (MDBA 2014). The strategy guides the planning and management of environmental water at a basin scale over the long term, so as to meet the environmental objectives under the Basin Plan.

Consistent with this strategy, states have developed, or are developing, regional long-term watering plans (LTWPs), which identify important environmental assets and ecosystem functions and their environmental watering requirements. The Barwon-Darling LTWP is being developed and is expected to be finalised in 2018. Ultimately, the LTWP will set the environmental objectives and water requirements for the NSW Government to use during development of water resource plan and to guide environmental water holders regarding use of environmental water.

This report is expected to provide early support to the LTWP. It should also be consistent, as the same base scientific literature and site-specific eco-hydrology information is largely being used. The LTWP will be the enduring plan for managing environmental water.

The environmental flow requirements developed for the Northern Basin Review and described in this report do not represent a prescription of what environmental flows must or should be delivered. Environmental water managers may however draw on this information when planning watering priorities and actions.

Ecological importance of low flows

This report focuses on the ecological importance of low flows (base-flows and small freshes) while also acknowledging that the other components of the flow regime (large freshes, bank-full and overbank flows) are an important part of a rivers environmental water requirements. It is the entire flow regime, over broad spatial and temporal scales, which influences the maintenance and improvement of ecosystem condition for the Barwon-Darling River (Puckridge et al. 1998).

The environmental water requirements for the Northern Basin Review describe larger in-channel freshes, bank-full and overbank flows for the Barwon-Darling (MDBA, 2016a). In addition, the Barwon-Darling LTWP being developed by the NSW government will establish objectives and environmental water requirements for the whole flow regime in the Barwon-Darling and for connectivity with other catchments.

As outlined previously, for the purposes of this report low flows have been defined as being generally ≤ 2,000 ML/d at key gauge locations across the river system. This definition is consistent with the assessment of low flows used in the independent scientific review of the Barwon-Darling in the mid-1990s (Thoms et al. 1996).

In addition, several sources have identified the 80th percentile flow as an ecologically significant threshold for base-flows in the Barwon-Darling (Sheldon, 2017; Thoms et al. 1996; NSW DPI, 2015). These flows under without development conditions are: 261 ML/d at Walgett, 346 ML/d at Brewarrina, 440 ML/d at Bourke, 401 ML/d at Louth and 361 ML/d at Wilcannia).

Figure 4 provides a range of photos that show low and no-flows at different points along the river.

Figure 4: Low flows on the Barwon-Darling. Clockwise from top left: u/s of Walgett gauge - 0 ML/d on 13 April 2016, Bourke weir - 647 ML/d on 19 January 2004, Louth Weir - 589 ML/d on 17 March 2006, d/s of Tilpa weir - 145 ML/d on 2 December 2004.

The ecological needs for low in-channel flows in the Barwon-Darling river system include:

- Maintaining populations of native fish and other aquatic biota (like mussels) by replenishing refuge pools and maintaining aquatic habitats; providing opportunities for movement between habitats; and supporting key ecosystem functions (including cycling of nutrients and provision of carbon for productive food webs);
- Supporting regular breeding, recruitment and dispersal of fish and other invertebrates with short life cycles to maintain populations and genetic diversity.
- Maintaining water quality through regular flushing of refuge pools to mitigate against issues such as algal blooms and salinity spikes in areas prone to high salinity groundwater inflows.
- Providing longitudinal connectivity through the Barwon-Darling river system and its tributaries to support the ecological needs above, maintain in-channel and riparian vegetation condition, and provide natural cues for flow responsive fish and other aquatic biota.

In addition to the ecological outcomes, low flows also provide water for downstream communities to ensure reliable and good quality water for critical human water needs (such as town water and stock and domestic uses), and water to support cultural and recreational values.

Figure 5 provides a cross-section conceptual diagram of the river system with the main flow components (no-flow, base-flows, freshes, bank-full flows and overbank flows) and the physical features of the river identified. No flows, base-flows and small in-channel freshes are all within scope in the definition of low flows adopted in this report. The following section provides information on the ecological role and importance of each of these flow components.

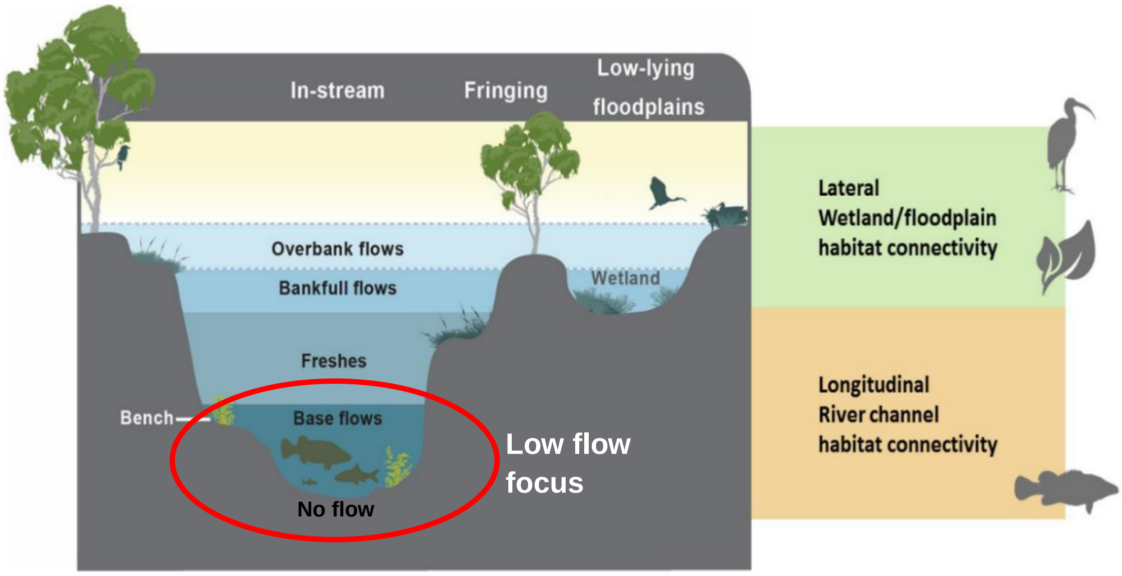


Figure 5: An illustrative river cross-section showing flow regime components.

Base-flows are an important component of the flow regime as they maintain aquatic habitat for fish, plants and invertebrates. Base-flows are small magnitude, long duration flow events that support refuge pools during dry periods and contribute to nutrient dilution during wet periods or after a flood event. The provision of these flows also enables longitudinal dispersal and provides conditions that stimulate spawning and support the recruitment of many native fish species (Rolls et al. 2013). Base-flows following fish spawning can assist with the survivorship of juveniles by facilitating increased productivity and food supply, assisting with dispersal of larvae and providing juveniles with access to appropriate nursery habitat (NSW DPI, 2015; Stuart and Sharp, 2017).

In-channel freshes are small-to-medium flow events which inundate benches or small anabranches, but stay in the river channel. They are relatively short in duration (i.e. a few days to a month). These events increase longitudinal connectivity, improve water quality in previously disconnected reaches, 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—important sites for fish spawning events and macroinvertebrate assemblages (Boys and Thoms, 2006). The increased turbidity and mixing can reduce the frequency and severity of algal blooms by preventing the stratification of pools (Mitrovic et al. 2006). These flows occur every year (to varying magnitudes) in the Barwon-Darling with multiple freshes a normal aspect of the hydrology which is driven by the timing of different tributary inflows.

No flows or cease to flow (CTF) periods are a normal and important aspect of the flow regime in the Barwon-Darling. No-flow periods allow the development of a diversity of biofilms and aquatic plants, and periods of stress that promote resilience and can control the population of invasive species such as carp that are not as well adapted to the highly variable flow regime of Australia's semi-arid rivers. Studies from other catchments have shown short-term increases in the abundance and richness of invertebrates and fish towards the start of a no-flow period (Rolls et al. 2012; Stubbington et al. 2011; Dewson et al. 2007). However, as periods of no flow or very low flows increase, conditions become worse as aquatic biota is forced into contracting refugia often with reducing water quality (Rolls et al. 2012).

Rolls et al. (2012) presented a conceptual model that describes four principles for the importance of low flows that generally apply to riverine ecosystems:

- Principle 1: Low flows control the extent of physical aquatic habitat, thereby influencing composition and diversity of biota, trophic structure and carrying capacity;
- Principle 2: Low flows mediate changes in habitat conditions, which in turn, drive patterns in the distribution and recruitment of biota;
- Principle 3: Low flows affect the sources and exchange of energy in riverine ecosystems, thereby affecting ecosystem production and biotic composition; and
- Principle 4: Low flows restrict connectivity and diversity of habitat, increases the importance of refugia, and drives multiscale patterns in biotic diversity.

Figure 6 provides this conceptual model which summaries the interaction between low flows and ecological responses within habitats and between habitats (i.e. refuge pools). These interactions do not operate in isolation, and many of the ecological consequences of changes to low flows are likely to overlap and occur simultaneously, resulting in synergistic and complex effects (Rolls et al. 2012). The ecological consequence of alterations to low flow include reduced resilience of the aquatic community and a transition to more generalist species with reduced diversity and abundance of species (Rolls et al. 2012).

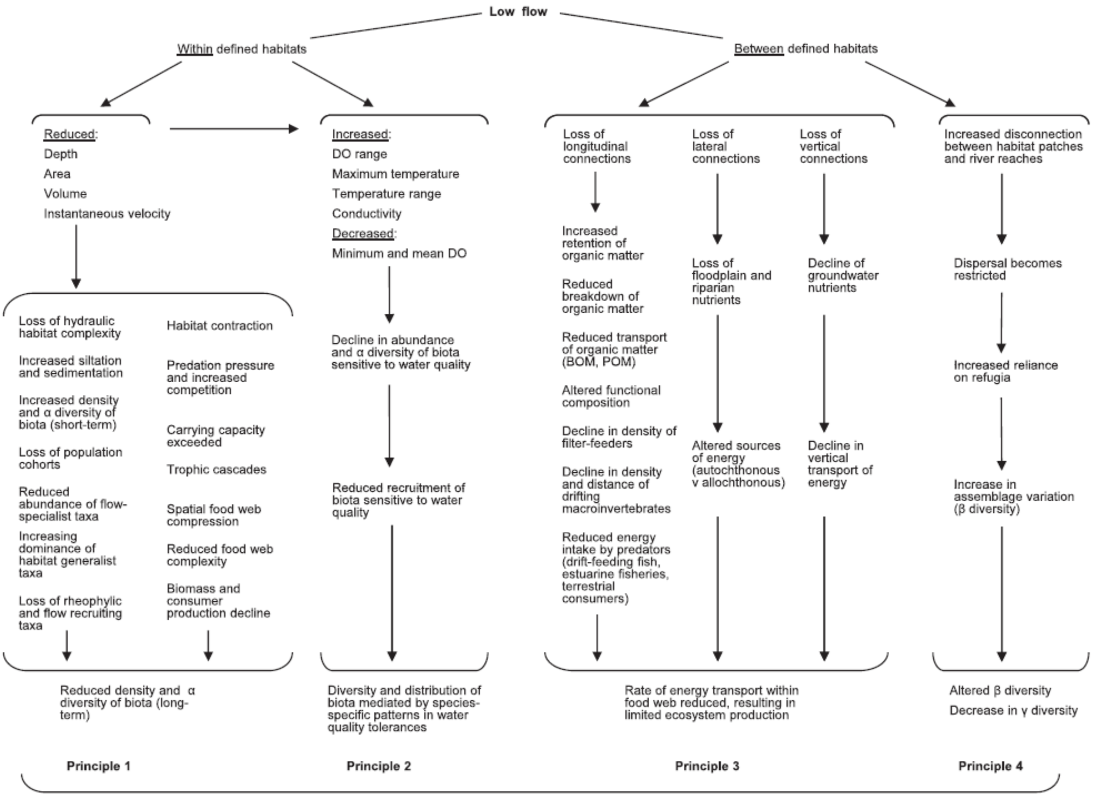


Figure 6: Four principles outlining the links between low flow processes and patterns in riverine ecosystems. DO = dissolved oxygen, BOM = benthic organic matter, POM = particulate organic matter. (Taken from Rolls et al., 2012).

In-stream habitat features

The Barwon-Darling river system contains a variety of in-stream habitat types, including deep pools, snags and benches which are all important for fish and other aquatic biota (Figure 7).

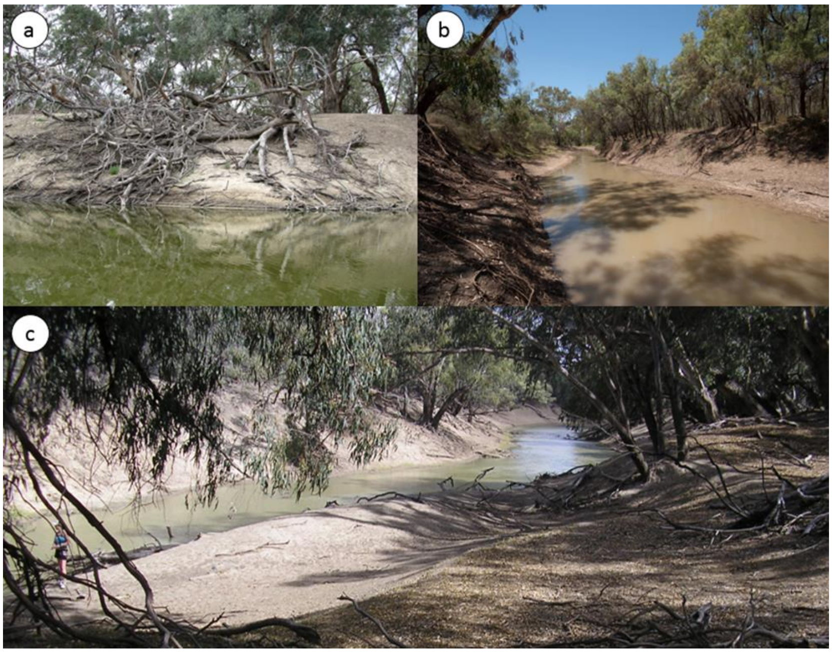


Figure 7: Examples of snags (a), pools (b) and benches (c) in the Barwon Darling River system.

Refuge pools

The Barwon-Darling river system naturally experiences no-flow periods where the river contracts to a series of disconnected pools. These pools are large (and supplemented by weirs constructed along the river), and provide refuges which are critical for the maintenance of healthy aquatic biota (McNeil et al. 2013). Using the pools, fish and other aquatic biota can recolonise other habitat areas once flow returns to the system.

DSITI (2015) assessed the persistence of waterholes in the Lower Balonne and Barwon-Darling based on a combination of: analysing Landsat remote sensing imagery (since 1988) to understand water presence at the landscape scale; and developing persistence models for representative waterholes for more detailed modelling of different flow regime scenarios.

A finding of DSITI (2015) was that the waterholes in the Barwon-Darling river system are highly persistent due to a combination of weir pools and very deep waterholes (some of which are deeper than 8 metres). The modelling of three representative waterholes suggested that they would have persistence times of more than 1,000 days which is much longer than the periods of no-flow under both pre-development conditions and current arrangements. For example the longest observed no flow spell for Bourke was 199 days in 2007. The exception to this was the Tilpa reach (roughly between Louth and Tilpa) which was observed to run dry twice during the Landsat record, after no-flow periods of 176 and 182 days at Tilpa. Knowledge gaps identified from DSITI (2015) were changes in habitat quality during long no-flow periods and the influence of pumping on pools.

In a parallel project, NSW DPI (2015) mapped pools and identified over 1,000 that had a depth greater than 3.5 metres between Walgett and Wilcannia under low flow conditions (Table 1). Roughly half the pools were above Bourke and half below. The average depth of the pools was between 4.5 m and 5.1 m. This analysis did not distinguish between natural and weir pools.

Table 1: Number, surface area, depth and volume of refuge pools recorded between Walgett and Wilcannia (source: NSW DPI 2015)

Zone	Zone Length (km's)	Total number	Total surface area (Ha)	Mean depth (m)	Average Volume (ML)
Walgett - Brewarrina	279	297	51.5	5.1	8.8
Brewarrina - Bourke	207	216	55.9	4.5	11.7
Bourke - Tilpa	355	374	157	4.7	19.7
Tilpa - Wilcannia	275	182	65.1	4.5	16.1

The zone between Bourke and Tilpa, had the greatest number of refuge pools overall and also the greatest total surface area (Table 1). Interestingly this zone also had the greatest number of snags (Table 2). The zone between Walgett and Brewarrina also contained a large number of refuge pools, however these were relatively small pools, with pools in this zone containing the lowest total surface area and average volume.

Flow events across gauges at Walgett and downstream will enhance local connectivity and water quality for the 1,116 refuge pools identified by NSW DPI (2015) within these sections of river.

Snags

Snags are important habitat in the Barwon-Darling, providing shelter and spawning sites for several native fish species (O'Connor, 1992; Lake, 1995; Crook and Robertson, 1999; NSW DPI, 2007; Koehn and Nichol, 2014). There is a strong association between snags and fish species such as golden perch and Murray cod in the Barwon-Darling river system (Boys, 2011). As snags break down they provide food for benthic algae, invertebrates and microorganisms that form a large part of the food web for a range of aquatic species (Treadwell, 1999; NSW DPI, 2007).

NSW DPI (2015) mapped snags and identified around 48,000 snags between Walgett and Wilcannia. As part of their analysis, it was found that there was a lower snag loading (expressed as the number of snags/km) in the zone between Tilpa and Wilcannia. Overall the snag loading across the 4 zones (Walgett-Brewarrina, Brewarrina – Bourke, Bourke - Tilpa and Tilpa – Wilcannia) was found to be 43 snags/km (Table 2). This falls just below the suggested ideal loading for this type of river of 47 snags per kilometre (Townsend, 2016), suggesting that this important aquatic habitat feature is functioning well in the Barwon-Darling. But further analysis of the data showed a severe lack of the complex snags that fish prefer. This type of wood only has a loading of 17 snags per kilometre, falling well below the ideal number.

Table 2: Number and distribution of snags recorded between Walgett and Wilcannia

Zone	Zone length (km's)	Total number	Loading/Distribution (snags/km)	Proportion of snags located outside of weir pools
Walgett - Brewarrina	279	12,566	45	63%
Brewarrina - Bourke	207	9,324	45	53%
Bourke - Tilpa	355	15,999	45	59%
Tilpa - Wilcannia	275	10,450	38	65%

NSW DPI (2015) also analysed the relationship between snag inundation and flow in four zones. To enhance the accuracy of the analysis, the flow/inundation relationships were based on the 29,000 snags (approximately 60% of all snags) located outside of weir pools (Figure 8). Of the snags located outside of weir pools between Walgett and Wilcannia, a between 20 and 45% remain inundated under no and low flow conditions. Given the large number of refuge pools identified between Walgett and Wilcannia (1,116) it is likely that these snags are predominantly located in refuge pools. Snags located in refuge pools and the lower sections of the channel provide native fish with access to important habitat during dry periods.

