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MURRAY–DARLING BASIN AUTHORITY

Assessment of environmental water requirements: Barwon–Darling river system

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Cover image: Darling River at Weir 19a, between Louth and Bourke, May 2016 (photo by Willem Vlotman)

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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 Darren Perry (Chair of the Murray Lower Darling Rivers Indigenous Nations) —

> *'the environment that Aboriginal people know as Country has not been allowed to have a voice in contemporary Australia. Aboriginal First Nations have been listening to Country for many thousands of years and can speak for Country so that others can know what Country needs. Through the Murray Lower Darling Rivers Indigenous Nations and the Northern Basin Aboriginal Nations the voice of Country can be heard by all'.*

This report may contain photographs or quotes by Aboriginal people who have passed away. The use of terms 'Aboriginal' and 'Indigenous' reflects usage in different communities within the Murray–Darling Basin.

Summary

This report describes the updated assessment of environmental water requirements for the Barwon–Darling river system as a step in the process towards setting the Sustainable Diversion Limits for the system. This report describes a set of flow indicators that are subsequently used in hydrological modelling to identify likely environmental outcomes from different levels and patterns of water recovery. The information from the environmental water requirements and environmental outcomes reports will then be considered along with social, economic and hydrological analysis during the review of surface water Sustainable Diversion Limits for the northern basin (Northern Basin Review report).

The Basin Plan provides a framework for the management of water resources in the Murray–Darling Basin. The objectives of the Basin Plan include to protect and restore water-dependent ecosystems and functions, with the aim of achieving a healthy working Murray–Darling Basin.

Before making the Basin Plan in 2012, the environmental water requirements of 24 large environmental assets (known as umbrella environmental assets) across the Murray–Darling Basin were assessed. These assessments, along with information from other disciplines, were used to inform the setting of long-term average Sustainable Diversion Limits in the Basin Plan.

At the time of making the Basin Plan, it was decided that there would be a review into aspects of the Basin Plan relating to the northern basin. The Northern Basin Review includes research and investigations in social and economic analysis, hydrological modelling, and environmental science, supported by stakeholder engagement. The environmental science program within the Northern Basin Review focused on relationships between river flows and the ecological responses of key flora and fauna (particularly fish and waterbirds) as well as broader ecosystem functions. The environmental science program also included an analysis of the persistence of waterholes that act as drought refuges, and the mapping of floodplain inundation, in-channel habitat and floodplain vegetation.

The Northern Basin Review is re-applying the established and peer reviewed Environmentally Sustainable Level of Take method. The environmental science steps of the Environmentally Sustainable Level of Take method require selection of umbrella environmental assets (UEAs) within catchments; identification of the hydrological characteristics and ecological values and targets for those assets; and selection of flow indicators that represent important flow-ecology relationships. Each flow indicator is made up of a number of hydrologic metrics (magnitude, duration, timing, frequency) that have eco-hydrological relevance within the related UEA and, by inference, the catchment more broadly.

For the Barwon–Darling river system, one umbrella environmental asset was selected: from the start of the Barwon River at Mungindi to Menindee Lakes (Figure 1).

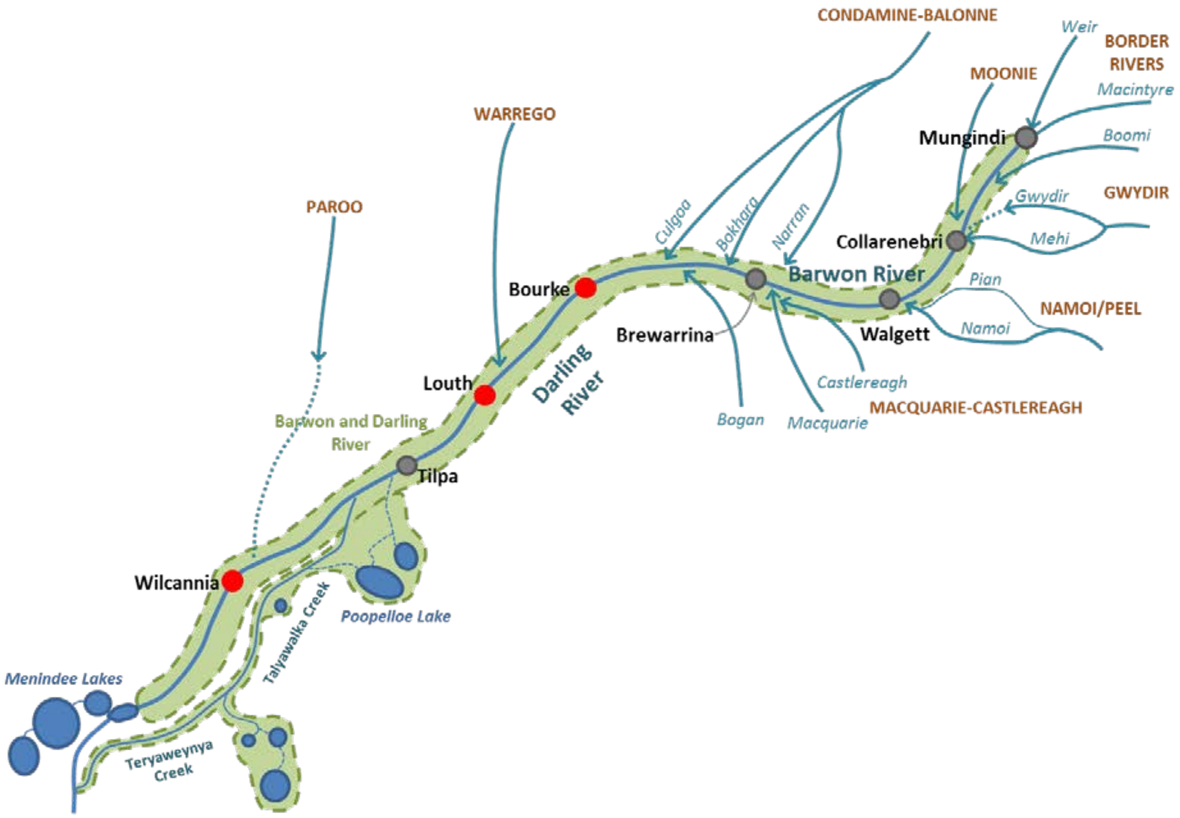

Figure 1: Stylised map of the Barwon–Darling river system. The location of the Barwon–Darling UEA is indicated by the green shading and dotted lines.

The ecological values of the Barwon–Darling river system UEA include species that are listed for protection under Commonwealth and NSW legislation, a large number of floodplain habitats providing foraging habitat for migratory bird species listed under international agreements, and wetlands listed on the Directory of Important Wetlands in Australia. In the Environmentally Sustainable Level of Take method, a number of ecological targets were specified to reflect these ecological values. The ecological targets from the original Basin Plan assessment for the Barwon–Darling river system UEA have largely been retained. 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
- supports hydrological connectivity between habitats, along the river (longitudinal) and between the river and its floodplain (lateral).

Two ecosystem functions have been used to inform the environmental water requirement assessments and link ecological targets and values to site-specific flow indicators. These ecosystem functions are:

- **longitudinal connectivity** – provide hydrological connections along watercourses that: link a diversity of aquatic environments for feeding, breeding, dispersal, migration and re-colonisation by native aquatic species; and facilitate geomorphic processes, sediment movement and nutrient spiralling.

- **lateral connectivity** – provide hydrological connections between watercourses and adjacent floodplains and wetlands that: link a diversity of aquatic environments for feeding, breeding, migration and re-colonisation by native water-dependent species; support the vigour and condition of native vegetation; and facilitate off-stream primary production, and nutrient and organic matter exchange.

Site-specific flow indicators were selected to represent the water requirements of each of these ecosystem functions. Each site-specific flow indicator for the Barwon–Darling river system is summarised in (Table 1).

The site-specific flow indicators described in this report are used in a broad-scale assessment of likely environmental outcomes under different water recovery scenarios using hydrological models. Results of this assessment are available in the Northern Basin outcomes report. How effectively different water recovery scenarios reach flow indicator targets constitutes one line of evidence that is used in conjunction with economic and social evidence to understand the implications of different possible Sustainable Diversion Limits.