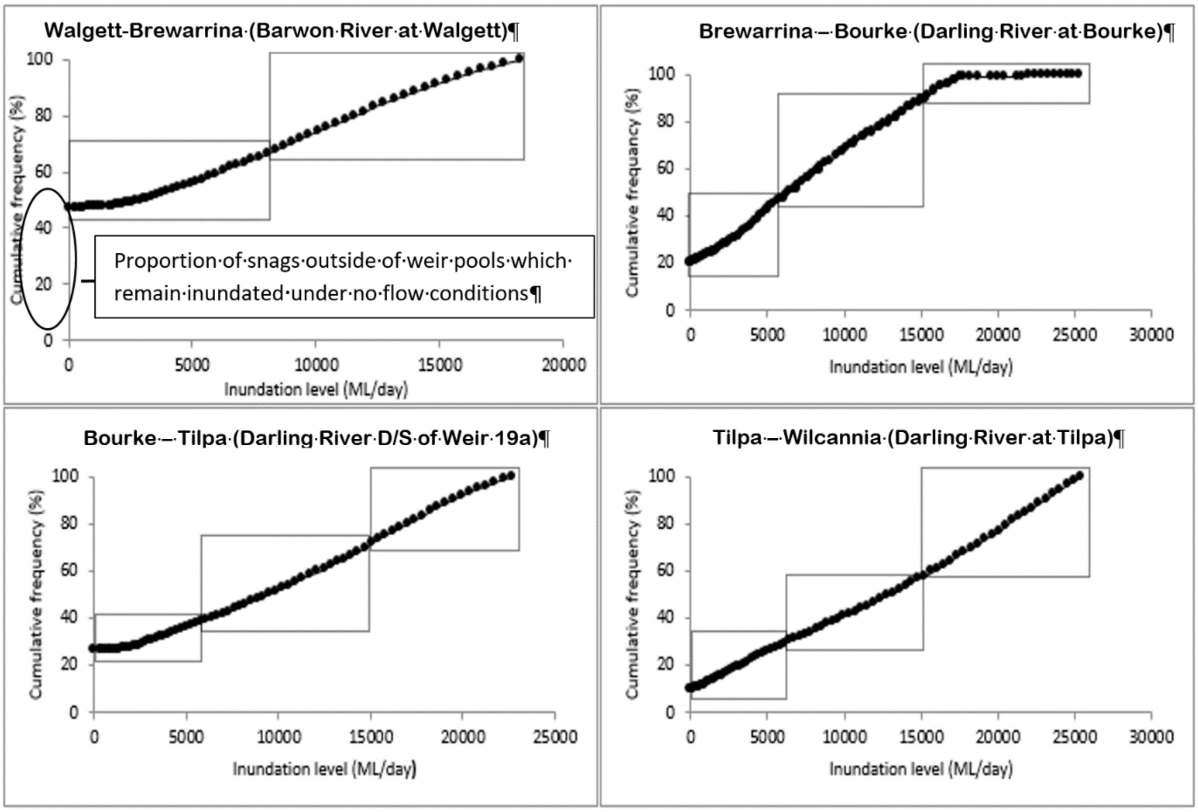


Figure 8: Relationship between snag inundation and flow (flow components represented by boxes moving left to right: small pulse, large pulse and bank-full).

Flows of 500 ML/d provide limited additional inundation of snags compared to no flow conditions but do enhance connectivity so fish can move between pools. At a threshold of 2,000 ML/d, there is about a 5% increase in snags inundated (as compared to no flow conditions).

While there have been few studies looking at the direct effect of in-channel flows on macroinvertebrates in the Barwon-Darling, Sheldon and Walker (1998) found the diversity and abundance of macroinvertebrates outside of weir pools was highest on snag habitats, with the highest diversity and abundance in weir pools occurring in submerged vegetation. There is also evidence from other dryland rivers in Australia that an increase in the abundance of macroinvertebrates is linked to flow pulses (Marshall et al. 2006). Increases in macroinvertebrates provides an important food source for fish and other higher order animals.

Benches

In-channel benches are relatively flat sections within the main channel that accumulate debris (such as leaf litter) which builds up over time and provide a source of carbon to the river when the bench is inundated. Benches also provide different and increased habitat and hydrodynamic diversity for fish and other aquatic animals. Benches play an important role in primary production which is the driver for the entire aquatic food web (Southwell, 2008).

As part of their work, NSW DPI (2015) analysed the relationship between bench inundation and flow for the approximately 600 benches (81% of all benches) located outside of weir pools (Figure 9). The Brewarrina to Bourke, and the Tilpa to Wilcannia zones contain the largest area of benches with inundation of benches in these two zones commencing at much lower flows. In these zones, flows of 500 ML/d inundate between 5 -20 % of the benches outside of weir pools.

For a flow of 2,000 ML/d inundation of benches increases to between 10 - 60 % of the benches outside of weir pools.

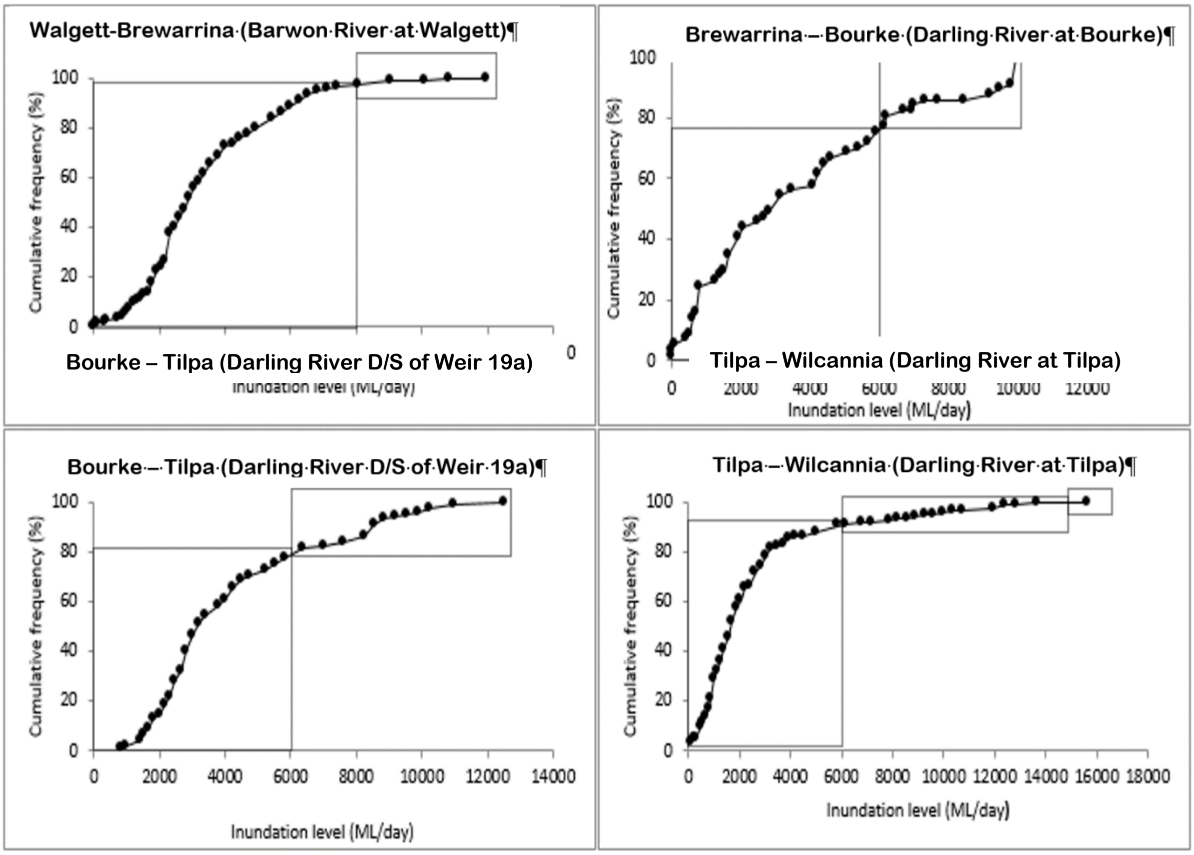


Figure 9: Relationship between bench inundation and flow (flow components represented by boxes moving left to right: small pulse, large pulse and bankfull)

Fish community of the Barwon-Darling

The extensive range of in-channel and floodplain habitats in the Barwon–Darling river system supports a diverse assemblage of 15 native fish species, as well as other important native aquatic fauna. NSW DPI (2015) report that bony bream appeared to be the most abundant native species between Walgett and Wilcannia with spangled perch and golden perch also common.

Other species known to occur in the river zones between Walgett and Wilcannia, include carp gudgeon, Murray-Darling rainbowfish (predominantly in lower end of the zone between Walgett to Brewarrina), Murray cod (predominantly in the zone between Brewarrina and Bourke and particularly near Barwon-Darling junction), and Hyrtl’s tandan (predominantly in the zone between Bourke and Tilpa). While rare within the Walgett to Wilcannia sections of the system, unspecked hardyhead has an isolated and patchy distribution upstream of Bourke.

In addition, a number of fish species expected to be found between Walgett and Wilcannia are listed as threatened under Commonwealth or NSW legislation (Table 3).

The fish community status in the NSW section of the Northern Basin is shown in Figure 10. Recent analysis of freshwater fish research data for NSW (completed as part of the Fish Community Status Project) has consolidated data collected over twenty years of biological surveys. This data has been combined with spatial distribution models to provide a delineation and spatial recognition of the condition of fish communities and threatened species across NSW (NSW DPI, 2016). The overall Fish Community Status was derived from the three condition indicators of Expectedness, Nativeness and Recruitment, with outcomes partitioned into five equal bands to rate the condition of the fish community; Very Good, Good, Moderate, Poor, or Very Poor. As can be seen in Figure 10 the fish community status for the Barwon-Darling is generally moderate to good. Figure 10 also identifies the carp hotspots for recruitment.

Table 3: Threatened fish species expected to be found in the Barwon-Darling system

Species	Status	Legislation
Purple spotted gudgeon	Endangered	NSW Fisheries Management Act 1994
Freshwater catfish of the Murray–Darling Basin	Endangered	NSW Fisheries Management Act 1994
Western population of olive perchlet	Endangered	NSW Fisheries Management Act 1994
Silver perch	Vulnerable Critically endangered	NSW Fisheries Management Act 1994 Environment Protection and Biodiversity Conservation Act 1999
Murray cod	Vulnerable	Environment Protection and Biodiversity Conservation Act 1999

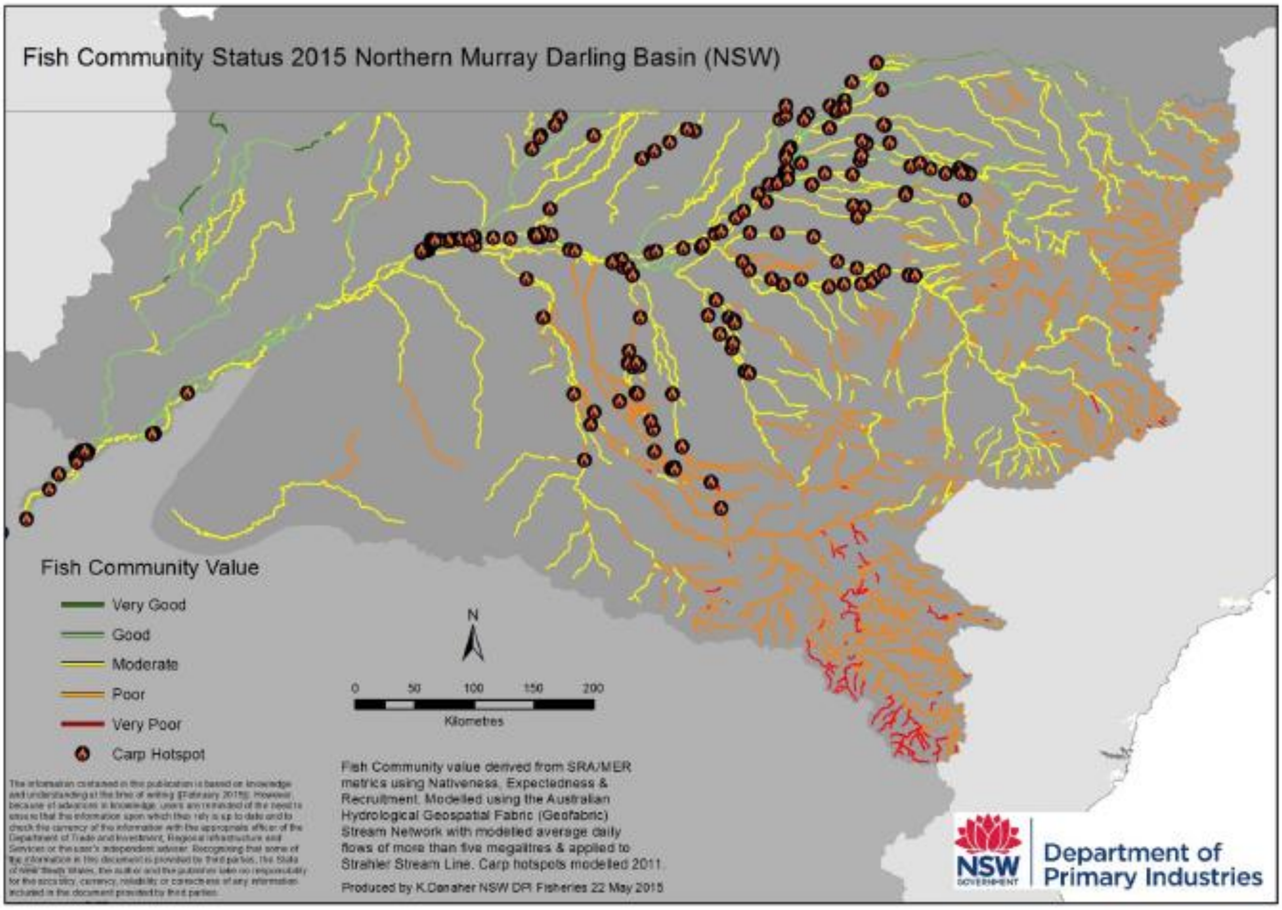


Figure 10: Fish community status for the NSW section of the Northern Basin, highlighting condition of fish communities and carp hotspots.

Golden Perch

The Barwon-Darling River has been shown to be a significant source for Basin populations of golden perch (Zampatti et al. 2015; Koster et al. 2017; Thiem et al. 2017). Research from the past five years as described in Stuart and Sharp (2017) has rewritten the conceptual model for the life-history of golden perch in the Northern Basin. This revised conceptual model highlights that previous life-history models underestimated the distance which spawned golden perch larvae drift downstream. This new understanding is based on a detailed review of age observations of golden perch and monitoring of larvae drifting at Walgett in late 2016 following a significant spawning event. Analysis of this data suggests that spawning had taken place in the Barwon or even Macintyre system with larvae drifting up to hundreds of kilometres downstream.

The new research by Stuart and Sharp (2017) is developing improved flow management plans for golden perch, which is demonstrating the importance of protecting flow events in the northern Basin through to the nursery habitat of the Menindee Lakes to support strong age classes dispersing into the southern connected basin and back up into the northern Basin from the Menindee Lakes.

The new science by Stuart and Sharp (2017) has not been finalised and is not available at the time of this reports publication. However, an environmental flow requirement that forms just one aspect of the plan has been included in this report. This is a flow of 3,000 ML/d for at least 20 days at Mungindi to support regular local spawning cues, larval drift, and in-channel development of juvenile fish. This flow requirement would drown-out Mungindi weir (2,500 ML/d) to improve fish passage in the upper Barwon River.

It is important to note that this requirement forms just on part of the flow plan for golden perch. For the greatest outcomes substantial flows (beyond the low flow focus of this report) are needed to pass through to the Menindee Lakes and beyond. It is recognised that a series of flows over multiple years will be needed to meet the spawning, dispersal, nursery recruitment, and then juvenile dispersal of golden perch to achieve the system scale population recovery.

Fish movement opportunities

Flows that elicit flow responsive fish to move between habitats and/or complete critical life cycle stages are an important part of the flow regime. Recent research on fish movements in the nearby Moonie River has demonstrated that water level, temperature and the first post-winter flow are important cues for the movement of golden perch and freshwater catfish (Marshall et al. 2016). The research found that fish responded to changes in river height of over 2 metres from commence to flow, and moved when water temperature was greater than 15 degrees Celsius (Marshall et al. 2016).

An average flow velocity of 0.3 metres per second is also thought to be a useful threshold for biota that need flowing water for lifecycle responses, such as golden perch (Passy, 2001; Mallen-Cooper and Zampatti, 2015).

NSW Office of Environment and Heritage is currently developing the Barwon-Darling LTWP which will provide the basis for the regional environmental water requirements to inform water resource planning. For this work, important flow bands for gauges across the river system are being informed (partially) by the flow heights needed for fish movement, with the following relationships identified:

- A rise of ≥ 0.3 m above cease to flow (CTF) to provide connectivity for small to moderate sized fish (Fairfull and Witheridge 2003).
- A rise of ≥ 0.5 m above CTF to provide connectivity for larger bodied fish (Fairfull and Witheridge 2003).
- A 2 m rise and/or 0.3-0.4 m/s average velocity for flow dependent fish to spawn and move (Marshall et al. 2016; Mallen-Cooper and Zampatti, 2015).

Table 4 provides the relationships between these heights and the corresponding discharge volume for a number of gauge locations. The 0.3 and 0.5 m rise from CTF is considered more relevant for the low flows being assessed here, however low flow events at the upper end of the 2000 ML/d threshold can provide for the 2 m rise (and/or >0.3 m/s velocity) at some of the gauge sites.

Table 4: Relationship between river heights considered sufficient for fish to move and discharge rate (ML/d) for a number a gauge locations along the Barwon-Darling river system.

Fish movement metric	Walgett	Bourke	d/s 19a	Louth	Tilpa	Wilcannia
0.3 m above CTF	68	972	155	328	75	71
0.5 m above CTF	146	2,490	359	799	189	195
The larger of 2 m above CTF or >0.3 m/s average velocity	1,690	15,000	7,280	5,940	2,580	3,110

Figure 11 shows a flow event between January and April 2015 for Bourke and Wilcannia that was preceded by an extended no flow period (44 and 139 days). This flow event maintained a flow of 500 ML/d for 22 days. This flow event provided a 1.86 and 2.1 metre rise at the downstream of Weir 19a gauge and Wilcannia respectively and would have provided connectivity for fish to move, especially important after such a long period between flows. The downstream of Weir 19a gauge was used to represent change in river height outside of the influence of the Bourke weir pool (~50 km pool) where fish movement is less of an issue as compared to the free flowing parts of the river weir pool.

Another example, from a smaller flow event in 2007 (as shown in Figure 13) also provided at least a 0.5 m rise in the river, showing that flow events of that maintain a threshold of 500 ML/d for 11-23 days at Bourke will generally provide the desired scale of fish movement opportunity for much of the Barwon-Darling river system.

However, these smaller in-channel pulses would not provide the large scale fish movement opportunities (1000s of km) due to the influence of the weirs along the length of the Barwon-Darling River which need higher flows to drown out and provide fish passage. Figure 12 provides the location of the 15 major fish passage barriers along the Barwon-Darling River with the estimated drown out values for each structure.

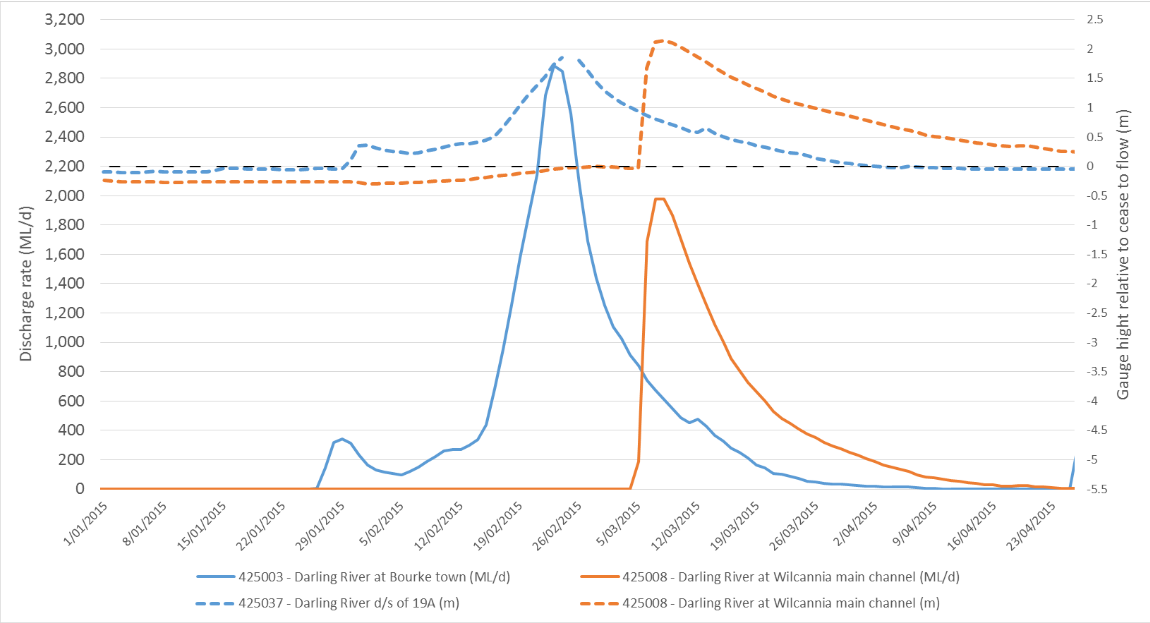


Figure 11: Flow event in 2015 showing the scale of connectivity between Bourke and Wilcannia and height rise the events provided to support fish movement opportunities.

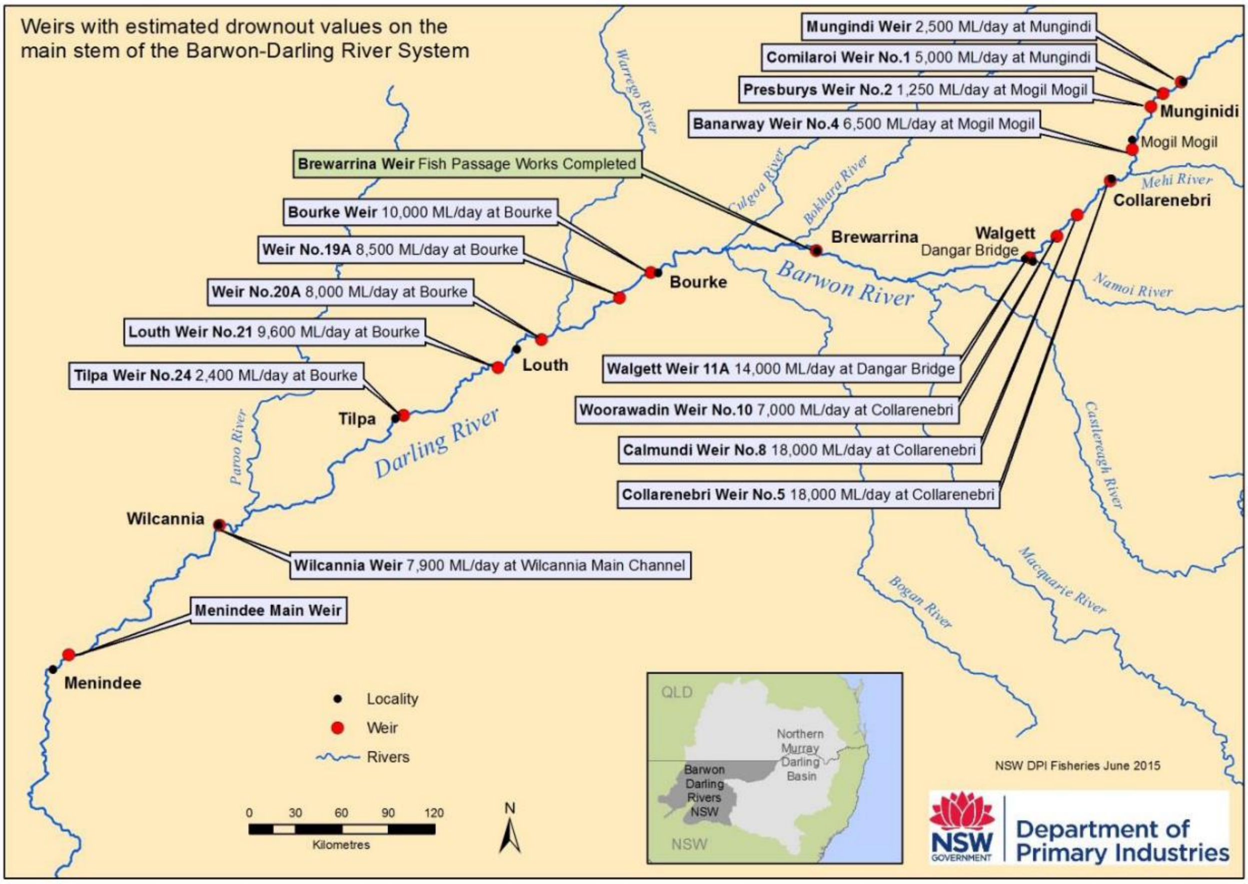


Figure 12: Location of the 15 major fish passage barriers along the Barwon-Darling River, with estimated drown out flow rates for fish passage (taken from Cooney (1994).

Longitudinal Connectivity

Longitudinal connectivity is essential for a healthy ecosystem and to support the populations of native fish and other aquatic biota that live in the Barwon-Darling river system.

Regular connectivity events provide a range of ecological functions, including:

- supporting movement opportunities for fish to access habitats and supporting critical life-cycle stages (such as cues for breeding for some species, flow for drifting larvae, base flows to increase survivorship and reduce predation, and migration opportunities);
- replenishing and freshening refuge pools to maintain adequate water quality;
- supporting and maintaining macroinvertebrate communities;
- maintaining riparian vegetation and water for downstream communities; and
- supporting key ecosystem functions like increased carbon cycling through wetting and drying of in-channel bars and benches.

In the Barwon-Darling river system, connectivity is dependent on the size of the flow and antecedent conditions. Smaller in-channel flow events that move partway through the river provide benefits for the upstream reaches. However, regular connectivity through to Wilcannia and Menindee Lakes is needed to support the environmental water needs across the river system. Connectivity can occur from a single pulse but is more regularly associated with a series of pulses down the river (see example from 2007 in Figure 13 below).

The MDBA has undertaken analysis of observed flow events with a magnitude of less than 3,000 ML/d at Bourke (between 1990-01 and 2016-17) to better understand the types of flows that provide longitudinal connectivity. This analysis looked at over 50 individual flow events with a minimum and maximum threshold of 500 and 3,000 ML/d at Bourke. It was found that most events did provide some level of longitudinal connectivity between Bourke and Wilcannia.

The exception to this was during dry periods when small in-channel flow events that did meet the 500 ML/d threshold at Bourke did not travel downstream and reach Wilcannia. All of these events were above 500 ML/d for a maximum of 11 days at Bourke, indicating that a longer duration is necessary to ensure connectivity through to Wilcannia.

To illustrate this, Figure 13 shows a series of small in-channel flow events between May and November 2007 for Bourke and Wilcannia (the events followed a 198 day no-flow spell at Bourke). The three events maintained a flow of 500 ML/d or greater for 11, 13 and 23 days, respectively at Bourke. The first event peaked at 1,600 ML/d and contained about 16 GL but did not reach Wilcannia. The flow did however result in over a 1 m rise downstream at the Weir 19a gauge and flow at the Tilpa gauge (located downstream of the Tilpa weir pool). The second and third events peaked at 800 ML/d and 1,100 ML/d and contained about 22 GL each. These events did maintain flow between Bourke and Wilcannia for extended periods.

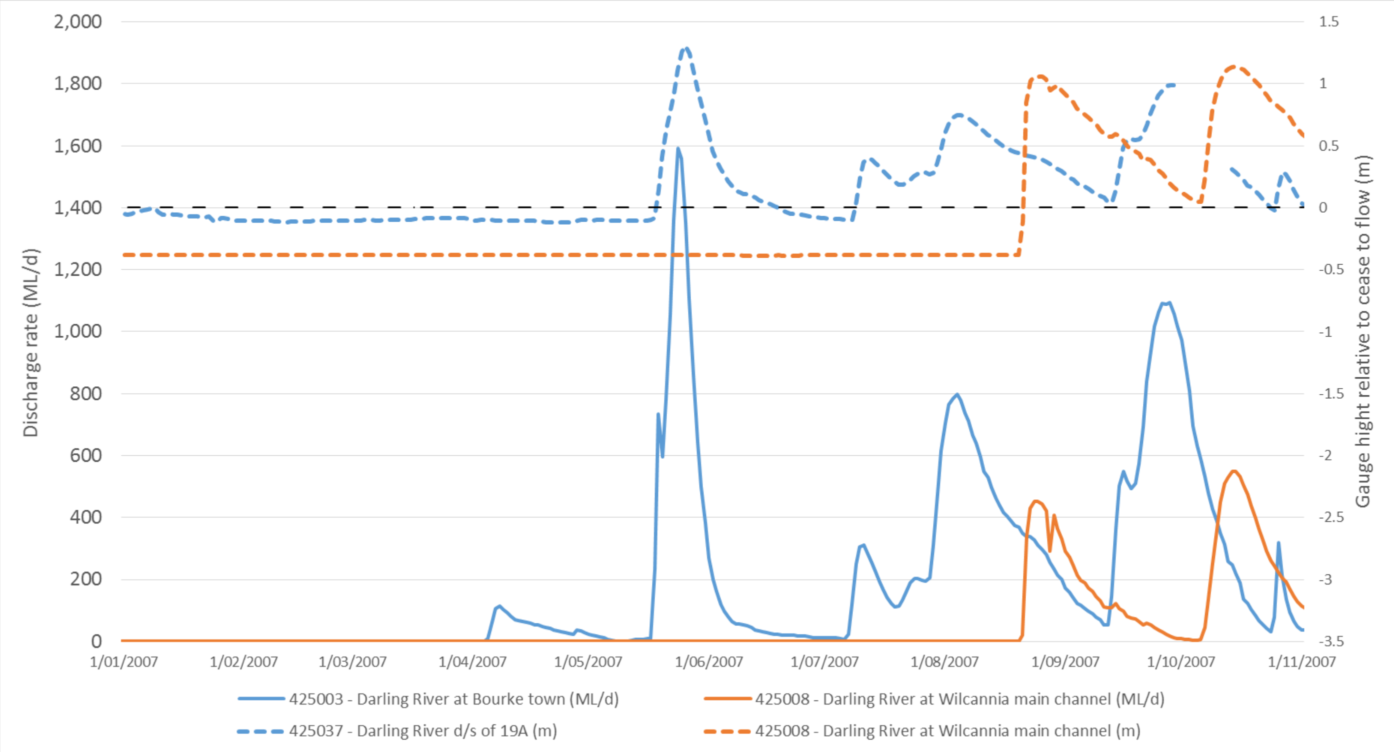


Figure 13: Series of flow events in 2007 showing the scale of connectivity between Bourke and Wilcannia and the height rise the events provided to support fish movement opportunities.

These flows would have been sufficient to refill and enhance water quality (and supress potential algal blooms - see algal bloom section) in the more than 500 large refuge pools between Bourke and Wilcannia. The flows would have also provided local connectivity for fish movement between habitats for the 630 km of river between Bourke and Wilcannia. Figure 13 shows that all of the pulses provided at least a 0.5 m rise above CTF (the black dotted line), which has been identified as an adequate depth for small and large bodied fish to move between habitats (see section on fish movement below). At these flow rates there would not have been connectivity between the weirs which need higher flows to drown-out and provide fish passage (see Figure 12).

The environmental demands and priorities for active management of Commonwealth environmental water in the Barwon-Darling for 2016-17, described the need for a low/base-flow pulse to replenish waterholes and improve water quality along the upper and mid-Darling (CEWO 2016). The specific requirement describes the delivery of 10-20 GL of tributary inflow based on a trigger of at least 40 days of no-flow at Bourke or 60 days at Wilcannia. This volume was based on observation of past flow pulses by the CEWO from the Gwydir system in November 2013 (inflow of 11 GL) and October 2014 (inflow of 13.5 GL).

Both of these CEWO actions occurred during very dry periods and, as such, did not provide connectivity through to Wilcannia (also did not meet 500 ML/d at Bourke). The Commonwealth environmental water was used to target fish outcomes in the Gwydir and provide connectivity between the Gwydir and Barwon systems. In addition to providing environmental benefits, the inflows triggered irrigation access for A and B class licences in zones of the Barwon River. If this water was protected, the flows could have moved further down the river. More detail on both of these CEWO watering actions is provided in case studies at Appendix B.

The volume of water required to provide longitudinal connectivity along the length of the Barwon-Darling River is dependent on a range of factors with the dryness of the preceding period, source of tributary inflow and level of take by consumptive users being primary drivers. For a very high likelihood of system scale connectivity, a volume of at least 20 GL at Bourke is required during a dry period. Flow events of this volume would generally take the shape of an event with a magnitude of 500 ML/d for a duration of at least 14 days with 20 days providing more certainty.

Water sharing arrangements and rules that can protect environmental water would enhance the probability of water passing further though the river.

Method for assessing ecological needs for low flows

The peer reviewed 'umbrella environmental asset' (UEA) approach as described by Swirepik et al. (2015) has been used for this assessment of environmental water requirements for low flows in the Barwon-Darling river system. This is the same approach used for the environmental water requirements that informed the Basin Plan and Northern Basin Review (MDBA, 2016a).

Imperfect knowledge of flow-ecology relationships is a universal challenge in determining the water needs of aquatic ecosystems (Poff and Zimmerman, 2010). It is generally not possible to explicitly know and understand the water requirements of all ecosystem components in large river systems, such as the Barwon-Darling river system. The disjunct between the timeframes for large-scale ecological investigations (decades) and the timeframes for policy development and implementation (years) creates the need to draw upon the existing and uneven knowledge base to inform the policy process. The umbrella environmental asset approach enables the integration of existing information for key sites, which are then used to represent environmental water requirements across larger areas.

The UEA approach includes the following main steps:

- Selection of the environmental asset
- Identification of the ecological values and targets
- Establish environmental flow requirements at flow indicator gauges to represent flow components that are linked to the ecological values and targets for the asset.

Selection of the umbrella environmental asset

The following five principles were used to guide the selection of UEAs:

- High ecological value. The Basin Plan lists five criteria for identifying environmental assets, and four criteria for identifying ecosystem functions, which indicate a site has high ecological value. These criteria are listed in Schedule 8 of the Basin Plan.
- Representative of water requirements. The water requirements are assumed to represent the water needs of a broader reach of river or an entire river valley.
- Spatially representative. The hydrology and geomorphic character is to be representative of river valleys, rather than sites of unusual hydrology or character.
- Significant flow alteration. Have experience significant departures from without development flows.
- Availability of data. Hydrological and ecological information needs to be sufficient to allow a detailed assessment of environmental water requirements.

By applying these principles, the Barwon–Darling River upstream of Menindee Lakes to Mungindi has been selected as the UEA. This is the same as original environmental water requirements assessment of the Barwon–Darling (MDBA 2012), and for the assessment for the Northern Basin review (MDBA 2016).

This recognises the importance of the entire Barwon-Darling river system as the connection between northern Basin catchments and the southern Basin. It also recognises the relatively consistent level of eco-hydrology information through the river system, especially between Walgett and Wilcannia where new habitat information (snags, benches, refuge pools) was collected for the Northern Basin Review.

Identify ecological values and targets

The ecological values of the Barwon–Darling river system UEA include species that are listed for protection under Commonwealth and NSW legislation, persistent refuge pools for fish and other aquatic biota, connection pathways for fish to move to other parts of the Murray-Darling Basin, and a large number of floodplain habitats providing foraging areas for migratory birds listed under international agreements, and wetlands listed on the Directory of Important Wetlands in Australia.

The ecological targets for the Barwon–Darling river system UEA have been retained from the Northern Basin Review. These targets focus on providing a flow regime which:

- supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates),
- supports the habitat requirements of waterbirds.
- ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition, and
- supports hydrological connectivity between habitats, along the river (longitudinal) and between the river and its floodplain (lateral).

Environmental Flow Requirements

Environmental flow requirements describe an ecologically important flow event and the frequency that it is required. This includes the following four hydrological metrics:

- magnitude: the minimum flow threshold in megalitres per day;
- duration: the minimum number of days the flow needs to be above the flow threshold;
- timing: the months of the year where the specified event is sought; and
- frequency: the percentage of years in which there is at least one event of the specified magnitude, duration and timing occurs (e.g. 90% of years).

In addition to the frequency, a threshold of concern has also been set which describes the period between an event (spell) considered likely to result in ecological risk.

The hydrological metrics that were most challenging to select was the frequency and threshold of concern for spells between events. It is likely that there are thresholds for many plants and animals beyond which their resilience is diminished and their survival or ability to reproduce is lost. However, the precise details of those thresholds are mostly unknown. As a result of these uncertainties, the frequency is given as a range from a low uncertainty of achieving an ecological target to a high uncertainty of achieving the target.

The environmental flow requirements within this document represent a synthesis of existing information and literature documenting the environmental water needs for low flows in the Barwon-Darling River. The environmental flow requirements are expressed in the same format as the site-specific flow indicators developed for the Northern Basin Review i.e. flow magnitude, duration, timing and frequency. The term environmental flow requirement has been used in this report to differentiate this work from the site-specific flow indicators developed previously as part of the Northern Basin Review.

Thirteen environmental flow requirements have been described for different points along the river, including at Walgett, Brewarrina, Bourke, Louth and Wilcannia (Table 5).

This approach provides spatial coverage of environmental water needs along the length of the river in recognition of the reach based differences in hydrology, geomorphology and ecology. Furthermore, irrigation extractions occur along the entire length of the Barwon River and in the upper sections of the Darling River around Bourke and hence understanding of environmental water needs for all reaches is important from a management perspective given they experience varying levels of flow alteration due to consumptive use. Description of flow requirements at Wilcannia is considered especially important as the last gauge on the Darling River and hence it represents the full impact of development and can be used to assess longitudinal connectivity for the entire river system.

Table 5 provides reference to the source literature for the environmental flow requirements including: ecological rationale, event shape (magnitude, duration and seasonal timing), and the target frequency. The flow magnitude, duration and timing for each of the 13 environmental flow requirements have been taken directly from the source literature. More information about the science behind these can be found in the source literature references.

The target frequency and threshold of concern are based on a combination of specification of the requirements in the literature, a comparison of the frequency and spells under without development modelling and expert advice. This ensures that the requirements are robust and can be used to compare the ecological outcomes and consequences of different flow regimes.