Table 1: Summary of site-specific flow indicators for the Barwon-Darling UEA

Barwon–Darling ecological targets	Ecosystem function	Flow indicator gauge	Magnitude: flow (ML/d)	Duration (days)	Timing	Frequency Low uncertainty	Frequency High uncertainty
Provide 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 • supports hydrological connectivity between habitats, along the river (longitudinal) and between the river and its floodplain (lateral)	Longitudinal connectivity (small fresh)	Bourke	6,000	14	Minimum of 1 event at any time of year	90% of years (with at least 1 event)	80% of years (with at least 1 event)
	Longitudinal connectivity (small fresh)	Louth	6,000	20	Minimum of 1 event between August and May	70% of years (with at least 1 event)	70% of years (with at least 1 event)
	Longitudinal connectivity (small fresh)	Wilcannia	6,000	7	Minimum of 2 events at any time of year	60% of years (with at least 1 event)	45% of years (with at least 1 event)
	Longitudinal connectivity (large fresh)	Bourke	10,000	14	Minimum of 1 event between August and May	80% of years (with at least 1 event)	60% of years (with at least 1 event)
	Longitudinal connectivity (large fresh)	Bourke	10,000	20	Minimum of 2 events between August and May	35% of years (with at least 1 event)	25% of years (with at least 1 event)
	Longitudinal connectivity (large fresh)	Louth	21,000	20	Minimum of 1 event between August and May	40% of years (with at least 1 event)	40% of years (with at least 1 event)
	Longitudinal connectivity (large fresh)	Wilcannia	20,000	7	Minimum of 1 event at any time of year	60% of years (with at least 1 event)	45% of years (with at least 1 event)
	Lateral connectivity (riparian zone)	Bourke	30,000	24	Minimum of 1 event at any time of year	2 years (average period between events)	3 years (average period between events)

Barwon–Darling ecological targets	Ecosystem function	Flow indicator gauge	Magnitude: flow (ML/d)	Duration (days)	Timing	Frequency Low uncertainty	Frequency High uncertainty
	Lateral connectivity (inner floodplain)	Bourke	45,000	22	Minimum of 1 event at any time of year	3.5 years (average period between events)	4 years (average period between events)
	Lateral connectivity (mid floodplain)	Bourke	65,000	24	Minimum of 1 event at any time of year	6 years (average period between events)	8 years (average period between events)
	Lateral connectivity (outer floodplain)	Wilcannia	2,350 GL (volume) measured once flow is above 30,000 ML/d	> 60	Minimum of 1 event at any time of year	10% of years (with at least 1 event)	7% of years (with at least 1 event)

Contents

1 Introduction

The *Water Act 2007* (Cwlth) established the Murray–Darling Basin Authority (MDBA) and tasked it with preparing a Basin Plan to provide for the integrated management of the water resources of the Murray–Darling Basin. The objectives of the Basin Plan include to protect and restore water-dependent ecosystems and functions in the context of a healthy working Murray–Darling Basin. The characteristics of a healthy working river system are presented in Box 1, and reflect a balance between the water available to the environment and that used by communities and industries.

Box 1: Characteristics of a healthy working river system (from MDBA 2014)

A 'healthy working river' is one in which the natural ecosystem has been altered by the use of water for human benefit, but retains its ecological integrity while continuing to support strong communities and a productive economy in the long-term.

For the many rivers in the basin, water is captured, extracted or diverted to support communities, agriculture and other industries. Communities also value healthy and functioning river and floodplain ecosystems, which provide many important services. These include clean water for drinking and agricultural use, nutrient cycling between the river and floodplain, fish stock for anglers, and an environment that supports tourism, recreation and cultural values. To achieve these multiple benefits, there needs to be a balance between the water available to the environment and the water that is used by communities and industries – hence the concept of a 'healthy working river'.

Typically, working rivers have dams, weirs and other infrastructure; and towns, agriculture and developments on adjacent floodplains. These will continue to exist, although how they are managed may evolve. A healthy working river also supports biological communities, habitats and ecological processes and is resilient to natural variability.

One of the key requirements of the Basin Plan is to establish environmentally sustainable limits on the amount of surface water and groundwater that may be taken for consumptive use, called Sustainable Diversion Limits (SDLs). SDLs are the maximum long–term annual average quantities of water that can be taken from the basin and reflect an Environmentally Sustainable Level of Take (ESLT). The method to determine an ESLT is described in the MDBA report, *The proposed 'environmentally sustainable level of take' for surface water of the Murray–Darling Basin: Methods and outcomes (*MDBA 2011). The method has been reviewed by a CSIRO-led group of scientists (Young et al. 2011). The ESLT method was applied across the Murray–Darling Basin prior to the making of the Basin Plan in 2012.

The Basin Plan provides a broad framework for the management of the water resources of the Murray–Darling Basin. Implementing the Basin Plan involves more detailed planning and management, of which examples are provided in Box 2.

Box 2: Examples of more detailed requirements under the Basin Plan

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

Consistent with this strategy, states are developing regional long-term watering plans, which identify important environmental assets and ecosystem functions and their environmental watering requirements. States may use similar or different environmental assessment methods to those in the ESLT method, most likely at a greater level of detail, to inform more detailed planning decisions. For example, state planners may use data from more gauges and use a greater number of environmental indicators, so long as those methods are consistent with the Basin Plan.

With respect to short-term management of environmental water at a catchment or valley scale, and associated river operations, a flexible and adaptive process is used to respond to opportunities as they arise. That is, environmental managers decide how best to use the available environmental water to achieve environmental outcomes based on environmental opportunities, antecedent conditions and short-term water availability. Such environmental watering decisions are couched within longer term watering plans. The environmental water requirements described in this report do not represent a prescription of what environmental flows must or should be delivered in the short term. Environmental water managers may however draw on this information when deciding how much water to deliver in a particular watering event.

In finalising the Basin Plan in 2012, the MDBA recognised there was less knowledge available for the northern basin than the southern basin, and provided an opportunity in the Basin Plan for additional investigative work in multiple disciplines to see if there is a case for refining the initial Sustainable Diversion Limits (Hart 2015). This is referred to as the Northern Basin Review. In undertaking this work, it is recognised that estimating the water needs of aquatic ecosystems at a broad scale is a challenging task (see Box 3).

Box 3: Universal challenge in estimating the water needs of aquatic ecosystems (from Swirepik et al. 2015)

Imperfect knowledge of flow-ecology relationships is a universal challenge in determining the water needs of aquatic ecosystems (Poff and Zimmerman, 2010). We are not aware of any large river basin where high-quality science and hydrological modelling could comprehensively describe the flow regime required to protect and restore each part of the basin. It is generally not possible to explicitly know and understand the water requirements of all ecosystem components in a large basin. 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 (which the MDBA has used) enables the integration of existing information for key sites, which are then used to represent environmental water requirements across larger areas.

The ecology and hydrology of the northern basin is complex and any environmental assessment method inevitably has some uncertainties which are acknowledged (Appendix A). To improve our knowledge of the northern basin, the MDBA conducted and commissioned different research projects. The work included environmental science research projects and literature reviews, hydrological modelling and socio-economic projects. This report considers the environmental water requirements of the Barwon–Darling river system based on the environmental science assessments. Other reports summarise the hydrological modelling and the socio-economic assessment.

The environmental science projects were selected using advice from basin governments, community groups, and findings from an independent scientific review (*Sheldon et al. 2014*). Other knowledge and advice, including that made available by basin jurisdictions through the Environmental Science Technical Advisory Group, was also considered. Organisations that provided input into the environmental science program are acknowledged in Appendix B.

New research since the making of the Basin Plan in 2012 in the Barwon–Darling catchment and/or the Condamine–Balonne catchment is indicated by italics throughout this report (e.g. *NSW DPI 2015*).

In this report we describe the rationale for the selection of different flow indicators (termed site-specific flow indicators) in the Barwon–Darling that are used to represent the environmental water requirements of these systems. The flow indicators are used to assess environmental outcomes in subsequent hydrological modelling. Other statistics, such as maximum dry spells, are used to provide additional resolution of the expected environmental outcomes in the associated environmental outcomes report.

2 The Environmentally Sustainable Level of Take method

2.1 Overview

The Environmentally Sustainable Level of Take (ESLT) method was applied in the development of the Basin Plan (MDBA 2011) and has been re-applied in the Northern Basin Review. A summary of the main steps in the ESLT method is in Figure 2. The ESLT method includes decision making based on socio-economic, hydrological and environmental science knowledge.