It should be noted that the threshold of concern is not an ecological tipping point. Very little is known about thresholds for ecological resilience in the Barwon-Darling river system (i.e. any step changes). However, the threshold of concern provides an indicative duration between events considered to be very long, outside of without development flow regime spells, and likely to result in ecological stress for comparison between flow regimes.

The threshold of concern information base includes:

- For maintaining native fish population environmental flow requirements, a threshold of 1 year (or the maximum spell between events in the without development model) has been used. This takes into account the target frequency to have an event close to annually (8-9 years out of ten), and advice from NSW fisheries that it is desirable to have annual in-channel pulses to maintain flow variability, habitat access and productivity to support fish populations.
- For enhancing native fish spawning and recruitment environmental flow requirements a threshold of 2 years has been used. This takes into account the target frequency to have an event in 7-8 year in ten, and advice from NSW fisheries that it is desirable for

flows that facilitate small bodied fish to breed to occur multiple times within their life-span (which is generally between 3-5 years).
- The regular breeding opportunities for Golden perch environmental flow requirement uses a threshold of 4 years. This takes into account the target frequency of 6-7 years in ten, and a threshold used by the Queensland Government for the Moonie and Lower Balonne catchments for considering risks during the development of water resource plans which considers a spell of more than 4 years between in-channel pulses for golden perch breeding as a moderate risk for the survival of the populations.
- The 2000 ML/d for 5 days environmental flow requirement at Wilcannia uses a 2 year threshold which takes into account the target frequency of 8-9 years in ten.
- The algal suppression threshold environmental flow requirements have been set at 150 days which represents the period between October and March. It is desirable for regular flows to meet this threshold over these months to mitigate against algal blooms and to have at least one event each year.

The environmental flow requirements have been compared to the modelled without development frequency to ensure that they are representative of the typical hydrology of the Barwon–Darling river system. This check was a practice retained from the original assessment (MDBA 2012) to gives confidence that the proposed environmental flow requirements are reasonable. In addition, given issues with hydrological model representation of low flows, observed flows from the past 27 years (1990 to 2017) have also been analysed as a better indicator of performance under existing water sharing arrangements than the modelled baseline scenario.

For the results section, the environmental flow requirements that specify multiple events within the requirement (i.e. 1 to 3 flow events within a year) have used the minimum number of events specified (i.e. 1 event).

The NSW Office of Environment and Heritage is developing the LTWP for the Barwon-Darling river system which will set the environmental objectives and water requirements used during the NSW Government's development of the water resource plan and for guiding decisions by environmental water holders regarding use of environmental water.

It is expected that the requirements described in the LTWP will be consistent with those described in this document as the same scientific literature base and site-specific eco-hydrology information is largely being used. The LTWP will be the enduring plan for managing environmental water in the Barwon-Darling river system at the regional scale. The environmental water requirements in the LTWP will supersede the requirements in this report once available.

Table 5: Low flow environmental flow requirements for the Barwon-Darling River describing the information source, ecological rationale, flow event magnitude, duration, timing and target frequency, and the threshold of concern for spells between events.

Ecological rationale	Magnitude	Duration (days)	Timing	Target frequency (% of years with an event)	Threshold of concern for spells b/w events (days)
CEWO Northern Unregulated Rivers Portfolio Management Plan (CEWO, 2017)					
Maintain native fish populations and in-channel ecosystem processes such as refuge pools and connectivity down the river. #set to match the without development maximum spell between events.	500 ML/d @ Walgett	7-20	Aug-May (1 to 3 events)	80-90	476#
	500 ML/d @ Bourke	7-20	Aug-May (1 to 2 events)	80-90	365
	350 ML/d @ Louth	7-14	Aug-May (1 to 2 events)	80-90	365
Enhance native fish spawning, and recruitment for reaches in the Barwon-Darling(especially small bodied fish)	500 ML/d @ Bourke	50	Sep-April	70-80	730
	1,500 ML/d @ Bourke	5	Sep-April	70-80	730
Golden Perch small pulse requirements (Stuart and Sharp, 2017)					
Regular opportunity for golden perch to migrate and spawn in the Barwon-Darling and Border Rivers, with larval development in- channel and downstream transport. The report specifies Mungindi but Brewarrina has been used represent flow downstream of an area of major consumptive use. The report describes other flows requirements, including large scale breeding (not included here).	3,000 ML/d @ Brewarrina	20	Any time (ideally when temp is above 18 degrees)	60-70	1460
Algal suppression/connectivity flow - Interim Northwest Unregulated Flow Plan - associated with the B-D water sharing plan (NSW, 2012)					
Flow pulse to the end of system during the hotter months to mitigate against stratification of pools and the development of algal blooms. Management target where access to unregulated flows can be restricted to achieve the event, unless this flow occurred within the preceding months.	2,000 ML/d @ Wilcannia	5	Oct-April	80-90	730
Algal suppression thresholds (Mitrovic et al., 2006)					
Critical discharge to suppress stratification of pools and *Anabaena circinalis* (toxic blue-green algae) growth during the hotter months of the year. *would indicate there has not been an algal bloom mitigation flow between October to March.	510 ML/d @ Brewarrina	1	15 Oct-15 March	100	150*
	450 ML/d @ Bourke	1	15 Oct-15 March	100	150*
	350 ML/d @ Wilcannia	1	15 Oct-15 March	100	150*

Results

Environmental Flow Requirement frequency

Table 6 presents the frequency results (% of years with a successful event) for the environmental flow requirements for the modelled without development scenario and for observed flows between 1990-91 and 2016-17.

The results show that the target frequency for all environmental flow requirement is achieved under the without development scenario. By comparison, 7 out of the 13 requirements meet the target when assessed against observed flows. Environmental flow requirements met are associated with the maintenance of fish populations and the small 1,500 ML/d for 5 days fresh at Bourke to enhance native fish spawning opportunities. One requirement of 3,000 ML/d for 20 days at Brewarrina for regular golden perch breeding in the Barwon River met the high uncertainty but not the low uncertainty target, indicating an increased level of risk.

Six of the requirements did not meet the high uncertainty frequency target based on analysis of observed flows.

The three algal suppression flow threshold requirements at Brewarrina, Bourke and Wilcannia did not meet the target, indicating that there was at least one year between 1990 to 2017 where the flow never met the threshold to mitigate against blue green algae risk for the high risk October to March period (when this occurred is included in the spells results in Appendix C).

The 500 ML/d for 50 days at Bourke requirement which aims to provide conditions for the successful recruitment of short lived fish (amongst other outcomes) also did not meet the target frequency. This flow event had the most impact from water resource development, being achieved close to annually under without development conditions but only for 63% of years under the observed flows. This is an important result as the longer duration is expected to be critical for successful recruitment of native fish species with lifespans less than 3-5 years.

The second largest threshold requirement (2,000 ML/d for 5 days at Wilcannia) was the second most impacted, achieving 100% under without development but 78% for the observed period. This event represents a small in-channel flow event at the end of system to provide a range of outcomes including pool freshening and mixing, water for riparian vegetation and downstream communities, and opportunities for fish to access habitats and breed.

Table 6: Frequency of years with a successful environmental flow requirement event for the without development model and observed flows between 1990-01 and 2016-17.

Location	Environmental Flow Requirement	Frequency of Years with an Event (%)			
		WOD	Observed	HU	LU
		1895 - 2009	1990 - 2017		
Walgett	500 ML/d (7 days) Aug to May	100	96	80	90
	500 ML/d (20 days) Aug to May	99	96	80	90

Brewarrina	3000 ML/d (20 days) any time of the year	97	63	60	70
	510 ML/d (1 day) Oct to March	100	93	100	100
Bourke	500 ML/d (7 days) Aug to May	100	100	80	90
	500 ML/d (20 days) Aug to May	100	93	80	90
	500 ML/d (50 days) Sep to April	97	63	70	80
	1500 ML/d (5 days) Sep to April	100	85	70	80
	450 ML/d (1 days) - Oct to March	100	89	100	100
Louth	350 ML/d (7 days) Aug to May	100	100	80	90
	350 ML/d (14 days) Aug to May	100	96	80	90
Wilcannia	2000 ML/d (5 days) any time of the year	100	78	80	90
	350 ML/d (1 days) any time of the year	100	89	100	100

Green: meets low uncertainty target; Yellow: meets high uncertainty target; Apricot: does not meet target. Frequency calculated using eFlow predictor (eWater software)

Environmental Flow requirement spells between events

Table 7 presents the average number of events per year, maximum spell between events, and the number of spells that are longer than the threshold of concern for the environmental flow requirements.

The average number of events show mixed performance with some meeting the target numbers of events (where specified) and having relatively small differences between without development conditions and observed flows. In contrast, other flow requirements do not achieve the target when assessed against observed flows and/or show marked change in the number of events compared to the without development scenario.

The events that are specified as ideally having more than one event in the year (see Table 5) generally achieve the desired number of events per year on average, except for the flow events specified by CEWO with duration expressed as a range. For the CEWO specified flow requirements where duration is expressed as a range the number of events exceeds the without development number of events for flow events at the upper end of the duration range. The events that show the most difference between the two scenarios are the larger freshes (3,000 ML/d for 20 days at Brewarrina and 2,000 ML/d for 5 days at Wilcannia). Mixed performance for number of events against the metrics under observed conditions is consistent with the findings from the frequency assessment.

Under without development conditions, no thresholds of concern are exceeded. In contrast, observed flows analysis illustrates that the maximum spell between events show large changes for all of the environmental flow requirements with most maximum spells approximately doubling in length and being longer than the threshold of concern. The number of spells that are longer than the threshold of concern is expected to impact on the maintenance of native fish populations in the Barwon-Darling and increase risks for water quality issues during extended dry periods.

The very long maximum periods between low flow environmental water requirements and their marked departure from without development conditions combined with the number of thresholds of concern that have been breached indicates risks to ecological needs as a result of extended dry periods. There is a need to consider management options that can reduce the length of the longest low to no-flow spells.

The 1,500 ML/d for 5 days at Bourke and the 3,000 ML/d for 20 days at Brewarrina are the two requirements that perform well against the threshold of concern. This contrasts with the frequency assessment for the Brewarrina requirement whereby the target is not met. The 3000 ML/d for 20 days at Brewarrina threshold has been set at 4 years which aligns with a threshold set for golden perch spawning opportunities for the Northern Basin Review (MDBA, 2016a). This ensures a number of spawning opportunities within the 15 year average life-span of golden perch in the northern basin (Stuart and Sharpe, 2017).

The distribution of dry spells for 1990 to 2017 for each of the indicator gauges is presented in Appendix 3. One interesting result is the 2,000 ML/d for 5 days at Wilcannia environmental flow indicator which was not met for 3.1 years between 2013 and 2016. This compares to the maximum spell of 2.4 years at the height of the Millennium drought. This finding is concerning as this flow best represents the connectivity needs of the entire river system as it is represents a small in-channel fresh at the end of the Barwon-Darling river system.

Table 7: Average number of events per year, maximum spell between events and number of spells longer than the threshold of concern for the environmental flow requirements

Location	Environmental Flow Requirement	Average number of events per year (# of events)	Maximum Spell between events (days)			Number of spells longer than the threshold of concern (# of spells)		
		WOD	Obs	WOD	Obs	WOD	Obs	
		1895 - 2009	1990 - 2016	1895 - 2009	1990 - 2016	1895 - 2009	1990 - 2016	
Walgett	500 ML/d (7 days) Aug to May	3	3.1	278	531	0	2	
	500 ML/d (20 days) Aug to May	2.3	1.8	476	633	0	4	
Brewarrina	3000 ML/d (20 days) any time of the year	Not available	Not available	720	1239	0	0	
	510 ML/d (1 day) Oct to March			10	153	0	2	

Bourke	500 ML/d (7 days) Aug to May	2.3	2.7	247	407	0	1
	500 ML/d (20 days) Aug to May	1.9	1.8	291	607	0	1
	500 ML/d (50 days) Sep to April	1.3	0.9	587	1031	0	4
	1500 ML/d (5 days) Sep to April	2.7	1.7	355	684	0	0
	450 ML/d (1 days) - Oct to March	2	3.4	18	153	0	3
Louth	350 ML/d (7 days) Aug to May	2	2.9	243	408	0	1
	350 ML/d (14 days) Aug to may	1.9	2.1	275	479	0	1
Wilcannia	2000 ML/d (5 days) any time of the year	2.6	1.3	428	1147	0	2
	350 ML/d (1 days) any time of the year	2	2.6	19	153	0	3

Green: spells shorter than threshold of concern; Apricot: spells longer than threshold of concern

Trends in Algal Suppression Flows

The occurrence of algal blooms in the Barwon-Darling, such as the wide-spread blue-green algae bloom in the summer of 1991 that covered over 1,000 km, are related to thermal stratification of water in pools. This stratification occurs in the hotter months (between October and March) when flow rates are low. The 1991 blue-green algal bloom was at a time of low flow (~100's ML/d) and hot/still conditions. The sustained low flow allowed influx of saline groundwater which caused clay flocculation, water clarification and increased photosynthesis in the surface water (Donnelly et al. 1997). These conditions were ideal for the boom in algal growth.

There are many factors that influence the development of algal blooms (with the interaction between these factors generally not well understood). The factors include wind, saline groundwater inflow, turbidity and its associated effect on light penetration, concentrations of nutrients and metals and other biological and physical processes. However, during the hotter part of the year when algal blooms are more likely, flow events can prevent thermal stratification by mixing pools and also reduce ingress of groundwater inflow or dilute its impact, and so inhibit blooms from developing.

Work by Mitrovic et al (2006) has identified critical velocities and discharges required to mix the water column within weir pools to prevent stratification and suppress blooms from forming at three sites along the Barwon-Darling; at Brewarrina (510 ML/d), Bourke (450 ML/d) and

Wilcannia (350 ML/d). These critical discharge rates correspond to a velocity of 0.04 m/s. It is estimated that it takes 12 days with flows below this threshold for weir pools to stratify.

In addition to mitigating the risk of algal blooms, these flow thresholds are of a size to provide other outcomes, such as small scale fish movement opportunities, increased productivity, freshening of pools, and water for riparian downstream communities (NSW DPI, 2015).

Previous long-term modelling of the Water Sharing Plan arrangements using the Barwon-Darling Integrated Quantity and Quality model (Foster and Cooke, 2011) aimed to determine the impact of water sharing arrangements on the thresholds identified by Mitrovic (2006).

Notwithstanding the limitations of the hydrological model in representing the part of the flow regime, this analysis indicated that the number of events that exceed the critical flow threshold for the suppression of algal blooms at Brewarrina, Bourke and Wilcannia has increased as a result of the water sharing arrangements in the northern Basin (as compared to without development conditions). However, the modelling showed that despite the increase in frequency, there was a reduction in the average volume of events exceeding the thresholds. The mean number of days since a previous event exceeding the critical threshold was reduced under without development conditions to baseline conditions from 38 to 28 days at Brewarrina, from 35 to 19 days at Bourke, however increased from 42 to 62 days at Wilcannia.

As a comparison to the findings of Foster and Cooke (2011), the observed hydrology from 1990/01 to 2016/17 has been analysed for trends in the average number of days that flows are below the critical threshold and the average length of these spells (Figure 14, Figure 15). The spells are for between 15 October and 15 March and longer than 12 days. Key statistics for each year is included at Appendix A.

The figures have been split into three periods (1990-1999, 2000-2010 and 2011-2017), with 2000/01 corresponding with the commencement of cease to pump rules for protecting instream values in the Barwon-Darling river system and 2011-17 the commencement of the water sharing plan (NSW, 2012). Both figures show that all three sites the 2000-2010 and 2011-2017 periods had longer periods below the critical threshold compared to 1990-1999; likely to be due to a combination of differences in climate and development of water resources. However, it is interesting that 2011-2017 had longer spells between flows as compared to 2000-2010 which corresponded to the Millennium drought. Also, it is the trajectory of the lines that provides insight into potential increases in risk for algal blooms.

For the average number of days the flow is below the critical threshold, all sites show an increasing risk of algal outbreaks between the three periods. However, there is also a difference between the trends at Brewarrina and Bourke and the trend at Wilcannia. Wilcannia exhibits a more rapid increase in days below the critical flow threshold and average spells between the critical thresholds for the 2000-2017 period compared to the other two sites. This data suggest an increasing risk of algal blooms at Wilcannia during the 2000-2017 period as compared to the upstream sites (and more so for the 2011-2017 period which is associated with the water sharing plan established in 2012).

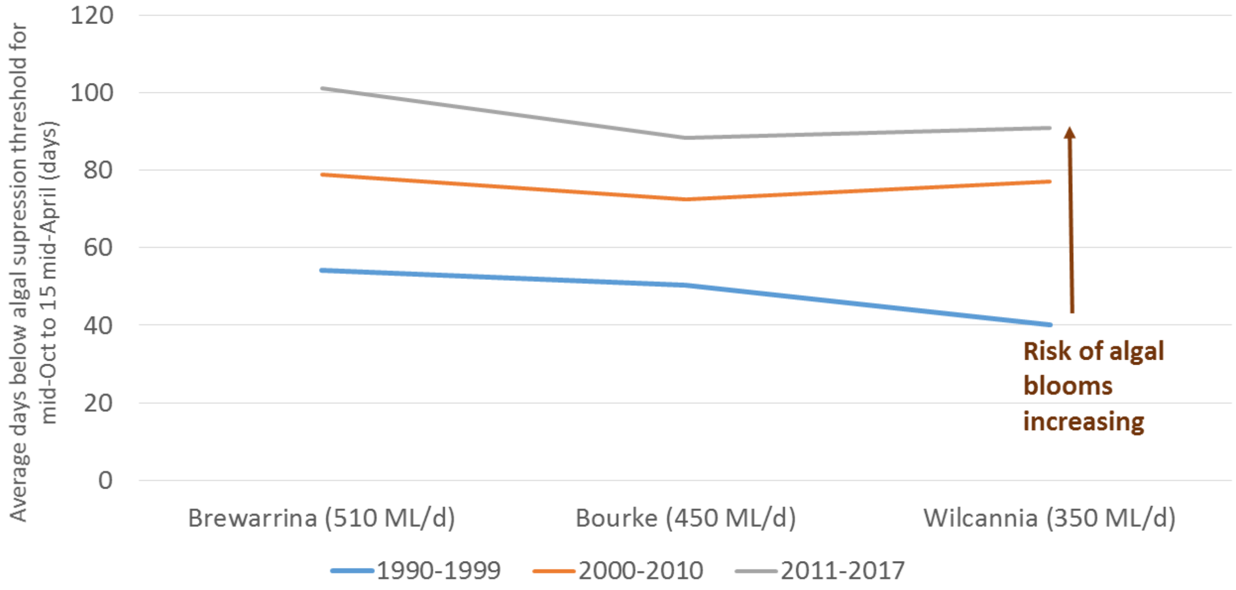


Figure 14: Average number of days flow is below the identified algal suppression flow between 15 October and 15 March when there is the highest risk of algal outbreaks, critical thresholds and seasonal timing drawn from Mitrovic et al (2006).

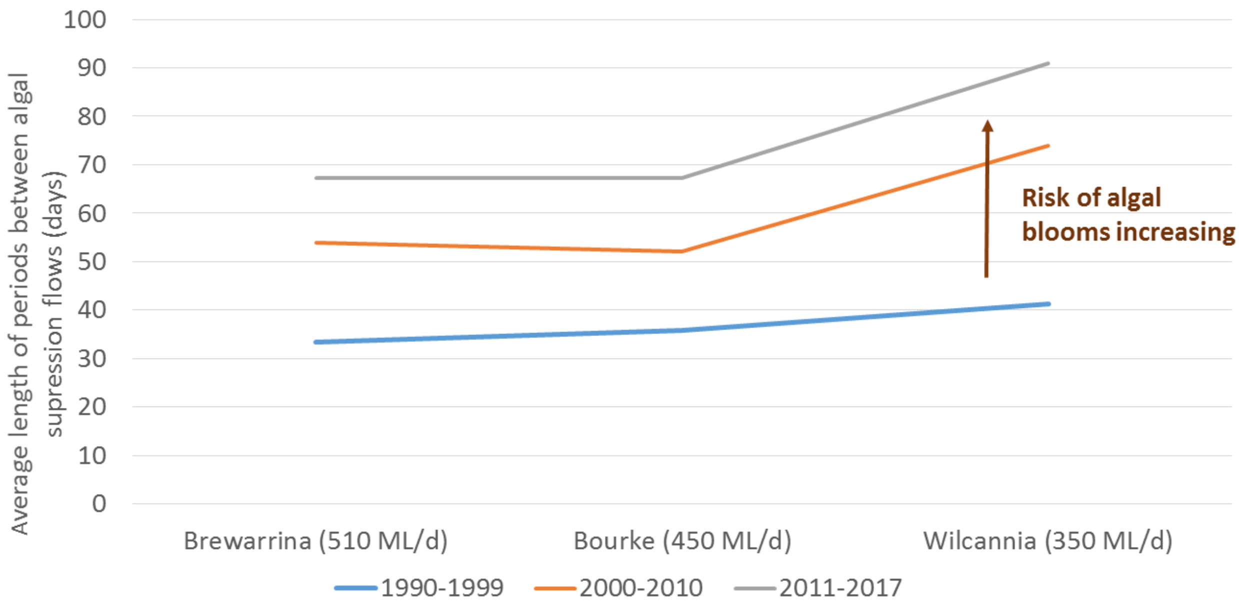


Figure 15: Change in length of spells between algal suppression flows for Brewarrina, Bourke and Wilcannia. The critical thresholds, min 12 day length of spell and seasonal timing have been drawn from Mitrovic et al (2006).

Trends in dry spells

Hydrology analysis of the Barwon-Darling river system conducted by the MDBA (MDBA, 2017b), included analysis on historical dry spells throughout the river system, the main conclusions of which are presented here. The aim was to identify trends in either the length or frequency of dry spell events spatially and temporally, which can help indicate a change in hydrological behaviour of the Barwon-Darling river system.

The length of each dry spell was determined for each of the fifteen gauges along the Barwon-Darling, and any period where the flow was continually less than 20 ML/d contributed to the analysis (the 20 ML/d was selected as a flow considered sufficiently large to ensure connectivity had recommenced). The results were then used to calculate both the number of dry spells and the average dry spell length at each of the gauges.

Figure 16 shows that dry spell behaviour is correlated from upstream (green) to downstream (orange through red) gauges, as would be expected in an arid system, where there are fewer individual dry spells present at downstream gauges but their average length increases. As this includes dry spells of any length, this would be largely driven by local climate. However for the downstream gauges dry spells have become very long, with a spell of at least 80 days having occurred every year since 2013 at Wilcannia.

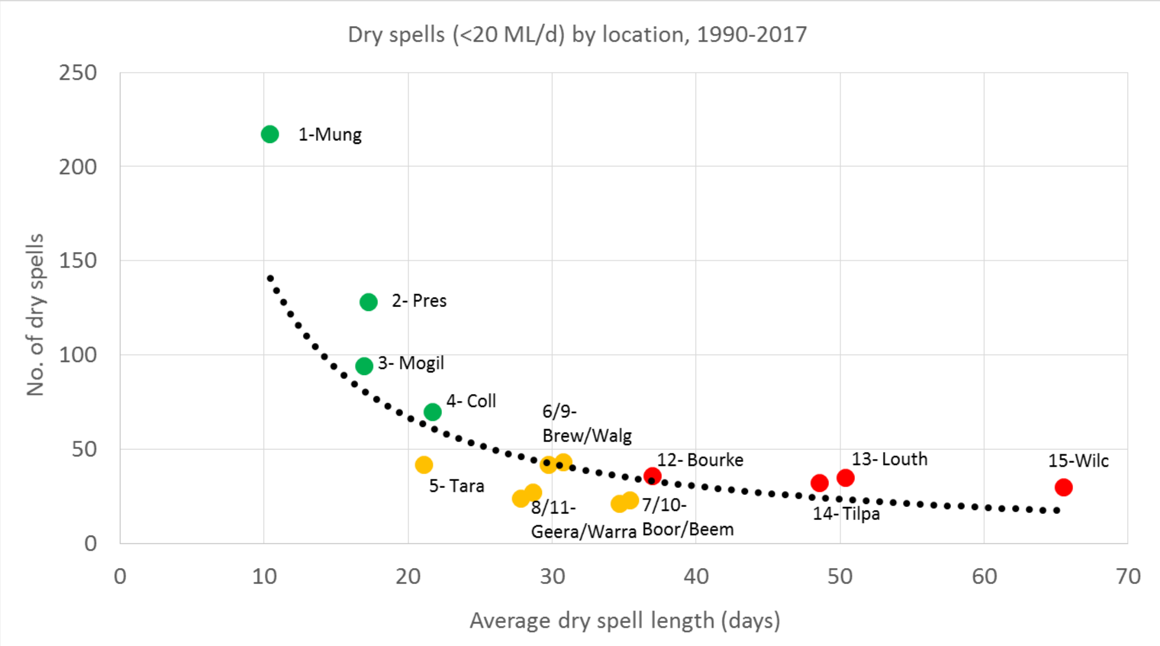


Figure 16: Number and length of dry spells for each of the 15 gauges in the Barwon-Darling. Black dots show the number and length of dry spells for each gauge and the dotted line shows the upstream to downstream trend (MDBA 2017b).

As well as studying historic dry spells spatially, their temporal behaviour was also studied, by analysing the average length of dry spell for key time periods since 1990. Figure 17 presents the results by comparing 1990-1999, 2000-2010 and 2011-2017 dry spells.

It can be seen that dry spells downstream of Bourke are higher for the period covering the Millennium drought, suggesting that local climate (IE the Millennium drought itself) is playing a role in determining dry spells in the lower reaches of the river, as would be expected. However for Walgett and Brewarrina the average dry spell length post the Millennium drought is similar to that experienced during the drought, whereas previously they were shorter in length, indicating a driver in addition to climate is possibly at play in that particular part of the system.

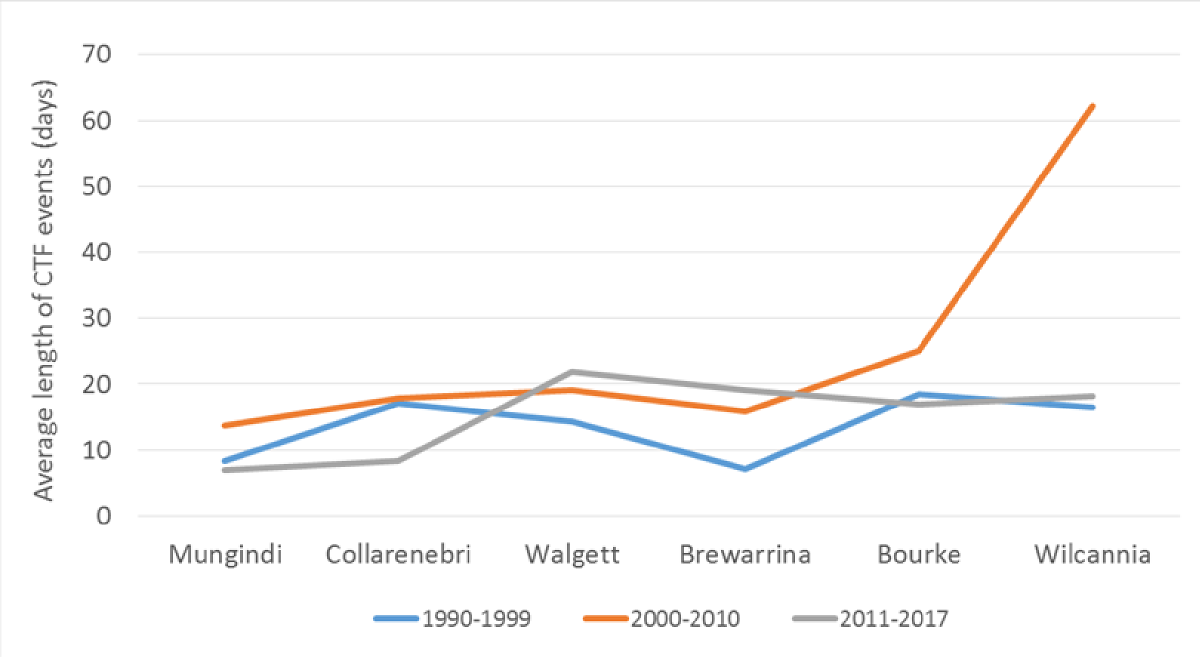


Figure 17: Change in average length of dry spells for key gauges along the Barwon Darling River, for three time periods: 1990-1999, 2000-2010 and 2011-2017 (MDBA 2017b).

Further work by Sheldon (2017), looked at the same dry spells data as used by MDBA but overlayed them with information on the Southern Oscillation Index (SOI). This was based on the work of Leigh et al (2010) which showed that there is a strong relationship between the long-term flow regime in the Barwon-Darling and the SOI. The SOI gives an indication of the development and intensity of El Niño and La Niña events.

This analysis showed that from 1989 to 2000 negative SOI values were associated with an increased number of dry spells (as would be expected under El Niño conditions which tend to be drier than normal) and positive SOI values were associated with fewer dry spells (as expected under La Niña conditions).

From 2001 to 2010 the pattern changed. While negative SOI values from 1989-2000 (and from the long-term flow record of Leigh et al. 2010) were associated with increased number of dry spells, positive SOI values from 2001-2017 were also associated with dry spells. There was no difference between the 1989-2000 and 2001-2017 time periods in the annual average number of dry spells when the SOI was strongly negative (<-7), suggesting wetter than normal periods ($t = 2.8$, $df = 12$, $p>0.05$). However, the difference between the 1989-2000 and 2001-2017 periods when the SOI was strongly positive (>7), suggesting drier than average conditions, was highly significant ($t = 2.05$, $df = 26$, $p<0.01$). Sheldon (2017) concluded that given the strong correlation between flow patterns and SOI from the long-term flow record (Leigh et al. 2010) it is likely the difference in the correlation between dry spells and SOI for the 2001-2017 period reflects the increased level of extractions from the Barwon-Darling during this time.

Observed salinity during periods of very low flow periods

Saline groundwater discharge below Weir 19a is well known and it the reason for the Upper Darling salt interception scheme being built in 2012-13 (NSW DPI, 2017). This scheme starts about 100-200 m downstream of Weir 19a and intercepts approximately 37 tonnes of salt per day when in operation. The Scheme is generally in operation when the flow in the river is below

4,000 ML/d. Above this flow, the gradient between the groundwater level and the river is towards the groundwater which supresses groundwater inflow into river.

During prolonged very low flow/no-flow periods (i.e. <10s of ML/d) a high proportion of the flow in the river for reaches between Weir 19a and Tilpa can come from the saline groundwater discharge which causes salinity in the river to increase to very high levels. Small in-channel flow events are thus vital for moderating water quality parameters, including diluting salinity.

There is limited site-specific information regarding the salinity tolerances for fish and other aquatic biota in the Barwon-Darling river system. However, salinity can cause mortality of animals, particularly juvenile fish and benthic (bottom dwelling) organisms such as freshwater mussels, as the saline water tends to drop to the bottom of standing water (Sheldon, 2017).

Research from other areas shows that salinity can cause physiological stress in freshwater organisms, with most freshwater plants and animals beginning to show signs of stress at salinities more than 1 g/L (~1,500 µS/cm), with severe impacts above 3.5 g/L (~5,000 µS/cm) and few freshwater biota persist above 10 g/L (15,000 µS/cm) (Dunlop et al. 2005; Nielsen and Brock, 2009). Increases in salinity can also exacerbate declining water quality in pools through flocculation of suspended clay which can increase light penetration and stimulate algal growth which can reduce oxygen levels (Bowling and Baker, 1996, Dunlop et al. 2005).

An example of a salinity spike is presented in Figure 18, where in 2014, after about 40 days of low flows, the salinity in the river downstream of Weir 19a gauge (downstream of Bourke) peaked at about 17,000 µS/cm. The small rise in water level in November 2014 corresponded to a Commonwealth environmental water release in the Gwydir River which resulted in an increase in flows to about 200 ML/d. This flow event provided short term freshening, reducing salinity to approximately 3,000 µS/cm, before the salinity continued to rise later in November 2014 due to no-flow conditions returning. The salinity peaked at the end of second no-flow period of about 60 days at about 20,000 µS/cm. Information presented above on ecological thresholds suggest that these salinities would have been lethal to nearly all native freshwater fish.

Following the second no-flow period, the in-channel event in February 2015 peaked at about 3,000 ML/d and provided enough flow to fully mix and freshen the river and enable downstream flows. This resulted in a reduction in salinity from the 20,000 µS/cm peak to a salinity less than 1,000 µS/cm (which is the threshold for drinking water). This second flow event in February 2015 maintained a threshold of 500 ML/d for 23 days at Bourke which corresponds to one of the environmental flow requirements (500 ML/d for 20 days to provide longitudinal connectivity).

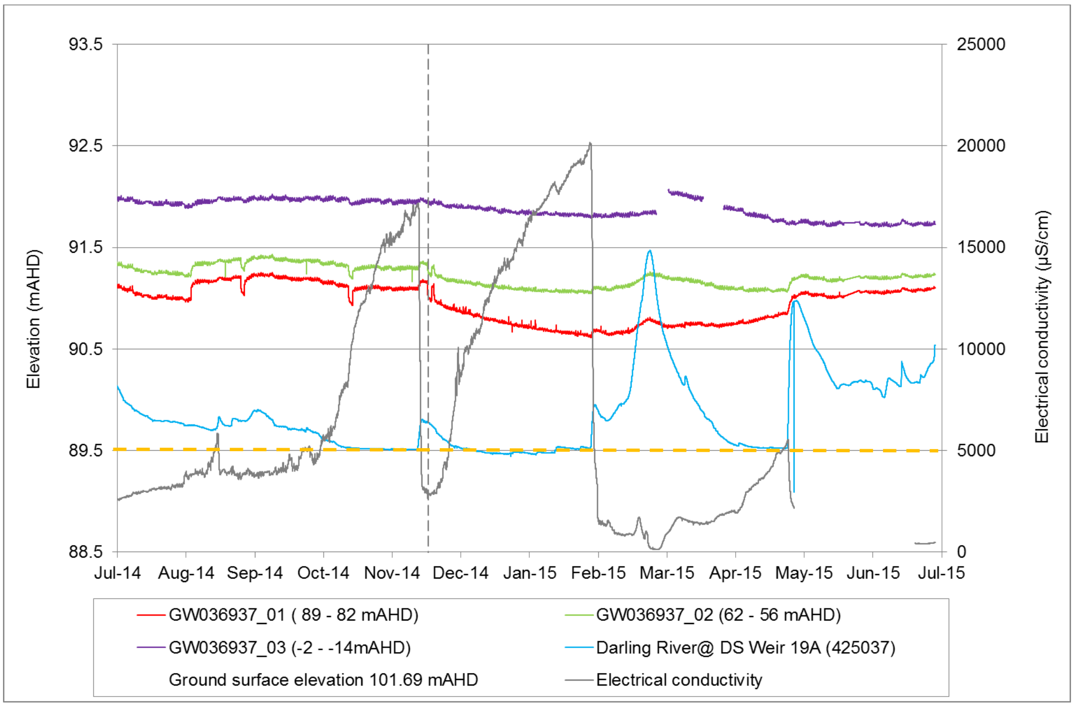


Figure 18: Monitoring of groundwater and surface water levels and salinity at the Darling River @ D/S Weir 19A gauge (orange dotted line represents low flow conditions - <10 ML/d; grey dotted line is when the Salt Interception Scheme production bores started).

Table 8 shows the salinity rise during other very low flow periods (<10 ML/d) at the downstream of Weir 19a gauge site for 2013 to 2016. The trend observed during each of these periods was the salinity rising rapidly at the start of the very low flows commencing, with the salinity diluted almost immediately by the passing of the next flow event. This trend shows the importance of regular flows in the Barwon-Darling to mitigate against salinity spikes that are likely to have sub-lethal and lethal impacts on aquatic biota and limit suitability for human and consumptive use.

Table 8: Summary of cease to flow conditions at gauge downstream of 19A and corresponding maximum salinity levels between 2013 and 2016 (Note: the SIS production bore started operating in mid-November 2014)

Number of days flow was less than 10 ML/d	Date range	Maximum EC (µS/cm) at gauge
34	January 2014 – February 2014	20,632
38	October-November 2014	16,904
64	November 2014 - January 2015	19,962
26	April 2015	5,396
63	December 2015 – February 2016	19,962
54	December 2015 – February 2016	11,258
35	April 2016 – May 2016	4,839
33	May 2016 – June 2016	6,234

The hydrological and water-quality metrics formulated to measure the ecological condition of reaches along the Barwon-Darling are summarised for Wilcannia in Figure 19. These metrics relate to water salinity, algal outbreak risk and loss of fish connectivity. A flow of ≥0.3 metres above cease-to-flow has been found to provide connectivity for small to medium-bodied fish

(Fairfull and Withebridge, 2003), which is essential in food access, shelter, access to new habitats and reproductive needs of native fish. A threshold of 1,000 µS/cm was set to indicate a decline in water quality as this is the threshold for drinking water. Risk of algal outbreak was defined as periods between October and March that exhibited flows below 350 ML/d. The October-March period was chosen as algal outbreaks are more likely to occur in hotter climates with thresholds of flow based off the work of Mitrovic et al., 2006. Figure 19 shows that declines in these metrics often occur simultaneously which consequently puts greater strain on the biota of the affected reaches.