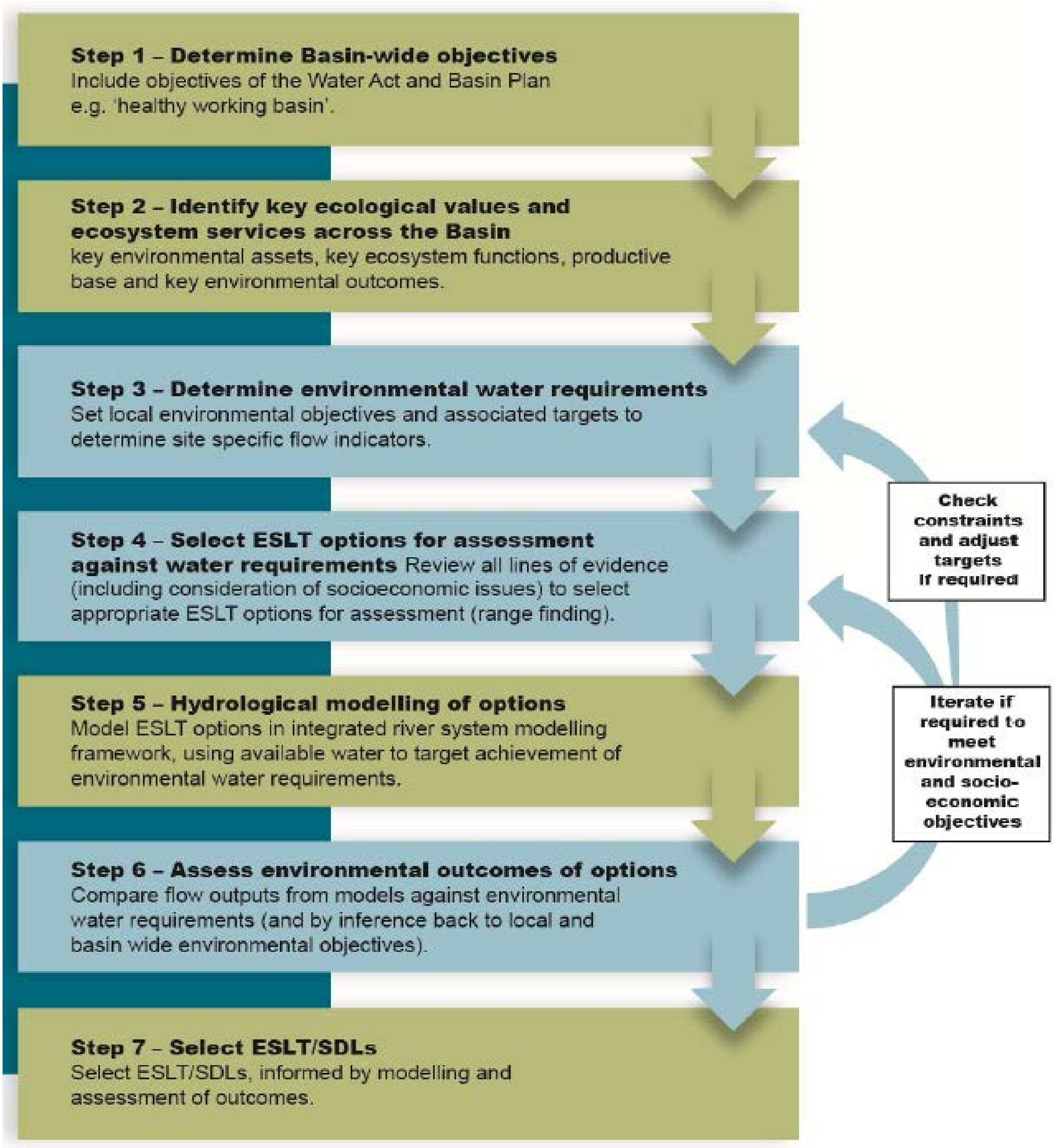

Figure 2: The Environmentally Sustainable Level of Take method (MDBA 2011). Steps 2 and 3 are the focus of this report.

This report documents the assessment of environmental water requirements (Steps 2 and 3 of the ESLT method). Importantly, this assessment does not determine the Sustainable Diversion Limits for the Barwon–Darling river system in the Basin Plan. Rather it provides environmental indicators that are used in hydrological modelling to provide information into a subsequent review of Basin Plan settings.

The integration of all the ESLT steps, including the hydrological modelling[1] and socio-economic assessments[2], is described in the Northern Basin Review report.

While the ESLT method is the same as that used in the development of the Basin Plan, some of the terminology has changed here to be more consistent with international practice, as discussed in more detail in Swirepik et al. (2015). One particular change relates to the term for the spatial units used in the environmental water requirements assessments. The ESLT method report (MDBA 2011) refers to these as 'hydrologic indicator sites' while the paper by Swirepik et al. (2015) uses the term 'umbrella environmental assets' (UEA) to better reflect their role in the assessment approach. The latter aligns with the concept of umbrella species in conservation biology (Lambeck 1997; Roberge and Angelstam 2004).

The term 'umbrella environmental asset' (UEA) refers to an area for which there is relatively rich knowledge with respect to flow-ecology relationships when compared to the broader region within which the area sits. The knowledge available for UEAs is used to develop flow-ecology relationships for a range of ecosystem functions (e.g. longitudinal connectivity, lateral connectivity) and the assumption of the approach is that the water needs of the UEAs will broadly reflect the water needs of a set of assets in the system. This approach directly addresses the issue of incomplete or developing knowledge, which is the typical situation in large-scale ecosystem management (Swirepik et al. 2015). There were 24 UEAs assessed across the Murray–Darling Basin to inform the Basin Plan[3], one of which was a UEA in the Barwon–Darling catchment: the Barwon–Darling upstream of Menindee Lakes (MDBA 2012).

2.2 Approach to assess environmental water requirements

This section describes the approach for determining the environmental water requirements for the Barwon–Darling river system. The steps in the approach are:

- selecting umbrella environmental assets (section 2.2.1)
- identifying ecological values and targets (section 2.2.2)
- identifying key flow components (section 2.2.3)
- considering evidence to inform selection of site-specific flow indicators (section 2.2.4)
- selecting site-specific flow indicators to represent important flow-ecology relationships (section 2.2.5)
- selecting flow indicator gauges (section 2.2.6)
- using site-specific flow indicators in hydrological modelling (section 2.2.7).

[1] Hydrological modelling is reflected in steps 1, and 4-7 of the ESLT method in particular
[2] Socio-economic assessments are reflected in steps 1, 4, 7 of the ESLT method in particular
[3] (click here to view these assessments or visit http://www.mdba.gov.au/publications/mdba-reports/assessing-environmental-water-requirements-basins-rivers)

2.2.1. Selecting umbrella environmental assets

Within each valley chosen for assessment, 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 Box 4.
- **Representative of water requirements**. The water requirements of a UEA are assumed to represent the water needs of a broader reach of river or an entire river valley. This principle tends to focus the selection of UEAs on large, water-dependent ecosystems, typically at the downstream end of a river reach or valley. Flows at these downstream sites are associated with a broad extent of inundation, and are assumed to have provided flows, connectivity and benefits to the upstream riverine environment on the way through.
- **Spatially representative**. The hydrology and geomorphic character of UEAs is to be representative of river valleys or large reaches, rather than sites of unusual hydrology and geomorphic character.
- **Significant flow alteration**. UEAs experience significant departures from without development flows (i.e. simulated conditions without water resource development) in parts of the flow regime.
- **Availability of data**. The quality and quantity of hydrological and ecological information associated with a UEA needs to be sufficient to allow a detailed assessment of environmental water requirements.

Applying these selection principles to the Barwon–Darling system has resulted in one UEA being selected. This is the Barwon–Darling River upstream of Menindee Lakes to Mungindi on the NSW/Queensland border, as shown in Figure 3. This is the same UEA that was used in the original analysis of the Barwon–Darling river system (MDBA 2012). A description of this UEA is provided in chapter 3.

Box 4: Relevant criteria from the Basin Plan

Criteria for identifying an environmental asset (from Basin Plan Schedule 8)

1. The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements.
2. The water-dependent ecosystem is natural or near-natural, rare or unique.
3. The water-dependent ecosystem provides vital habitat.
4. Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities.
5. The water-dependent ecosystem supports, or with environmental watering is capable of supporting significant biodiversity.

Criteria for identifying an ecosystem function (from Basin Plan Schedule 9)

1. The ecosystem function supports the creation and maintenance of vital habitats and populations.
2. The ecosystem function supports the transportation and dilution of nutrients, organic matter and sediment.
3. The ecosystem function provides connections along a watercourse (longitudinal connections).
4. The ecosystem function provides connections across floodplains, adjacent wetlands and billabongs (lateral connections).