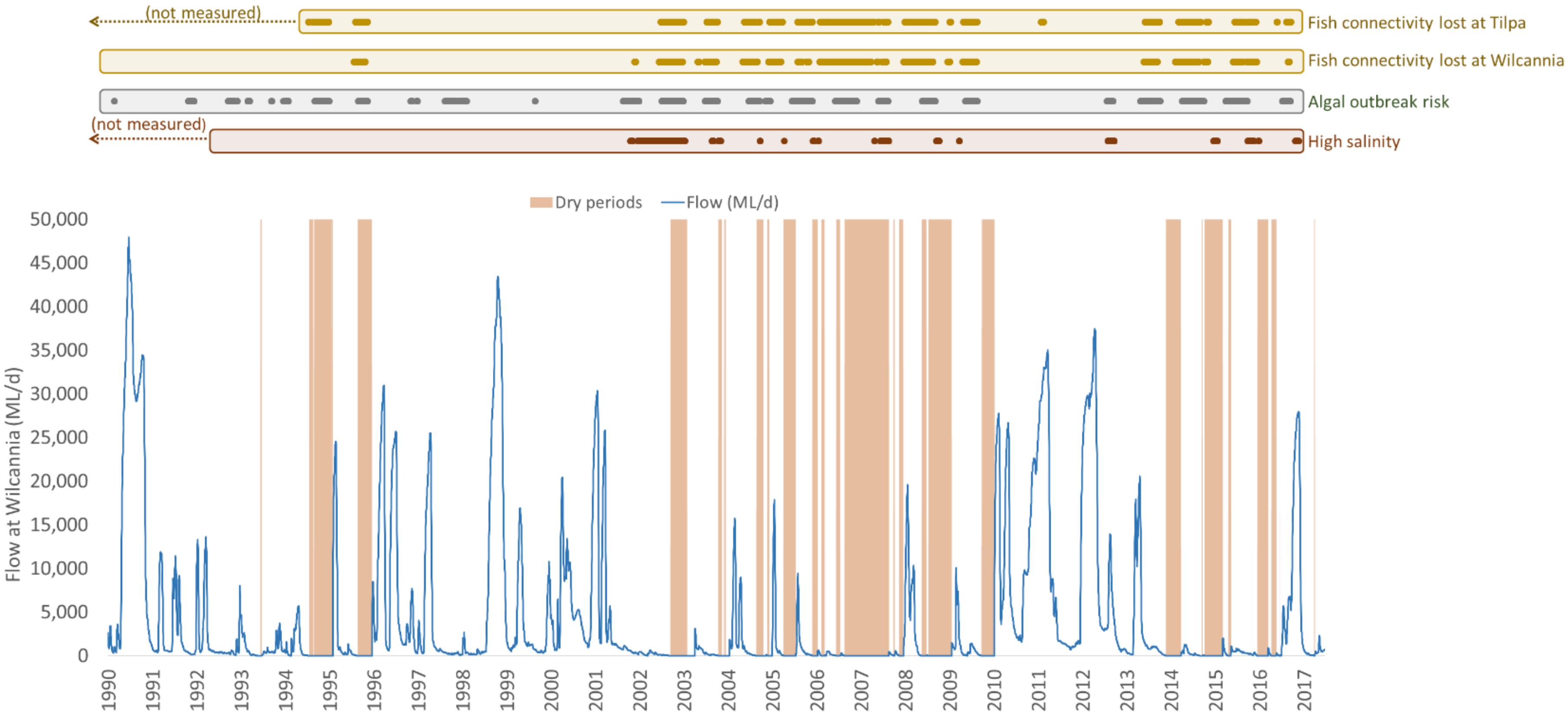


Figure 19: Hydrological and water-quality metrics used to determine ecological condition at Wilcannia compared to flow and dry periods.

Key findings and recommendations

Thirteen environmental flow requirements have been identified from the existing literature that collectively support the ecological needs for low flows in the Barwon-Darling river system:

- Maintaining populations of native fish and other aquatic biota (like mussels) by replenishing refuge pools and maintaining aquatic habitats; providing opportunities for movement between habitats; and supporting key ecosystem functions (including cycling of nutrients and provision of carbon for productive food webs);
- Supporting regular breeding and recruitment of fish and other invertebrates with short life cycles to maintain populations and genetic diversity.
- Maintaining water quality through regular flushing of refuge pools to mitigate against issues such as algal blooms and salinity spikes.
- Providing longitudinal connectivity through the Barwon-Darling river system and its tributaries to support the ecological needs above, maintain in-channel and riparian vegetation condition, and provide natural cues for flow responsive fish and other aquatic biota.

Analysis of observed flows between 1990/91 to 2016/17 shows that the environmental flow requirements have mixed performance against the identified frequency and dry spell targets.

However, the assessment of observed flows has identified very long maximum periods between the low flow environmental flow requirements being achieved and a marked departure from without development conditions. This combined with the number of thresholds of concern events being breached shows risks to the ecological needs during low flows in the Barwon-Darling as a result of extended dry periods.

The trends and impacts of the longer low or no-flow periods include:

- The maximum dry spell between flow low events is approximately doubled in length for many of the flow requirements described when comparing observed flows to the without development flow regime. In extreme cases, the maximum dry spell is greater than 10 times longer which is likely to place ecosystems under severe stress.
- Periods of low or no flow have increased for gauges downstream of Bourke post 2000 as compared to pre-2000.
- Algal bloom risks is increased through the system with the risk highest at Wilcannia (compared to Bourke and Brewarrina) and increasing for the period after 2010 (see figure below). The flow thresholds important for mixing pools to mitigate algal bloom risk are also associated with other positive outcomes, such as connectivity for fish movement between habitats.
- Salinity spikes (salinity going over 5,000 µS/cm) observed during periods of low flow for the reach between Bourke and Tilpa, as a result of saline groundwater inflows. This salinity is known to exceed the tolerance for many plants and invertebrates.
- Longer periods between opportunities for fish to move between habitats and breed, especially for smaller fish that generally live for less than five years.

It recommended that mechanisms be established for the protection of environmental water especially the flows that can limit very long dry spells. For this, it is recommended that management of unregulated flows in the Barwon-Darling river system occur at a reach scale and through management of individual flow events in order to optimise outcomes across all users, including the environment. Also, since the development of upstream catchments has an effect on flows in the Barwon-Darling, examination of the management rules in these areas could improve outcomes for the Barwon-Darling and provide a better understanding of system-wide linkages between catchments.

The impact of extraction on low flows is of highest significance for the first flow after a dry period as this event is critically important for the environment as it breaks the dry spell. However, there is acute pressure from competing demands, as irrigators also need access to this water, under their licence rules, to support the businesses. Measures for the protection of environmental water should be developed in a way that provides the environmental outcomes in a way that enables irrigation businesses to continue to operate.

No flow periods

Periods of no-flow are a natural feature of the Barwon-Darling river system due to its highly variable hydrology. However, when the length of no-flow spells are longer than the ecology of the river have adapted to, there is potential for negative ecological implications (Rolls et al. 2012). This includes reduced resilience for the aquatic community, and a transition to more generalist species with reduced diversity and abundance of more sensitive species.

In addition, no-flow spells have significant implications for communities along the river having reduced access to reliable and good quality water for town water and stock and domestic supply, and cultural and recreational purposes. Town water supplies for Collarenebri, Walgett, Brewarrina, Bourke, Louth, Tilpa, Wilcannia and Menindee are dependent on water supplies directly from the Barwon or Darling Rivers into their water treatment plants (NSW, 2012). Unlike irrigators, towns do not have off river storages.

There is limited site-specific information regarding critical thresholds for the different aquatic biota in the Barwon-Darling and their tolerance for extended dry spells. Long dry spells do impact on the ecosystem but there is no information on specific tipping points or the thresholds at which the ecosystem declines and loses its resilience (Sheldon, 2017).

However multiple lines of evidence can be used to inform what is considered a high risk no-flow spell, based on both ecological and critical human water needs considerations. Drawing upon information regarding the maximum dry spell that would have been experienced under modelled without development conditions, management options should be considered to limit no and very low flow periods from exceeding 60-80 days at Bourke and 120-150 days at Wilcannia, especially in spring-summer.

By comparison the maximum dry spell at Wilcannia in the without development model is 147 days, while a no-flow spell of 332 days observed during the millennium drought (2006-07). At Bourke the maximum without development no-flow period was 77 days as compared to 199 days observed in 2007.

The Northern Basin Review waterhole project (DSITI, 2015) found that Barwon-Darling waterholes are, for the majority, highly persistent. The exception to this is the reach of the river near Tilpa (roughly between Louth and Tilpa). This reach did run dry two times during the Landsat record (since 1988) with no flow periods of 176 days and 182 days at the Tilpa gauge. It would be desirable for flow events to be often enough to prevent this reach from going dry to prevent complete loss of habitat and provide for the supply of water for critical human needs. The recommendation above for flows at Bourke and Wilcannia will support persistence of pools in this reach of river.

The Darling River between Bourke and Tilpa is known to receive saline groundwater, with the impact greatest during times of very low flows (i.e. 10s of ML/d). There are several instances of salinity exceeding 5,000 µS/cm during no-flow spells (longer than ~30 days). There is information that indicates this is a threshold for many freshwater zooplankton and aquatic plants (Nielsen and Brock, 2009).

At Bourke and Wilcannia, the weir pool provides approximately 6 months (~180 days) and 4 months (~120 days) of town water supply (NSW, 2012). During low and no-flow periods, water restrictions are progressively implemented and access to alternate water sources (such as groundwater) are needed.

River system connectivity

The volume of water required to provide connectivity is dependent on a range of factors with the dryness of the preceding period and level of take by consumptive users being primary drivers. However, analysis of observed flows shows there is a very high likelihood of system scale connectivity, through to Wilcannia, with flow event volumes of at least 20 GL at Bourke. This would generally take the shape of a magnitude of 500 ML/d for at least 14 days, with 20 days providing more certainty. The volume needed would reduce under wetter antecedent conditions. This flow would also be sufficient to mix and freshen pools to improve water quality.

Water sharing arrangements and rules should be investigated that are able to protect the integrity of this type of flow event to pass through the river system that target minimising the identified no-flow periods at Bourke and Wilcannia.

Conclusion

The report describes environmental flow requirements for 'low flow and small fresh events' in the Barwon-Darling River based on a synthesis of existing information and literature. This report has described the types of flows that are ecologically important during drier conditions, which can be used to inform consideration of mechanisms to better protect environmental flows.

The regular occurrence of low and base-flows are critically important during dry times to support the environment and downstream communities. For the purpose of this report, low flows have been defined as representing events that typically contain flow peaks between 350 - 2,000 ML/d across the Barwon-Darling river system; consistent with the definition of ecologically significant flows adopted in previous studies. This is an important distinction as commence to pump thresholds for licences are generally within this flow range.

This work complements the previous assessment for the Northern Basin Review which focused on larger flow events (>6,000 ML/d) that are important for informing the total quantum of water to be recovered for the environment and describe the types of flows that are ecologically important during average to wetter conditions.

Thirteen environmental flow requirements were defined for different points along the river, including at Walgett, Brewarrina, Bourke, Louth and Wilcannia to describe the environmental values for low flows. These values include to maintain native fish populations and in-channel ecosystem processes, enhance native fish spawning and recruitment, mitigate against water quality issues (such as salinity and algal blooms), and provide longitudinal connectivity. These requirements will be superseded by the environmental water objectives and requirements developed for the NSW Long Term Environmental Watering Plan once available.

The performance of the environmental flow requirements show risks for the environmental values of low flows in the Barwon-Darling. The majority of environmental flow requirements show a very long maximum period between events and a marked departure from without development conditions. In addition, the number of thresholds of concern periods between events that have been breached indicates risks to ecological needs as a result of extended dry periods.

As part of another report, the MDBA has also undertaken hydrological analysis to investigate the historical behaviour of low flows (≤ 2000 ML/d) along the Barwon-Darling river system between 1990-01 and 2016-17 (MDBA, 2017b). The aim was to assess any observable changes to flow behaviour over this time period. The work produced a comprehensive catalogue of more than two thousand individual flow events to provide a robust dataset with which to undertake the investigation.

This analysis is part of ongoing work to understand and characterise the hydrology and associated ecological needs of the Barwon–Darling river system and ultimately use science and the best available information, including the lived experience of local stakeholders, to help frame options for protecting low and small fresh outcomes, in line with the conclusions of the Northern Basin Review and both the MDBA and NSW compliance reviews.

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Appendix A - Algal suppression flow spells

Table: Algal Suppression flow critical threshold summary for Bourke (assessing spells longer than 12 days)

Year	Number of spells longer than 12 days			Percent of time flow under threshold for between October and April (%)			Longest spell for the period between October and April (days)		
	Bre	Bourke	Wilc	Bre	Bourke	Wilc	Bre	Bourke	Wilc
1990-91	1	1	0	21	21	0	32	18	0
1991-92	1	1	1	37	50	34	55	60	51
1992-93	3	3	1	70	53	16	33	34	19
1993-94	2	1	1	47	34	20	55	50	30
1994-95	1	1	1	64	69	70	98	97	106
1995-96	2	1	1	43	34	43	47	52	66
1996-97	1	1	0	13	13	11	20	17	0
1997-98	3	2	2	37	41	69	32	37	37
1998-99	0	0	0	7	3	0	0	0	0
1999-00	1	1	0	18	14	1	27	15	0
2000-01	0	0	0	0	0	0	0	0	0
2001-02	3	3	3	65	68	61	40	43	55
2002-03	1	1	1	95	100	100	144	152	152
2003-04	2	2	1	43	45	61	48	48	61
2004-05	3	3	1	61	48	59	55	35	53
2005-06	4	3	2	70	75	91	41	67	88
2006-07	1	1	1	100	100	100	153	153	153
2007-08	2	1	1	44	30	38	47	43	58
2008-09	1	1	1	45	43	64	60	66	97
2009-10	1	1	1	47	49	56	72	74	85
2010-11	0	0	0	0	0	0	0	0	0
2011-12	0	0	0	0	0	0	0	0	0
2012-13	2	1	1	63	39	33	63	59	50
2013-14	1	1	1	100	100	100	152	152	152
2014-15	2	2	1	91	84	93	127	124	142
2015-16	3	1	2	93	78	96	87	78	110
2016-17	1	2	1	53	49	36	80	58	55

Appendix B - Case Study and CEWH environmental water deliveries

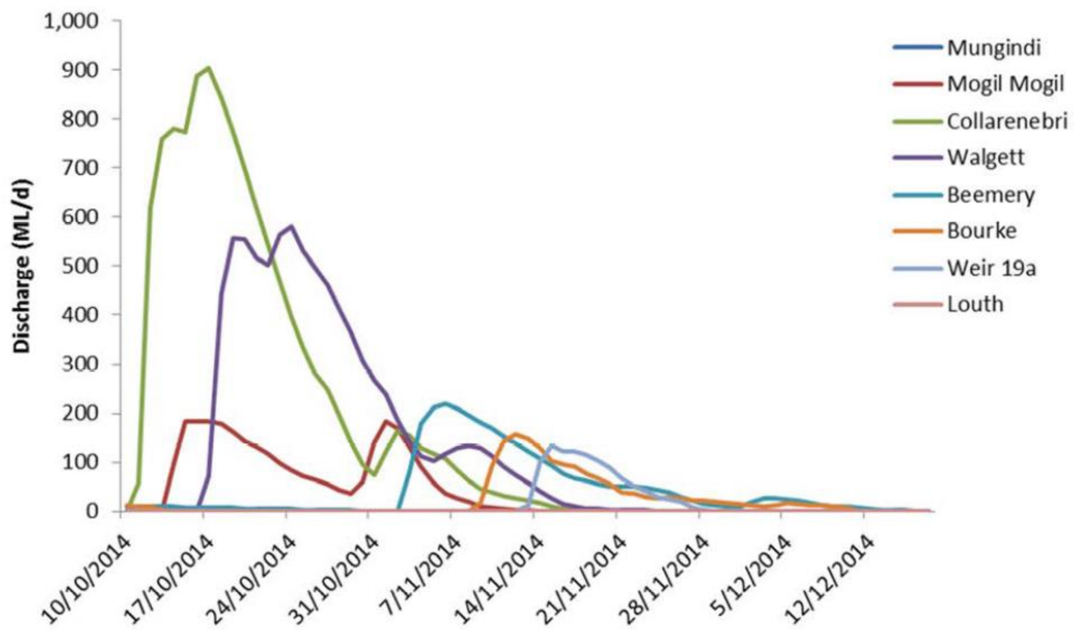
2014 connectivity event between the Gwydir River and Barwon-Darling River

Following an autumn in-channel pulse during April/May 2014, there was an extended period of low to no-flow lasting from May to October in the upper parts of the Barwon-Darling River, and through to January 2015 for the lower parts of the river system downstream of Bourke.

In October-November 2014, there was a regulated release of Commonwealth Environmental Water through the Gwydir catchment down the Mehi River and Carole Creek channels. The environmental water flowed into the Barwon-Darling River with a noticeable peak to Weir 19a, while no increase in flow was detected downstream at Louth.

The flow peaked at about 900 ML/d at Colleranebri, 600 ML/d at Walgett and 150 ML/d at Bourke (see hydrograph below). There was A and B class pumping downstream of Collarenebri, however further downstream pumping of this event would have been limited as commence to pump thresholds were not met. The Commonwealth environmental water was estimated to be 75% of the total volume in the event.

The event was above 500 ML/d for 8 days at Walgett, produced connectivity through the Brewarrina fishway for 10 days, and freshened pools through to Weir 19a.



Hydrographs at different points down the Barwon-Darling River showing how the Commonwealth environmental water inflow from the Gwydir catchment moved down the Barwon-Darling River

While there was flow in the Barwon-Darling River through to Weir 19a, the event did not provide connectivity to fill and freshen downstream pools or provide water for downstream communities. At Bourke, without the flow event there would have been about 100 days of no-flow instead of the 25 days before the event and 44 days after the event (before the next pulse in late December). At Louth and Wilcannia, the no-flow period lasted over 117 days, which is extreme (compared to 77 days as the maximum no-flow spell in the Basin Plan without development modelling for

Wilcannia). There would have been limited opportunities for fish and other aquatic biota to access habitat, flows at Bourke and downstream were not enough to mix weir pools and limit algal bloom risks and salinity became a significant problem for the reach between Weir 19a and Tilpa.

While it is not possible to know exactly, protection of this environmental water may have increased the volume that moved downstream, therefore providing relief for the environment and downstream communities during this critically dry period. It would also potentially have increased the connectivity for subsequent flow events as pools would have been topped up and transmission losses reduced. This can be important for the volume of water that reaches the Menindee Lakes Storages.