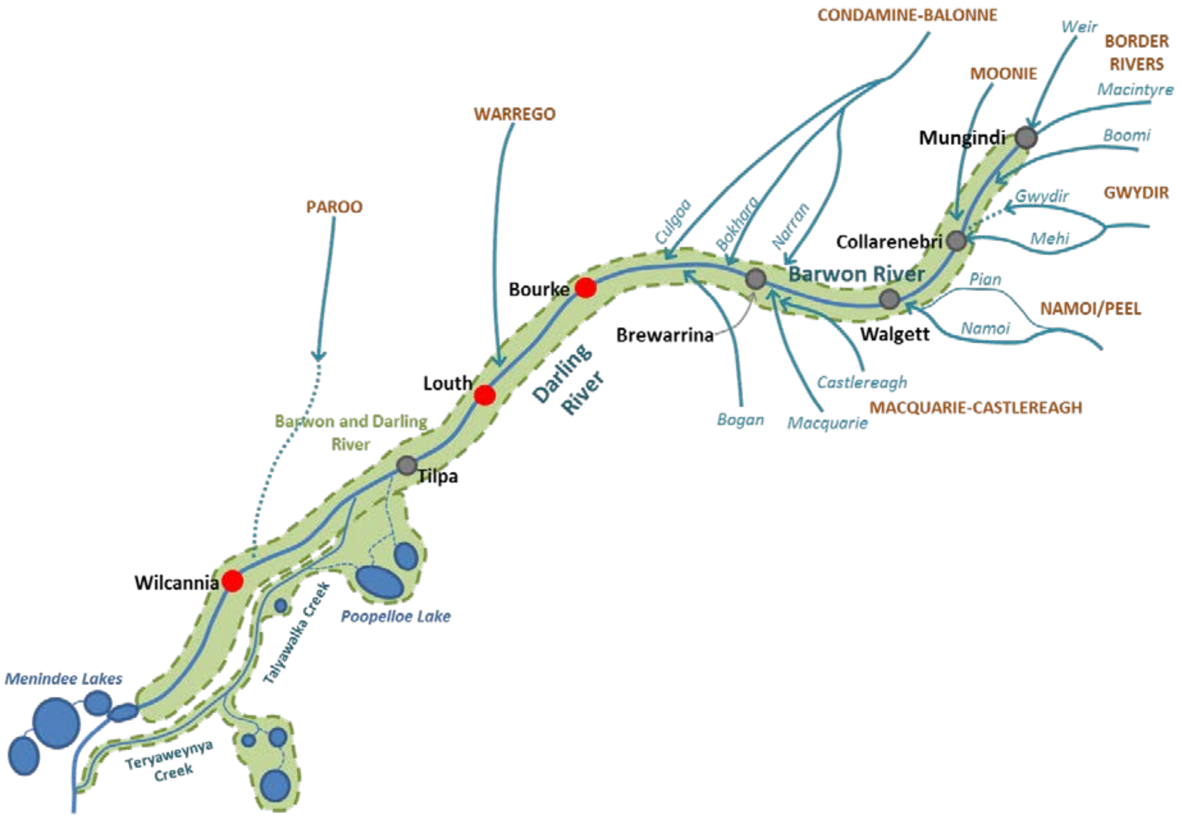

Figure 3: Stylised map of the Barwon–Darling river system, with the UEA extent indicated by green shading and a dotted perimeter.

The MDBA considered including a separate UEA for the Talyawalka Anabranch and Teryaweynya Creek system (Talyawalka–Teryaweynya system). However, it was decided that this was not necessary given the water requirements of the Talyawalka–Teryaweynya system are expected to be concurrently met by delivering water to achieve lateral connectivity with the floodplain in the broader Barwon–Darling system UEA. Furthermore, a review of available knowledge on the system's environmental values and eco-hydrology relationships did not support a compelling case for this being a separate UEA.

2.2.2. Identifying ecological values and targets

Establishing environmental water requirements for UEAs requires an understanding of ecological values of the different ecosystem components in the area. The ecological values for the Barwon–Darling river system UEA are described in section 4.1.

The establishment of environmental water requirements for UEAs is guided by basin-wide environmental objectives and ecological targets (*Water Act 2007* – Basin Plan 2012). Consistent with these and drawing on site-specific ecological knowledge, a series of qualitative ecological targets were determined for the Barwon–Darling river system UEA. These are listed in section 4.2. The 2012 targets were reviewed in light of the new knowledge stemming from the Northern Basin Review and were found to be consistent with this new knowledge, so they were retained. In addition, two ecosystem functions have been used to link the ecological targets to the site-specific flow indicators in chapter 5, as discussed in section 4.2.

2.2.3. Identifying key flow components

The flow regime is a primary determinant of the structure and function of ecosystems in streams and rivers (Poff et al. 2009). Alterations to flow regimes have been shown to result in ecological change in many systems (Poff and Zimmerman 2010). However, given the aim of a healthy working basin, it is not intended to return river flows back to what naturally occurred. This assessment of environmental water requirements focuses on the different flow components required to meet the key known needs of ecosystem components (fish, waterbirds, vegetation) in the Barwon–Darling river system UEA. The flow components are in-channel freshes, bankfull flows and overbank flows - and their connections to known ecosystem functions and processes are shown in Figure 4.

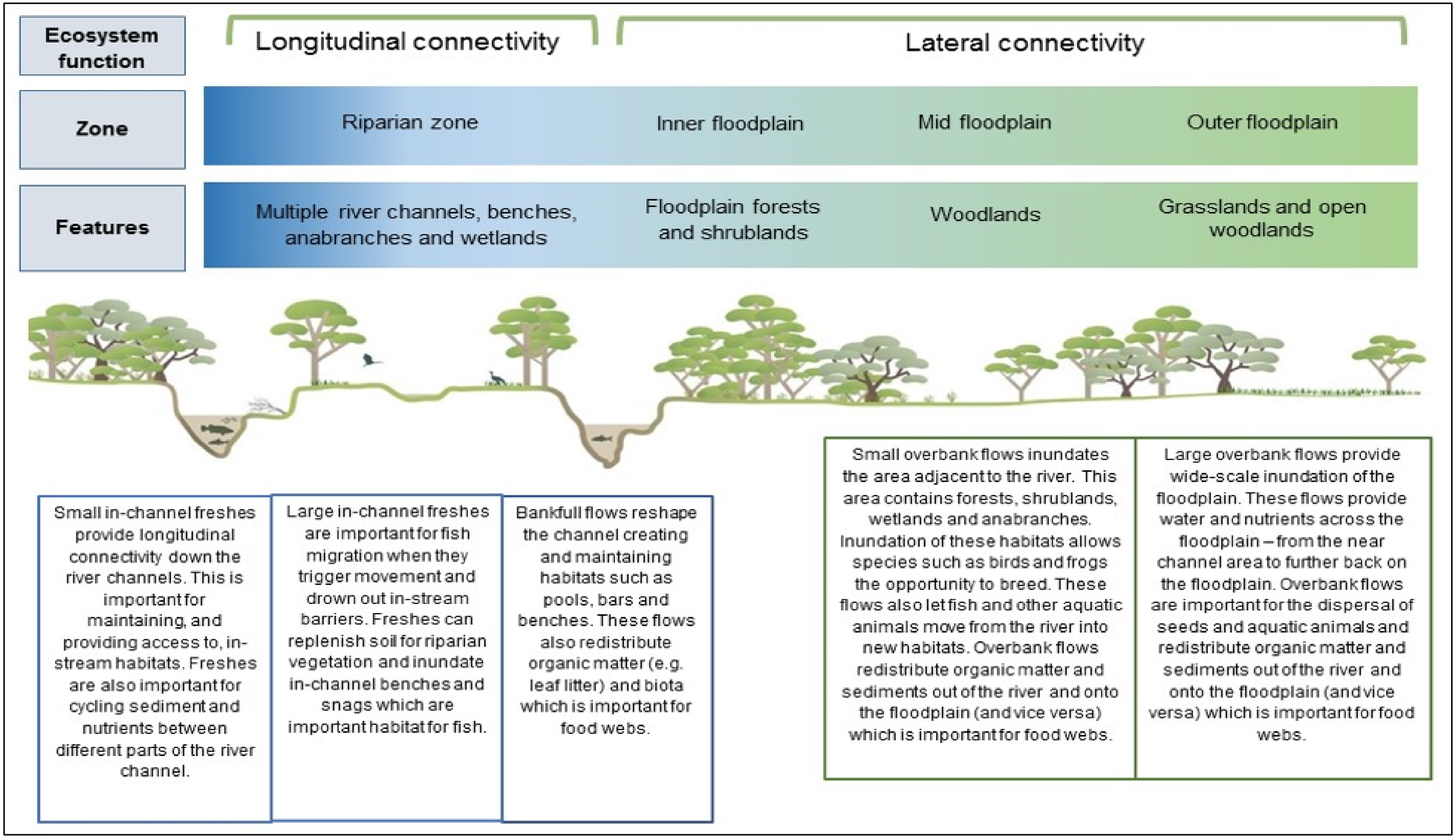

Figure 4: A stylised example of the zones, features and vegetation communities found in the Barwon–Darling river system, and some examples of their connection with ecosystem functions.

2.2.4. Considering evidence to inform selection of site-specific flow indicators

Multiple lines of evidence were considered when selecting site-specific flow indicators to represent the environmental water requirements of the Barwon–Darling river system UEA. The three components were: reviewing the evidence that was available prior to the making of the Basin Plan in 2012; generating new lines of evidence by commissioning science projects; and synthesising the resulting evidence. These components are discussed below.

The evidence available before the Basin Plan was made included some substantial research projects (e.g. Withers 1996; Brennan et al. 2002; Boys and Thoms 2006; and Southwell 2008). This evidence was reflected in the original assessment of environmental water requirements for the Barwon–Darling river system UEA (MDBA 2012). It was then considered by the MDBA and jurisdictional scientists, independent scientists (*Sheldon et al. 2014*), and the community[4], and knowledge gaps were identified.

In response to the most significant knowledge gaps, new lines of evidence were generated by undertaking new environmental science projects:

- reviews of literature and data on fish (*NSW DPI 2015*), waterbirds (*Brandis and Bino 2016*) and vegetation (*Casanova 2015*)
- research to identify groups of fish species with similar flow needs, mapping of fish habitat, and relating fish habitat to flows along 1,100 km of the Barwon–Darling River (*NSW DPI 2015*)
- mapping the location and assess the persistence of waterhole refuges in the Barwon–Darling system (*DSITI 2015*)
- analysing satellite imagery to determine areas inundated at different flow rates (*MDBA 2016*)
- mapping of extensive areas of floodplain vegetation (*Eco Logical Australia 2016*) which can be related to the areas inundated.

Three of these new projects involved extensive fieldwork (*DSITI 2015; NSW DPI 2015; Eco Logical Australia 2016*). Three of these projects included accessing and analysing existing unpublished data, such as the latest knowledge about fish life-cycle requirements for flows or satellite images of floodplain inundation, to update the best available eco-hydrology knowledge for the Barwon–Darling (*NSW DPI 2015; MDBA 2016; Brandis and Bino 2016*). Three of these projects involved workshops of experts so that the project team could test whether the interpretation of eco-hydrology data was reasonable (*Brandis and Bino 2016; NSW DPI 2015; Casanova 2015*). One of the projects made recommendations for seven site-specific flow indicators for the Barwon–Darling river system UEA associated with longitudinal connectivity (*NSW DPI 2015).* Hydrological analysis was undertaken by the MDBA, with respect to the without development and baseline scenarios, to provide the system hydrology context (see Appendix E). Reports from each of the above projects are available on the MDBA website[5]. Other science that had become available since the Basin Plan was made was also considered (Baumgartner et al. 2013; Rolls et al. 2013; *Marshall et al. 2016*).

[4] such as through meetings in the independent review process, and discussions with the Environmental Science Working Group of the Northern Basin Advisory Committee

[5] http://www.mdba.gov.au/publications

The MDBA synthesised of the best available evidence by taking into account the quality, suitability, and relevance of knowledge from the pre-Basin Plan studies and the more recent studies. This involved consideration of the knowledge that was most relevant to the UEA, the study methodology, and the extent that which the project linked ecology and hydrology.

2.2.5. Selecting site-specific flow indicators to represent important flow-ecology relationships

For a UEA, each site-specific flow indicator consists of a set of four hydrologic metrics. These are:

- **magnitude**: either a specified minimum daily flow (ML/d); or a volume (ML), which is a specified minimum quantity of water over a period of time (and may or may not specify a minimum daily flow)
- **duration**: for flow, the number of days a flow remains at or above the specified magnitude (ML/d); for volume, the period of time flow contributes to meeting the specified quantity of water (ML)
- **timing**: the months of the year a flow of a specified magnitude and duration is sought
- **frequency**: frequency is expressed in several ways depending on the context of the flow indicator: the percentage of years in which there is at least one flow event of a specified magnitude, duration and timing (e.g. 60%); or the average period between events (e.g. 6 years); or a maximum return interval (e.g. once every 10 years).

An example of a site-specific flow indicator for the Barwon–Darling UEA is described in Box 5.

Box 5: Example of a site-specific flow indicator for the Barwon–Darling

A flow of a magnitude of 30,000 ML/d, at the gauge for the Darling River at Bourke, for a duration of 24 days, at any time of year, with an average period between events of two years (low uncertainty, which means more confidence of achieving an ecological target and less risk) to three years (high uncertainty, which means less confidence and more risk).

The water needed to fulfil ecosystem functions was assessed based on identified ecological values and targets, known flow-ecology relationships, and hydrological analysis. The resulting site-specific flow indicators, and the associated lines of evidence, are in chapter 5.

Of the hydrologic metrics considered, frequency was often the most challenging to select, as is discussed in Box 6.

Once draft site-specific flow indicators were selected, they were compared to the modelled without development flow patterns (conditions prior to significant human development) to ensure that the indicators selected were representative of the typical hydrology of the Barwon–Darling River. This check was a practice retained from the original assessment (MDBA 2012). The frequency by which a site-specific flow indicator would be met for modelled water recovery scenarios (i.e. scenarios that incorporate water recovery) would generally be expected to be more often than under baseline conditions and less often than under without development conditions (no water resource development). This hydrological check gave confidence that the proposed site-specific flow indicators were reasonable (see Appendix E). Additionally, technical advice was sought from jurisdictional scientists and consultants, and a local context review was undertaken by community representatives on advisory groups[6]. Indicators were finalised after considering this advice and analysis.

Box 6 - Discussion of the frequency hydrologic metric

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 metric in the ESLT method is usually given as a range from a low uncertainty of achieving an ecological target to a high uncertainty of achieving the target. This range is referred to as the 'frequency range'. It was specified in this way in the original environmental water requirement reports used to develop the Basin Plan (e.g. MDBA 2012a; MDBA 2012b), and consistently used across the Basin. Where watering requirements are more certain, only one frequency target is specified.

For the low-uncertainty frequency, there is a high likelihood that the ecological targets will be achieved (MDBA 2011). Conversely, the high-uncertainty frequency is considered to represent a boundary beyond which there is a high likelihood that the ecological targets will not be achieved (MDBA 2011).

The condition of the water dependent ecosystems is expected to vary in response to climatic conditions, especially in the northern Basin given the highly variable nature of rainfall. In particular, the frequency of flow events (and therefore ecological condition) will respond to weather patterns and decline during periods of prolonged drought, even under natural or without development conditions. For this reason, the frequency of events in site-specific flow indicators are usually long-term averages, with events occurring more often in wetter times and less often in drier times. Examples of these frequency metrics include the average number of years between environmental watering events (calculated using 114 years of modelled data), and the percentage of years within which a watering event occurs.

The site-specific flow indicators, particularly the frequency, were tested using hydrological modelling to check whether the indicators were reasonable in the context of the system's hydrology.

[6] Environmental Science Working Group of the Northern Basin Advisory Committee, and the Lower Balonne Working Group

2.2.6. Selecting flow indicator gauges

The flow requirements of each UEA are expressed at one or more flow indicator gauge. These are river gauges within (or close to) the UEA which record flow on a daily basis. Three factors were taken into account when selecting the flow indicator gauges for the Barwon–Darling river system UEA. Firstly, the gauges selected can be used in the assessment of whether a site-specific flow indicator is met, by testing against a flow-ecology relationship that has been established for the gauge, or can be established through attenuation relationships between gauges. Secondly, the gauges were located below the zone of major water diversion. Finally, the gauges are key reference points in hydrological models used in the hydrological modelling framework.

After considering these factors, flow indicator gauges on the Darling River at Bourke, Louth and Wilcannia were selected for the site-specific flow indicators.

2.2.7. Using site-specific flow indicators in hydrological modelling

Once all the site-specific flow indicators were confirmed, they were incorporated into a linked basin-wide hydrological modelling framework. This framework routes water through all rivers and UEAs in the basin over a 114 year period of historical inflows (1895—2009) and represents the level of water resource development in 2009 (baseline). The framework is described in the accompanying hydrological modelling report.

The hydrological models are used to assess whether the site-specific flow indicators are met under different SDL scenarios (that is, scenarios of different environmental water recovery). A 'successful' flow event is recorded when the hydrologic metrics for a site-specific flow indicator are fully met by the flows in the model (as measured at the flow indicator gauge). The results of the modelling analysis are provided in the environmental outcomes report and the hydrological modelling report.

In addition to analysis against site-specific flow indicators, the environmental outcomes report includes analysis of complementary modelling statistics, including the extent of partially met flow indicators (i.e. indicators whose frequency of occurrence is outside the 'frequency range') and changes in dry spells (i.e. the number of consecutive years without a specified flow event), as these periods may put biota at risk. These complementary assessments provide another layer of analysis to the frequency metrics and give a fuller picture of likely outcomes.

3 Overview of the Barwon–Darling river system

3.1 Physical attributes

The Barwon–Darling catchment covers 699,500 square km (Thoms et al. 2004). It comprises the catchments of the Paroo, Warrego, Condamine–Balonne and Moonie systems to the north, and the Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh systems to the east (Figure 3). The Barwon River flows from Mungindi to the confluence with the Culgoa River, a distance of 577 km. The Darling River flows from the Barwon River junction with the Culgoa River to the River Murray, a distance of 1,545 km. This report focusses on the environmental water requirements of the Barwon–Darling river system umbrella environmental asset (UEA) from the start of the Barwon River to the upstream end of the Menindee Lakes and does not include tributaries, which have separate environmental water requirement assessments.

Important physical attributes of the Barwon–Darling river system UEA include in-channel features, lateral connectivity to the floodplain, and the Talyawalka–Teryaweynya system, a creek and wetlands system at the downstream end. In-channel features of the Barwon–Darling River include deep pools, suspended load depositional ‘benches’, higher floodplain ‘benches’, braided channels, snags or coarse woody debris, gravel beds and riffle zones (NSW DPI 2007a). Some of the features are shown in Figure 5. The hydrological connection of these features through flows provides important access to habitat, and allows for the cycling of nutrients and sediment (Boys and Thoms 2006; Southwell 2008; *NSW DPI 2015*). For example, organic material washes off in-channel benches and is incorporated directly into the river’s food webs (Sheldon and Thoms 2006).

There are at least 15 major weirs along the river which restrict movement of biota. However, many habitats within the main-channel become connected when flows are large enough to 'drown out' the weirs. In this ephemeral river system, there are many deep pools (waterholes), up to eight metres deep, where water persists as important drought refuges for aquatic biota (NSW DPI 2007a).