Comparison between the 2013 and 2017 connectivity events between the Gwydir River and Barwon-Darling River

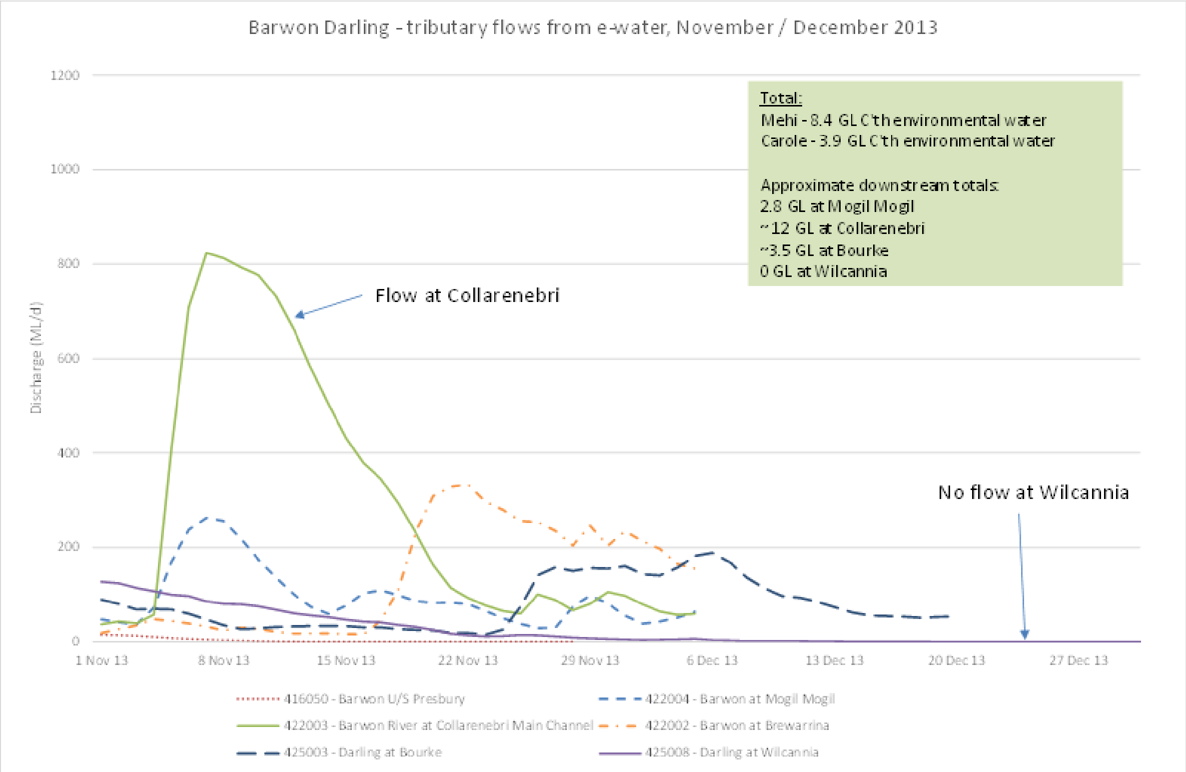
There were two similar small in-channel fresh events in the Barwon-Darling that originated from Commonwealth environmental water deliveries in tributaries in 2013 and 2017 which resulted in different levels of river system connectivity. These events were:

- A flow event in 2013 from the Gwydir system but not the Macintyre (hence very little flow u/s Presbury), where there was some pumping in the Barwon-Darling as permitted under the water sharing plan (see hydrograph below)
- A flow event spring 2017 from the Border Rivers and Gwydir systems, where Barwon-Darling water users made the decision not to divert water from this event even though some had the opportunity under their water sharing plan commence to pump rules (see hydrograph below).

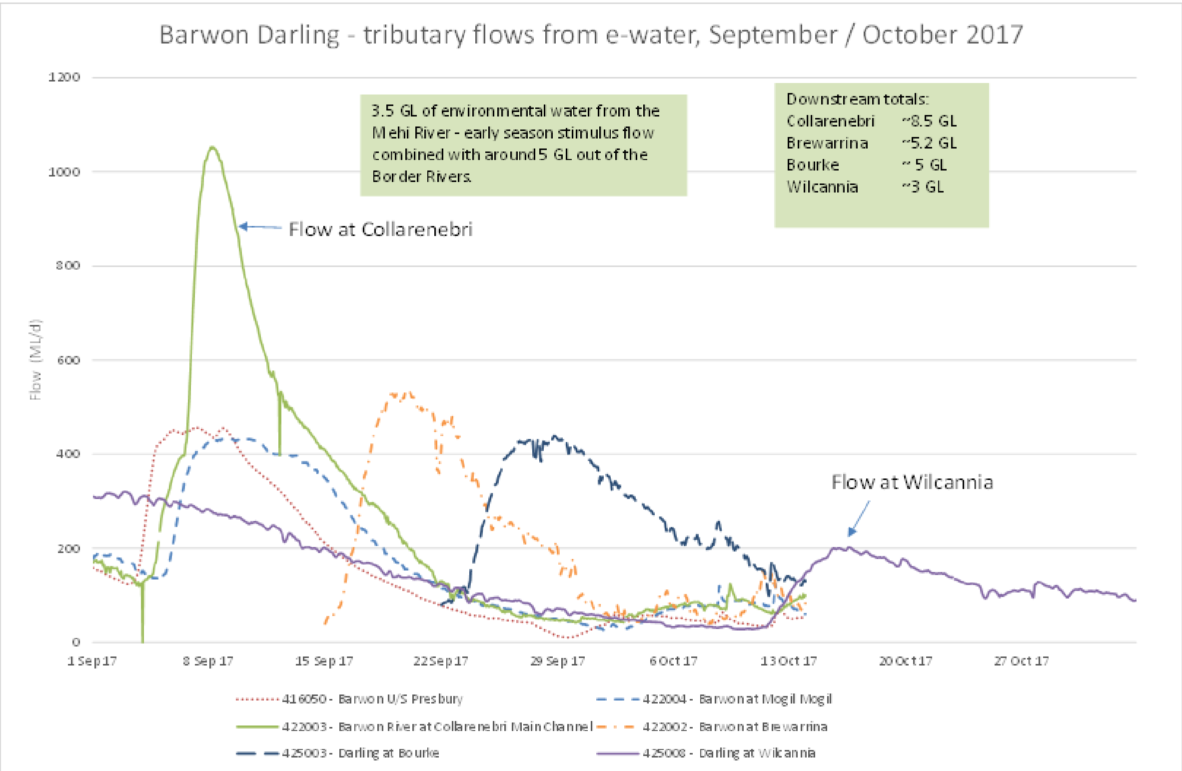
In both years, there was flow at Wilcannia in the month preceding the events. As such, the pools would likely have been close to full and transmission losses between the two years would be similar (i.e. similar antecedent conditions).

As can be seen in the hydrographs, in 2013, the flow did not make it to Wilcannia (the purple flow at Wilcannia), while in 2017, the flow did make it to Wilcannia.

This example provides a line of information to support the consideration of mechanisms for the protection of environmental water.



Flows at different points along the Barwon-Darling River between November and December 2013, following an inflow from the Border Rivers - no connectivity to Wilcannia (hydrograph provided by the Commonwealth Environmental Water Holder).



Flows at different points along the Barwon-Darling River between September and October 2017, following an inflow from the Border Rivers - no connectivity to Wilcannia (hydrograph provided by the Commonwealth Environmental Water Holder).

CEWH events contributing to flows in the Barwon-Darling River: 2012/13 to 2016

Commonwealth environmental water delivered in tributary catchments of the Barwon-Darling can provide benefits to the Barwon-Darling River, with the relative contribution and outcomes varying depending on the conditions in the river at the time and the size of the event.

The information below provides information on Commonwealth environmental water that has contributed to flows in the Barwon-Darling. This information has been sourced from the CEWH website (available at: https://www.environment.gov.au/water/cewo/catchment. Only actions that may have contributed to the Barwon-Darling are included.

Border Rivers

2016-17

- As of 30 October ML,15,291 ML of Commonwealth unregulated water in the Macintyre-Dumaresq River may have improved end-of-system flows as the Commonwealth's share of the flow event could not be extracted by other authorised users.

2014-15

- 564 ML Commonwealth unregulated water in the Macintyre-Dumaresq River may have improved end-of-system flows as the Commonwealth's share of the flow event could not be extracted by other authorised users.

2013-14

- In the NSW Severn River, 4,000 ML of Commonwealth environmental water was used in conjunction with 4,000 ML of NSW planned environmental water (released from Pindari Dam into the NSW Severn River) in the second half of August 2013. The flow was likely to have improved end of system flows (Mungindi) from residual flows that carried through the system.

2012-13

- 895 ML of Commonwealth environmental water in conjunction with 4,000 ML of NSW planned environmental water and 7,105 ML of water being released to meet downstream irrigation orders, to provide a high velocity, high peaked 'stimulus' flow in the NSW Severn River.
- The combined release of 16,000 ML from Pindari Dam commenced on 1 December and was delivered over 10 days. The co-delivery of a large volume of irrigation water reduced the Commonwealth contribution required (4,000 ML had been approved for the action).
- Some residual flows from the release carried through to the end of the system (Mungindi) where flows peaked at 800 ML/day in late December.

Gwydir

2014-15

- Commonwealth environmental water (13.3 GL in the Mehi River and 3.7 GL in Carole Creek) was delivered in October 2014 in conjunction with a block release of irrigation water. These flows contributed to the Barwon River, activating the Brewarrina fishway for a period of ten days.

- There were no inflows from upstream in the Barwon, therefore, all the flow in the Barwon River was a result of flows from the Gwydir. The flow was recorded through to the downstream of Weir 19a gauge but not to Louth.

2013-14

- In October- November 2013, residual EOS flows from regulated watering actions in the Mehi River and Carole Creek (~11 GL) generated a small flow pulse in the Barwon River between Mogil Mogil to Dangar Bridge.

Condamine-Balonne

2016-17

- In September to October 2016, the largest flow event since April 2013 occurred in the system (peaking at around 41,000 ML/day at St George on 23 Sept 2016 and a total of 270 GL passing). From this event an estimated 18 GL entered the Narran Lakes Nature Reserve and 42 GL into the lower Culgoa River, with Commonwealth environmental water contributing approximately 30% of total water left in-stream (17 GL was estimated as inflow to the Barwon-Darling. This water inundated approximately 1500 hectares, including core rookery habitat. Another moderate flow event occurred in late March 2017 (peaking at around 16,000 ML/day at St George on 7 April 2017). For both flow events, 43,750 ML of Commonwealth environmental water was provided, with the expected environmental outcomes of this watering action contributing to:
  - supporting a more naturally variable flow regime in this system, including overbank
  - supporting key ecosystem functions such as fish movement across the system and into the Barwon River
  - improving the resilience of native plant and animal communities with widespread inundation of the lignum nesting areas around Back and Clear Lakes (Narran Lakes Nature Reserve).

2015-16

- 110 GL entered the Lower Balonne system over January-March 2016, with 88 GL passing during the water harvesting event (7 to 15 February 2016). Commonwealth entitlements contributed 9.5 GL to in-stream flows during the water harvesting event.
- CEW is estimated to have increased cross-border flows (all distributary channels) by around 4.6 GL or 17% of the total (26.5 GL) and inflows into the Darling River by 2.5 GL.

2014-15

- Commonwealth environmental water contributed 17.2 GL out of a total of 186 GL of flow entering the Lower Balonne distributary system between December 2014 and March 2015. Commonwealth environmental water, in conjunction with flow protection rules (10 percent reduction in water harvesting), helped ensure that 'flow through' was achieved in all the Lower Balonne channels in this event.

- Small volumes reached the Barwon-Darling through the Birrie and Bokhara rivers in early March. These systems had not flowed in over 18 months.
- The Commonwealth environmental water improved flows in the Culgoa River, with 30 GL estimated to have reached the Barwon-Darling.

2013-14

- Commonwealth environmental water comprised around half of the 30 GL passing the Brenda gauge near the Qld-NSW border. Commonwealth environmental water combined with some local catchment inflow from the west of the Culgoa contributed to higher than expected inflows to the Barwon-Darling.
- This event followed a year-long spells of no flow, so the additional environmental water had particular benefits in replenishing and connecting waterholes throughout the distributary system and extending the period of flows.

2012-13

- During February and March 2013, nearly 65 GL of Commonwealth environmental water contributed to sequential medium flood events in the Lower Balonne system. Commonwealth environmental water is estimated to have increased end-of-system flows to the Barwon-Darling via the Culgoa and Birrie/Bokhara rivers by around 28 GL, or more than 10% of total volume reaching the Barwon River up to the end of April 2014.

Namoi

2016-17

- 7,852 ML of Commonwealth environmental water was delivered in the Lower Namoi River from March to May 2017 to provide a cue for fish, flows to support conservation stocking of silver perch between Gunnedah and Narrabri, connectivity to freshen pools and improve vegetation health, and support fish moving from the Barwon River into the Namoi River.

2012-13

- 7,728 ML of Commonwealth environmental water was delivered in the Namoi River at the end of January 2013. An estimated 6,500 ML reaching the Barwon River at the end of February 2013.
- Commonwealth environmental water combined from the Namoi, unregulated inflows from the Condamine- Balonne (~60 GL) and resulted in greater flows in the Barwon-Darling.

Macquarie

Estimating the contribution of Commonwealth environmental water to the Barwon-Darling from the Macquarie catchment is difficult:

- Depending on where environmental water is delivered, the contribution to the Barwon-Darling can be estimated based on flows from the Macquarie River at the Bells Bridge gauge (outflow from the Northern Marshes), and Marthaguy Creek at the Carinda gauge (outflows from the Eastern Marshes and upper Marthaguy unregulated flows).
- There are no gauges on the Macquarie River closer to the Barwon-Darling than at Bells Bridge.
- The potential maximum contribution to the Barwon River from the Macquarie includes all sources of water (e.g. environmental, stock and domestic, surplus flows).
- Water in the lower Macquarie River downstream of Carinda can be extracted when flows are above 50 ML/day and the volume of unregulated pumping below Bell's Bridge is unknown.

2016–17

- Between 16 April and 15 May 2017, 27,583 ML of Commonwealth environmental water was delivered to the lower Macquarie River to provide connection from to the Barwon River, via the mid-Macquarie and Macquarie Marshes.
- The objective of the watering action was to facilitate the movement of native fish between the Macquarie and Barwon rivers (in both directions). Environmental water was also expected to provide additional environmental benefits, including the inundation of wetland vegetation, provision of waterbird foraging habitat, and continued replenishment of groundwater systems.

2015–16

- 14,239 ML of Commonwealth environmental water was delivered to the Macquarie River and Marshes in winter-spring 2015 and winter 2016 (in conjunction with NSW environmental water).
- It is expected that the contribution of Commonwealth environmental water to the Barwon-Darling would have been small, with low flow rates being recorded at Bells Bridge between September and December 2015. Flows remained below the 50 ML/day threshold over which unregulated pumping can occur, so much of this water is expected to have reached the Barwon River.

2013–14

- 10,000 ML of Commonwealth environmental water was delivered to the Macquarie Marshes in winter-spring 2013, in conjunction with NSW environmental water.
- Some connectivity with the Barwon River is expected to have occurred. Observational data indicated that environmental flows entered Marthaguy Creek from the Eastern Marshes, and passed Carinda. This water may have joined the lower Macquarie River, however, there are no gauging sites to determine this. It is estimated that approximately 10,000 ML (including but not limited to environmental water) passed Bells Bridge on the Macquarie River between June and December 2013. However, the portion of Commonwealth environmental water is unknown, and where flows were above 50 ML/day this water would have been subject to unregulated extraction.

2012–13

- 100,000 ML of Commonwealth environmental water was delivered to the Macquarie Marshes in spring 2012, in conjunction with NSW environmental water.
- It is likely that some connectivity with the Barwon River occurred, however, the actual contribution is not clear. Flows were above the threshold of 50 ML/day during and after the delivery of Commonwealth environmental water, so it is likely that water may have been extracted as unregulated water downstream.

Warrego River at Toorale

2016–17

- In October 2016, approximately 7,800ML of environmental water from Warrego River licences was left in stream to provide a flow to connect the Warrego and Darling rivers to support fish, habitat and ecological processes in the Warrego River.

2013–14

- Approximately 1,292.65ML of environmental water (Warrego and Darling entitlements) was used to enhance natural flow variability in the Darling River and the Lower Warrego at Toorale.

2011–12

- Approximately 7,826ML of environmental water (Warrego River entitlements) was used to enhance in-stream flows in the lower Warrego and Darling Rivers.

Barwon-Darling

Use of Commonwealth environmental water in the Barwon-Darling is dependent on river flow triggers in licence conditions under the NSW Water Sharing Plan Barwon-Darling Unregulated and Alluvial Water Source.

Commonwealth environmental water operates under the same rules as irrigation water. Water that becomes available from the Commonwealth's unregulated holdings in the Barwon-Darling River is left in-stream to support natural river flows and contribute to a more naturally variable flow regime. How flows extend through the system depends on the size and duration of individual flow events.

2016-17

- Approximately 26,796 ML of environmental water entitlements from the Barwon River entitlements and the Darling River entitlements at Toorale was left in-stream to support natural river flows (baseflows, freshes, bankfull and overbank component). These flows contributed to a more naturally variable flow regime to improve the resistance of aquatic biota and the resilience of the system.

2015–16

Approximately 7,640 ML of environmental water entitlements from the Barwon River near Collarenebri and the Darling River entitlements at Toorale was left in-stream to support natural river flows (baseflows, freshes, bankfull and overbank component) and contribute to a more naturally variable flow regime in this system to improve the resistance of aquatic biota and the resilience of the system.

2014–15

- Approximately 1,715 ML of environmental water entitlements from the Barwon River near Collarenebri and the Darling River entitlements at Toorale was left in-stream to support natural river flows (baseflows, freshes, bankfull and overbank component) and contribute to a more naturally variable flow regime in this system to improve the resistance of aquatic biota and the resilience of the system.

2013–14

- Approximately 13,009 ML of environmental water entitlements from the Barwon River near Collarenebri and the Darling River entitlements at Toorale was left in-stream to support natural river flows (baseflows, freshes, bankfull and overbank component) and contribute to a more naturally variable flow regime in this system to improve the resistance of aquatic biota and the resilience of the system.

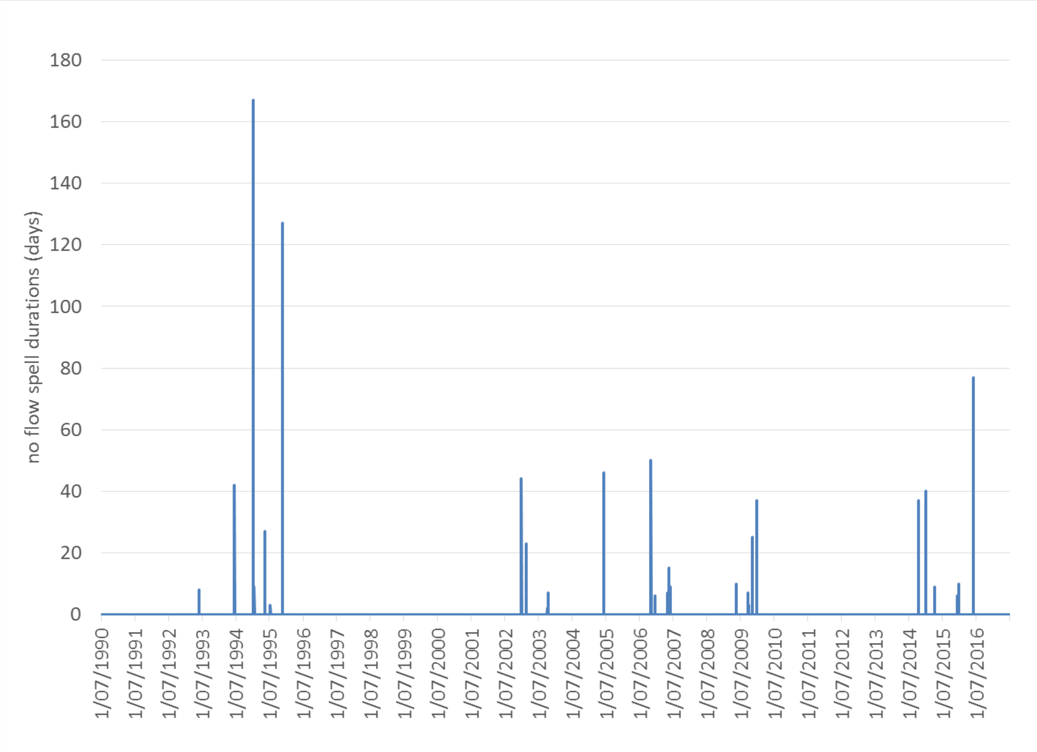
2012–13

- Approximately 25,616 ML of environmental water entitlements from the Barwon River near Collarenebri and the Darling River entitlements at Toorale was left in-stream to support natural river flows (baseflows, freshes, bankfull and overbank component) and contribute to a more naturally variable flow regime in this system to improve the resistance of aquatic biota and the resilience of the system.