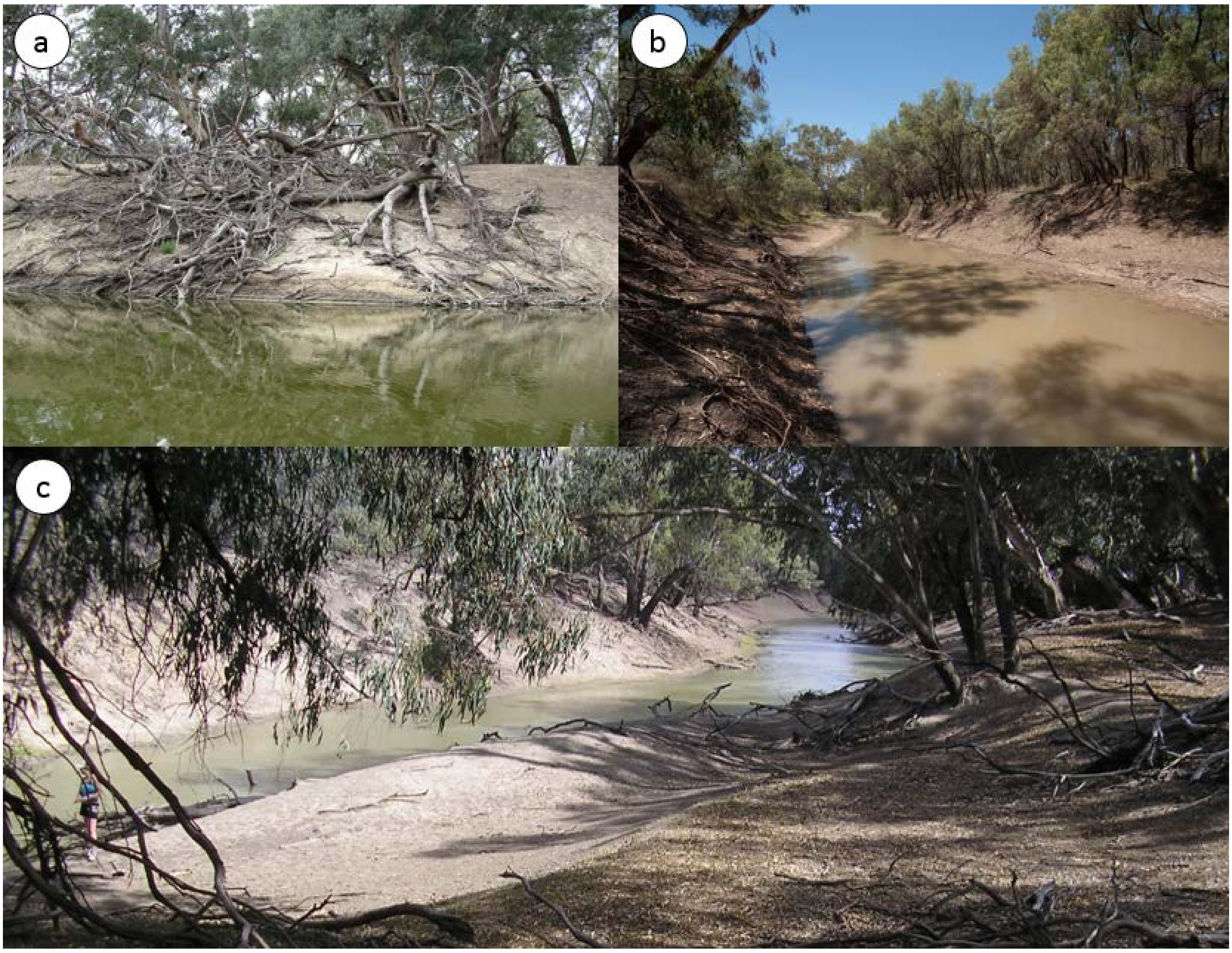

Figure 5: Examples of habitat features in the northern basin: snags (a), a pool (b) and a bench (c) (Photo: Adam Sluggett)

The floodplain is a key part of the Barwon–Darling river system UEA. There are a diversity of features located in this zone including flood runners, anabranches and billabongs (SKM 2009). There are many wetlands in the Barwon–Darling, with an initial assessment showing a total of 583 wetlands between Mungindi and Menindee, dominated by anabranches in the upper reaches and larger, complex billabongs in the lower sections (Brennan et al. 2002).

The Barwon–Darling river system UEA has a significant downstream wetland system, a feature also found in other northern basin rivers such as the Narran, Gwydir, and Macquarie. The Talyawalka–Teryaweynya system is a distributary system from the Darling River near Wilcannia. The system has braided channels, interspersed by a series of varying sized lakes (DEWHA 2010).

3.2 Hydrology

3.2.1 Hydrology prior to the development of water resources

The hydrology of the Darling catchment is complex with low rainfall and increasing temperature and evaporation occurring from the temperate headwaters in the east to the semi-arid western margins (Thoms et al. 2004; Thoms et al. 2004). Average rainfall is low across the catchment, ranging from around 500 mm/year at Mungindi in the east to 250 mm/year at Wilcannia in the south-west. Annual river flow may range from just 1% to over 1,000% of the annual mean, and periods of no-flow can persist from months to years (Saintilan and Overton 2010).

Rainfall in the Barwon–Darling catchment is extremely variable, resulting in highly variable river flows. Typically rain events are summer dominated with the largest events tending to be associated with ex-tropical cyclones that have moved inland (Thoms et al. 2004). As an example, Figure 6 shows the modelled without development flow regime for the Darling River at Bourke over a five year period. This period shows some typical events: short events with flows of a high magnitude, some days with in-channel flows for short and long durations, and more days with low or no-flows. These flow components can occur at any time of the year.

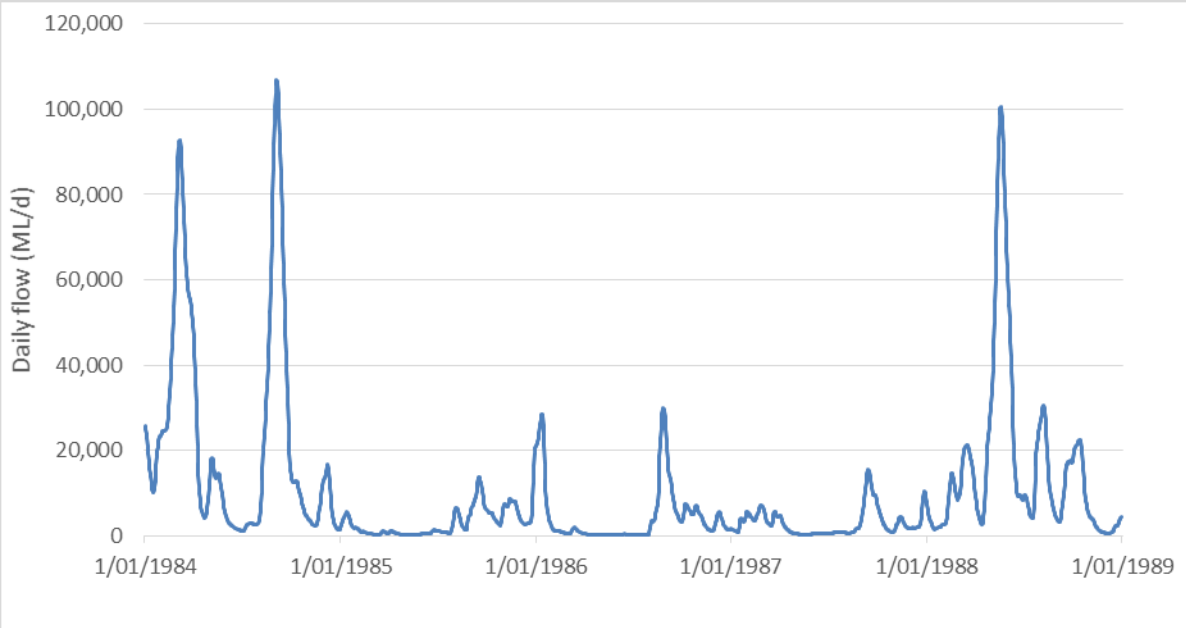

Figure 6: Daily flows of the Darling River at Bourke over a five year period from 1984 to 1989 (modelled without development conditions)

3.2.2 Hydrology following the development of water resources

Water management has modified flow regimes across the Murray–Darling Basin, including the Barwon–Darling River. Tributaries of the Barwon–Darling, such as the Macquarie, Namoi, Gwydir, Border Rivers, and Condamine–Balonne are regulated to varying degrees by major dams and weirs and private diversions, and many are only well connected with the Barwon–Darling during large flows. Once flows reach the Barwon–Darling they are contained in a series of constructed low-level weirs until their capacity is exceeded and they overflow. The presence of weirs alters geomorphic processes such as sediment movement (Thoms and Walker 1993).

Water extraction from the Barwon–Darling River tends to be either large volumes that are diverted from the river opportunistically for subsequent use in irrigated agriculture, or small volumes that are diverted often to provide stock and domestic water including for towns. Large diversions are extracted from the river or harvested as floodplain runoff, often being transferred to large private off-river storages. Most water entitlements under the current Water Sharing Plan[7]

[7] Water Sharing Plan for the Barwon–Darling Unregulated and Alluvial Water Sources

allows diversions when flows reach levels specified in water licences (i.e. pumping thresholds), reducing the amount of flow remaining in the river.

For the Darling River at Bourke, a comparison between without development and baseline (pre Basin Plan conditions) is given for daily flows (Figure 7).

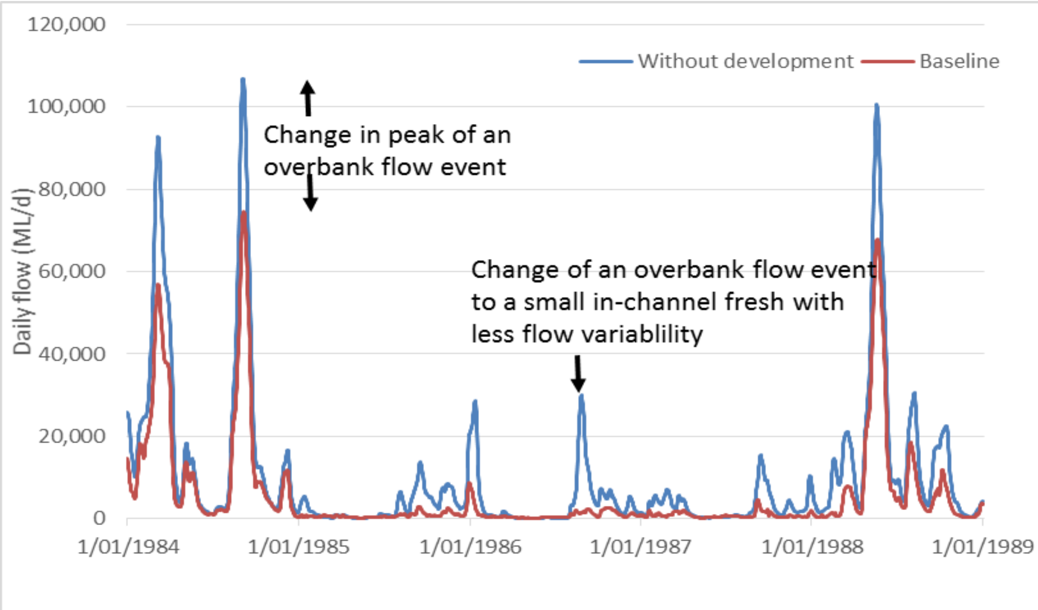

Figure 7: Daily flows of the Darling River at Bourke over a five year period from 1984 to 1989 (modelled without development conditions and baseline conditions)

Figure 7 shows that flows under baseline conditions are much lower than under without development conditions. As a result of development, flow events are usually reduced in magnitude and sometimes duration – and occasionally are lost altogether (e.g. small in-channel freshes), which increases the time between flow events and reduces the frequency. Very large flow events tend to be less modified as there is not the capacity to capture much of the water. Water extraction has increased the duration of no-flows, causing prolonged dry spells.

Water management has changed the natural hydrology of the system, generally reducing lateral connectivity between the main-channel and wetland habitat by 40% along the Barwon–Darling (Brennan et al. 2002).

3.3 Eco-hydrology

Similarly to many dryland rivers, the ecology of the Barwon–Darling River is driven by periods of hydrological connection and disconnection both longitudinally down the rivers length and laterally between the river channel and adjacent riparian channels, wetlands and floodplains (Sheldon et al. 2010). As discussed earlier, this longitudinal and lateral connectivity is highly variable, and has been influenced by water resource development along the river and its upstream tributaries.

The construction of low level weirs along the length of the Barwon–Darling has increased the permanence of waterholes and places of refuge during low- and no-flow periods. Extended periods of no-flows can increase the risk of thermal stratification occurring in these waterholes that may cause algal blooms (Mitrovic et al. 2003). Small flow freshes that reconnect the weir pools and promote water mixing have been encouraged to minimise the occurrence of these algal blooms (Mitrovic et al. 2003, 2006).

The frequency of in-channel freshes that promote fish spawning, recruitment and dispersal have been significantly reduced (*NSW DPI 2015*). Analysis using modelled daily flow under without development and baseline conditions (2009 development) shows a reduction in within-channel freshes along the Barwon–Darling river system UEA, as observed at the Walgett, Bourke, Louth and Wilcannia gauges. The results show an average reduction of around 40% in the number of flow events between 6,000 ML/d and 20,000 ML/d across the four locations (Table 2). The reduction in flow events that inundate in-channel features and the floodplain has reduced the cycling of nutrients and organic material (Sheldon and Thoms 2006, Southwell 2008) and the access to habitat and migration opportunities for aquatic animals such as fish (Boys and Thoms 2006; *NSW DPI 2015*).

Table 2: Analysis of flows under without development and baseline hydrological model scenarios showing the change in flow events over the 114 year model period. Note baseline results are within the brackets

Gauge	Flow (ML/d)	Number of flow events	Number of years with a flow event
Walgett	6,000-10,000	155 (103)	81 (65)
	10,000-15,000	107 (79)	67 (48)
	15,000-20,000	61 (33)	43 (27)
Bourke	6,000-10,000	113 (72)	69 (53)
	10,000-15,000	98 (55)	70 (38)
	15,000-20,000	67 (32)	56 (27)
	20,000-30,000	77 (44)	56 (34)
	30,000-45000	56 (22)	44 (18)
	45,000-65,000	28 (12)	26 (11)
	60,000-100,000	19 (7)	18 (6)
	100,000 and above	21 (16)	16 (11)
Louth	6,001-10,000	124 (65)	70 (48)
	10,001-15,000	80 (44)	59 (35)
	15,001-20,000	46 (29)	37 (25)
Wilcannia	6,001-10,000	106 (57)	65 (43)
	10,001-15,000	69 (39)	52 (32)
	15,001-20,000	50 (27)	39 (23)

For higher flows, extractions have been shown to reduce the size and duration of flood events (Thoms and Sheldon 2000). Flow events that inundate wetlands and the inner to mid floodplain have been substantially decreased with the development of water resources. Table 2 shows that the number of flow events between 20,000 ML/d and 100,000 ML/d at Bourke have reduced by an average of 53% under baseline conditions when compared to without development. The frequency of large flooding events that inundate the outer floodplain have not been as heavily impacted - for example, hydrological modelling shows an average reduction of 24% in the number of flow events above 100,000 ML/d at Bourke under baseline conditions when compared to without development.

4 Ecological values, targets and functions

4.1 Ecological values

Step 2 of the Environmentally Sustainable Level of Take (ESLT) method (Figure 2) includes an assessment of the ecological values of umbrella environmental assets (UEA). The assessment is guided by the criteria for identifying environmental assets and ecosystem functions from the Basin Plan (Box 4).

Based on the ecological values identified for the Barwon–Darling river system UEA, the various elements of the system meet all environmental asset criteria in Box 4 - that is linkages to international agreements or threatened species legislation, naturalness, vital habitat, and significant biodiversity.

The natural geomorphology of the Barwon–Darling River is complex. When flooded, the various features (e.g. flood runners, anabranches, billabongs) are important extensions of the river channel, and work upstream on the Macintyre River has established they provide large amounts of dissolved organic carbon, which is essential to aquatic ecosystem function (Thoms et al. 2005).

Due to its morphology and variable hydrology, the river provides a multitude of vital habitats that play a critical role in the life-cycles of a variety of species (NSW DPI 2007a). The NSW Fisheries Scientific Committee consider the region to have high fish diversity, with 15 native fish species recorded across the Barwon–Darling system (NSW DPI 2012). Several of these species are listed under threatened species legislation (Appendix D): freshwater catfish (*Tandanus tandanus*), Murray cod (*Maccullochella peelii*), silver perch (*Bidyanus bidyanus)* olive perchlet (*Ambassis agassizii*) and purple spotted gudgeon (*Mogurnda adspersa*).

Four migratory bird species listed in international agreements (Japan–Australia Migratory Bird Agreement; China–Australia Migratory Bird Agreement; Republic of Korea–Australia Migratory Bird Agreement) have been recorded throughout the Barwon–Darling system (see Appendix D). These are the Caspian tern (*Hydroprogne caspia*), common sandpiper (*Actitis hypoleucos)*, eastern great egret (*Ardea modesta*) and glossy ibis (*Plegadis falcinellus)* (*Brandis and Bino 2016*). When inundated, lakes and wetlands along the Darling River system provide habitat for large numbers of waterbirds, including migratory birds (DEWHA 2010). Kingsford et al. (1997) identified Poopelloe Lake, Talyawalka Creek and Pelican Lake within the Talyawalka–Teryaweynya system, as well as the Darling River floodplain near Louth, as areas known or predicted to support 20,000 or more waterbirds. While not recognised as an important colonial waterbird breeding site, the Talyawalka–Teryaweynya system provides habitat for roosting, nesting and foraging (*Brandis and Bino 2016*).

The Directory of Important Wetlands in Australia (DEWHA 2010) reports that Talyawalka–Teryaweynya system is relatively unaltered and representative of black box (*Eucalyptus largiflorens*) dominated semi-arid inland floodplain wetland systems. This system of channels and lakes is nationally important and has been listed in the Australian Wetlands Database.