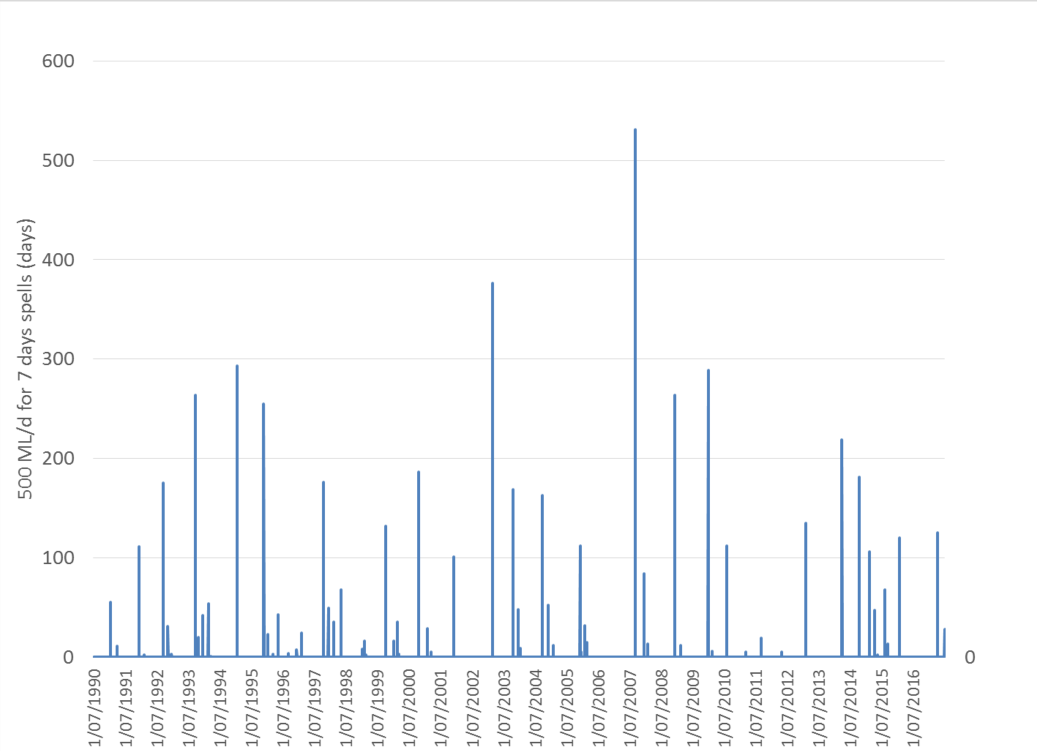
2011–12

- Approximately 8,100 ML of Toorale entitlements was used to enhance in-stream flows to benefit assets in the Warrego River downstream of Boera Dam and Darling River below the junction with the Warrego.

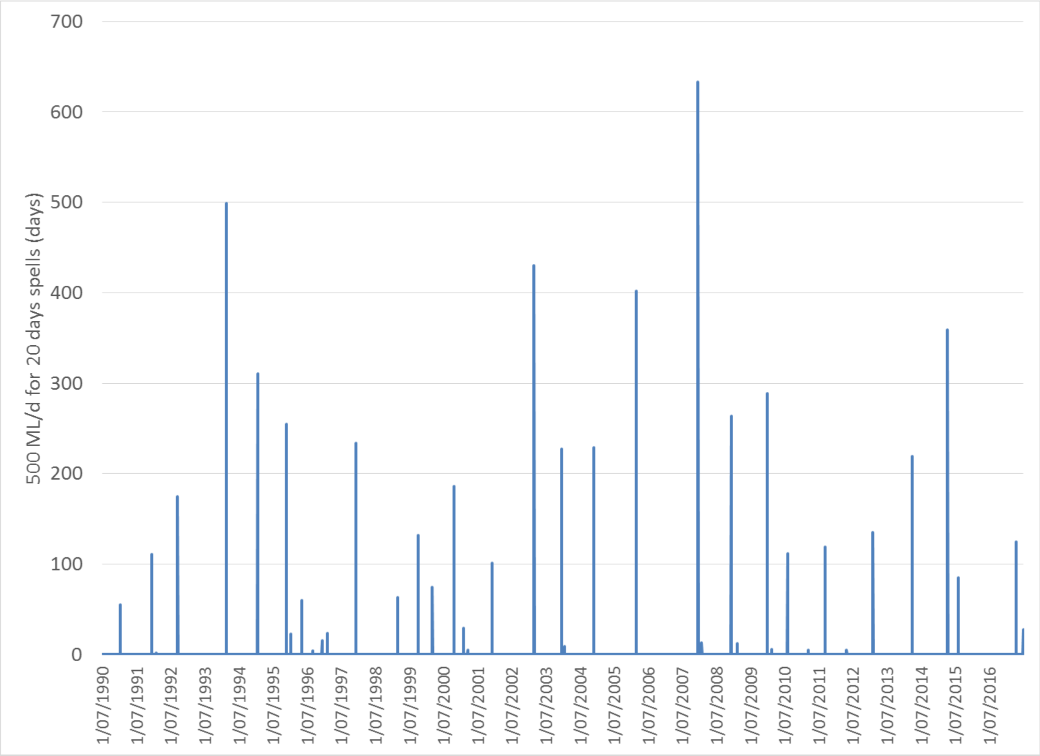
Appendix C - Distribution of environmental flow indicator spells for between 1990 and 2017.



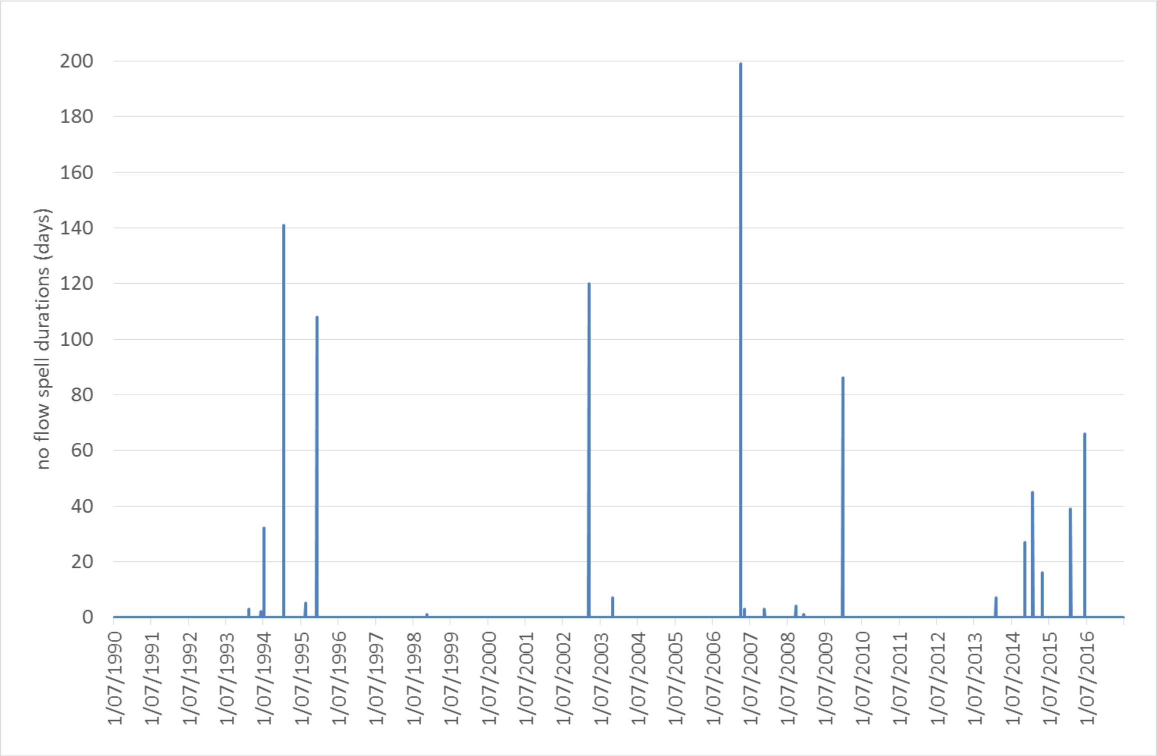
Observed no-flow spells durations - 1990-01 to 2016-17 at Walgett



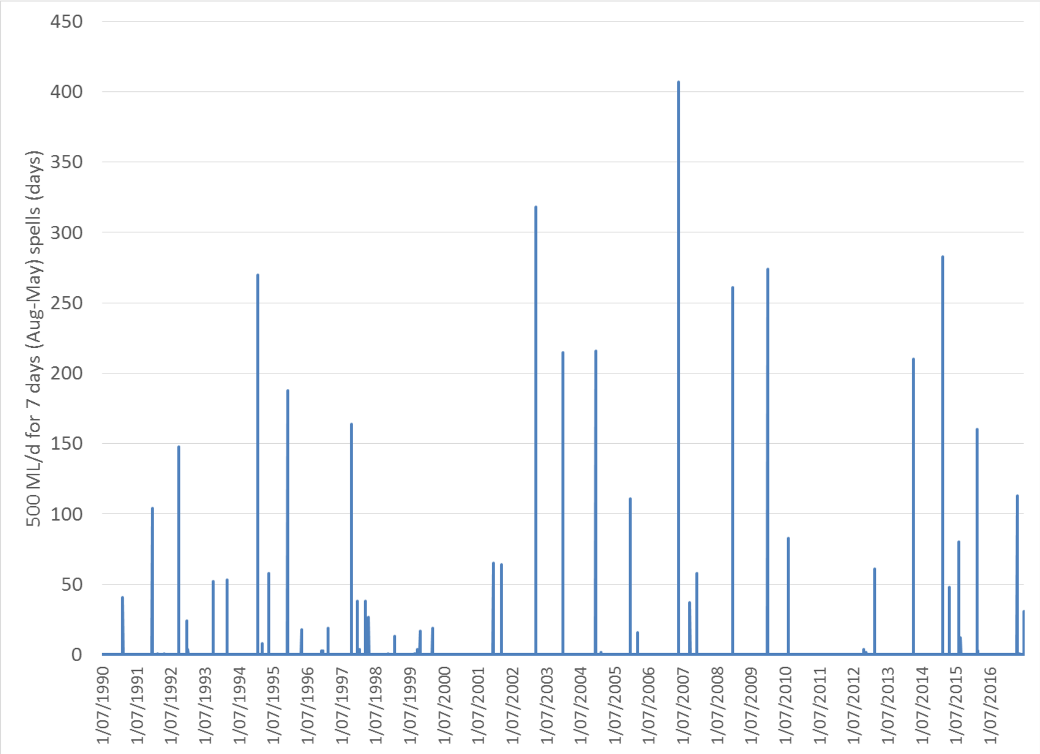
Observed spells between a flow event of 500 ML/d for 7 days - 1990-01 to 2016-17 at Walgett



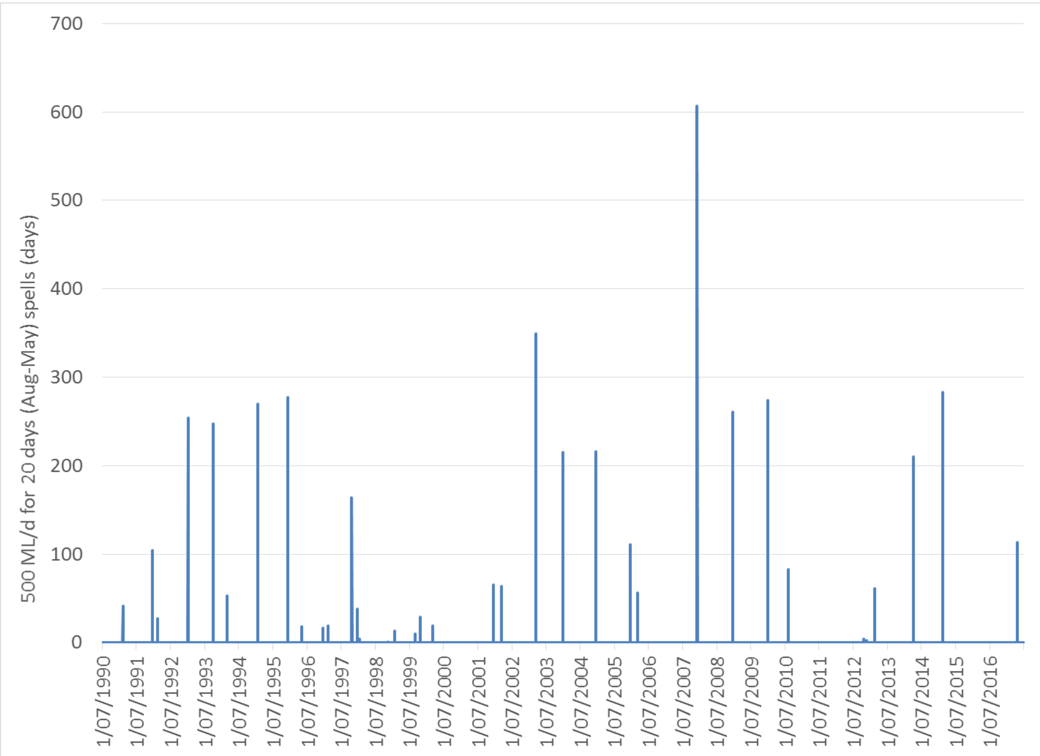
Observed spells between a flow event of 500 ML/d for 20 days - 1990-01 to 2016-17 at Walgett



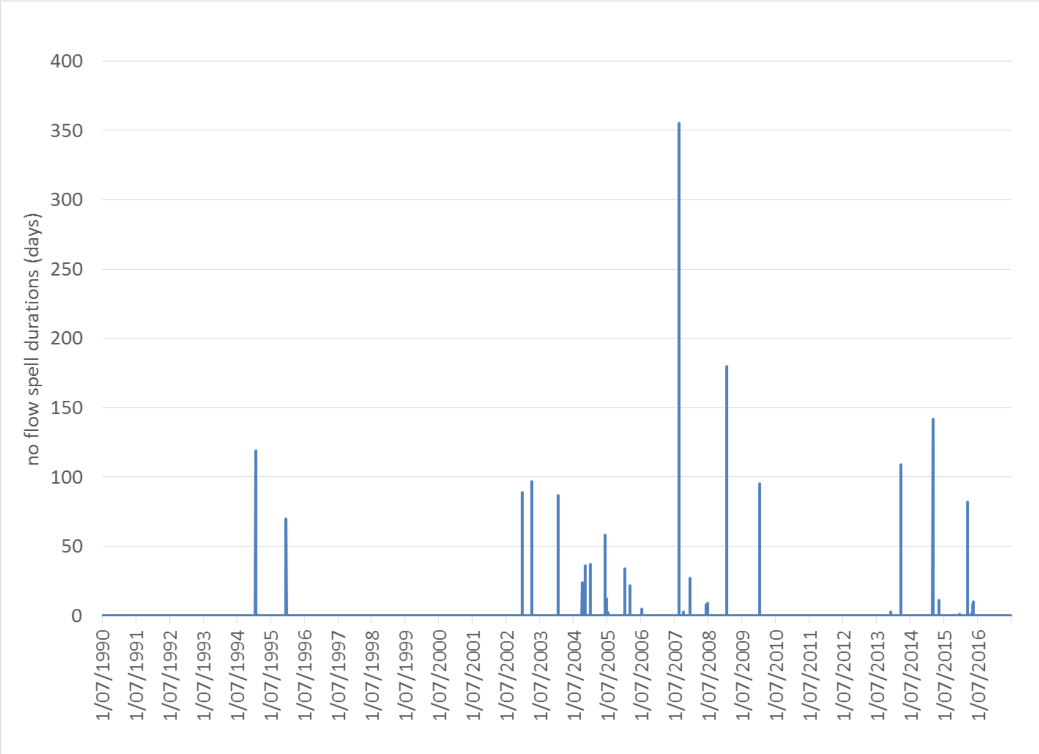
Observed no-flow spells durations - 1990-01 to 2016-17 at Bourke



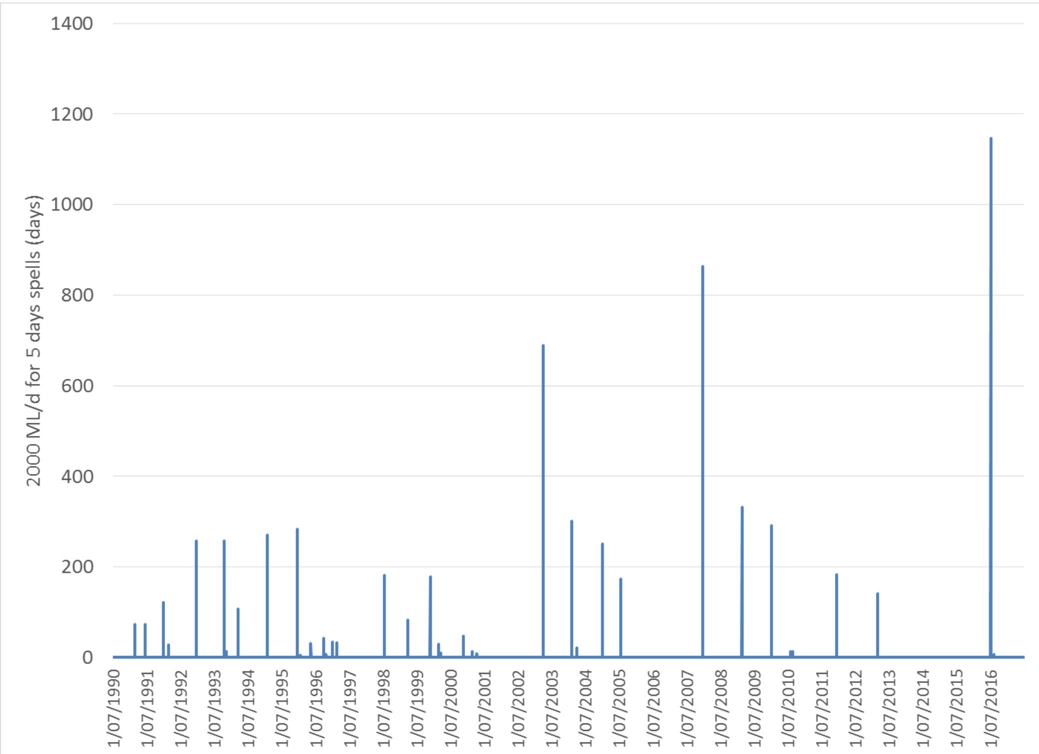
Observed spells between a flow event of 500 ML/d for 7 days (Aug-May) - 1990-01 to 2016-17 at Bourke



Observed spells between a flow event of 500 ML/d for 20 days (Aug-May) - 1990-01 to 2016-17 at Bourke



Observed no-flow spells durations - 1990-01 to 2016-17 at Wilcannia



Observed length of spells between flow events of 2,000 ML/d for 5 days at Wilcannia using the observed flow record between 1990-91 and 2016-17. The figure shows the significant period between events between 2013 and 2016 (3.1 years); longer than the most significant spell experienced during the millennium drought in 2007 (2.4 years).