4.2 Ecological targets and functions

Step 3 of the ESLT method (Figure 2) includes developing ecological targets based on the ecological values of a UEA, which are then used to guide the assessment of environmental water requirements. The ecological targets from the Basin Plan assessment of environmental water requirements for the Barwon–Darling river system UEA (MDBA 2012) were reviewed in light of the new science and have largely been found to be suitable, hence they have been retained for consistency. One change, however, involves removing the target relating to breeding of colonial nesting waterbirds as recent evidence suggests breeding events are generally small in the Barwon–Darling (*Brandis and Bino 2016*). The ecological targets focus on providing a flow regime which:

- ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition
- supports the habitat requirements of waterbirds
- supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates)
- supports key ecosystem functions, particularly those related to connectivity along the river and between the river and the floodplain.

Since the original UEA assessment (MDBA 2012), further work has been done to recognise the relationships between ecosystem functions and environmental watering. For example, the basin-wide environmental watering strategy emphasises the functional aspects of longitudinal and lateral connectivity (MDBA 2014). With relevant wording from the Basin Plan in mind (Box 4), and considering the ecological and hydrological evidence available for the Barwon–Darling river system UEA, two ecosystem functions have been considered:

- **longitudinal connectivity** – provide hydrological connections along watercourses that: link a diversity of aquatic environments for feeding, breeding, dispersal, migration and re-colonisation by native aquatic species; and facilitate geomorphic processes, sediment movement and nutrient spiralling.[8]
- **lateral connectivity** – provide hydrological connections between watercourses and adjacent floodplains and wetlands that: link a diversity of aquatic environments for feeding, breeding, migration and re-colonisation by native water-dependent species; support the vigour and condition of native vegetation; and facilitate off-stream primary production, and nutrient and organic matter exchange.[9]

Longitudinal and lateral connectivity are illustrated in Figure 8.

[8] The longitudinal connectivity function is derived from the criteria for identifying ecosystem function in the Basin Plan (Schedule 9, criteria 2 and 3).
[9] The lateral connectivity function is derived from the criteria for identifying ecosystem function in the Basin Plan (Schedule 9, criteria 2 and 4)

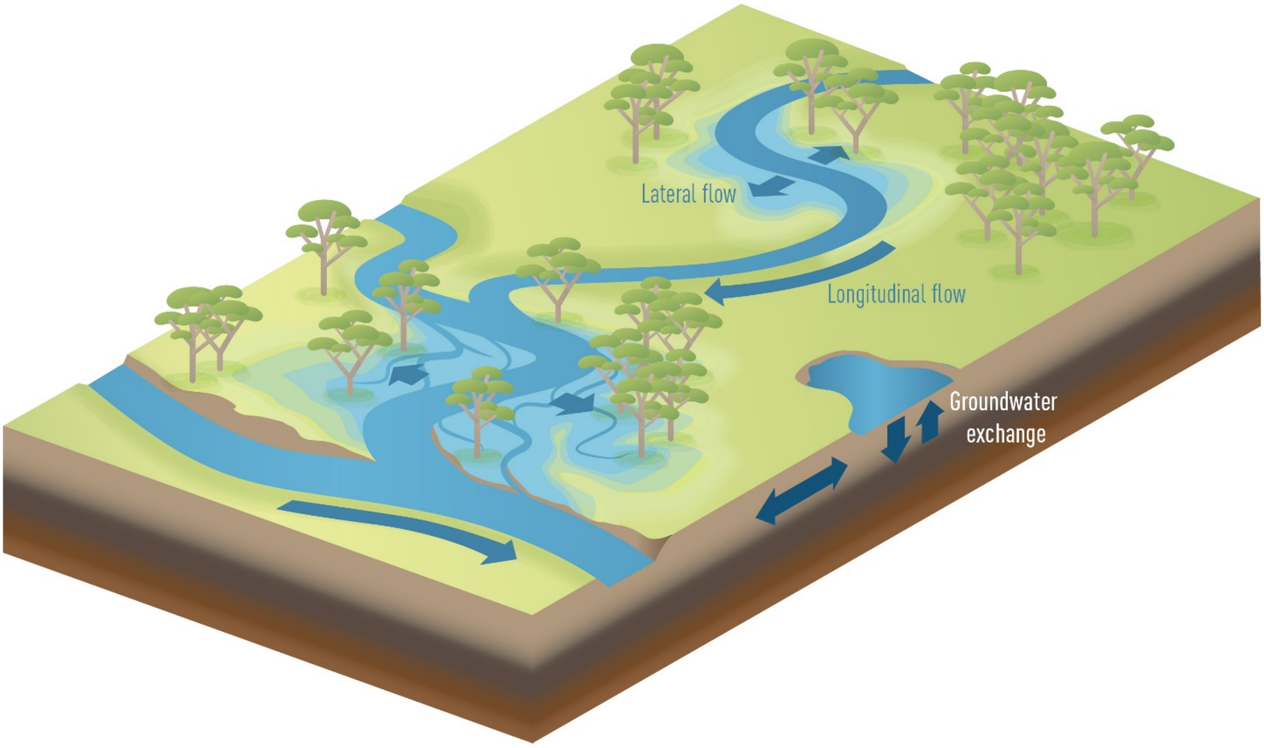

Figure 8: Conceptual diagram of the longitudinal and lateral connectivity of flows in a river system

The ecosystem functions are expressed in a way that reflects different parts of the flow regime (e.g. longitudinal connectivity is important for fish migration during fresh flows, lateral connectivity is important for vegetation health during overbank flows). For this reason, they provide a convenient set of sub-headings in which to describe environmental water requirements. In chapter 5, the ecological targets and ecosystem functions described above are linked to the specification of site-specific flow indicators for the Barwon–Darling river system UEA.

Unlike the assessment of environmental water requirements for the Condamine–Balonne river system, flow indicators have not been developed for drought refuge or habitat for waterbirds specifically, for reasons discussed below.

The waterholes and weir pools along the Barwon–Darling are critical drought refuges supporting the viability of aquatic biota that lack specific adaptations to drought (e.g. all species of fish, turtles, and some invertebrates). Populations of these species depend upon the network of waterholes that persist during periods when flow ceases and connect during flow events (*DSITI 2015)*. In an effort to better understand waterhole hydrology in the Barwon–Darling, a research project was commissioned as part of the Northern Basin Review (*DSITI 2015*) using satellite imagery captured between 1988 and 2015 to detect water during periods of no flow to locate waterholes and estimate their persistence time. This work was supplemented with field measurements including bathymetry, depth and calculation of the rate of drawdown. The field measurements and modelling showed that the depth of waterholes studied in the Barwon–Darling varied between 3 and 8.5 metres and that some persist for as long as five years without significant inflow. As a result of this work it was determined that waterholes in the Barwon–Darling River, such as that shown in Figure 9, hold water for considerably longer than the expected duration of no-flow periods even during droughts under baseline conditions, therefore flow indicators have not been developed for drought refuge.

Figure 9: Waterhole at Black Rocks on the Darling River. (Photo: Neal Foster)

5 Selecting site-specific flow indicators for the Barwon–Darling river system umbrella environmental asset

5.1 Longitudinal connectivity (along watercourses)

The Barwon–Darling river system UEA is recognised for its extensive range of aquatic habitats and ability to support significant populations of native fish, which includes 15 native fish species (Gehrke and Harris 2004; *NSW DPI 2015*). The Barwon–Darling river system UEA is also recognised as a key movement corridor for aquatic species; especially for fish with life-cycle requirements to undertake migrations such as silver perch and golden perch (MDBA 2014).

5.1.1 Summary of available evidence

Site-specific flow indicators for longitudinal connectivity were developed after considering a range of information sources, including a mixture of existing research and recently commissioned studies in the Northern Basin Review.

The primary new line of evidence was a project that reviewed the relationship between fish and flows in the northern basin, with an emphasis on the Barwon–Darling River (*NSW DPI 2015*). This project brought together over 20 fish ecology experts and water managers, who considered more than 150 items of research (*NSW DPI 2015*). This project used the most up-to-date research on flows and the relationship to fish spawning, recruitment, movement, migration and condition. The project classified fish into northern basin-specific functional groups based on fish with similar life-cycle requirements for flows (Box 7). For some functional groups, such as the flow dependent specialists and in-channel specialists, there is a particularly strong need for certain types of flows at some stages of their life-cycle (Box 7).

Box 7: Native fish functional groups (adapted from NSW DPI 2015)

Group 1: Flow dependent specialists. (golden perch, silver perch, spangled perch (*Leiopotherapon unicolor*), and Hyrtl's tandan (*Neosilurus hyrtlii*)).

Group 2a: In-channel specialists - flow dependent (Murray cod).

Group 2b: In-channel specialists - flow independent (freshwater catfish, purple spotted gudgeon).

Group 3: Floodplain specialists (Darling River hardyhead (*Craterocephalus amniculus*), olive perchlet and Rendahl's tandan (*Porochilus rendahli*)).

Group 4: Generalists (bony bream (*Nematalosa erebi*), carp gudgeon (*Hypseleotris klunzingeri*), flat-headed gudgeon (*Philypnodon grandiceps*), Australian smelt (*Retropinna semoni*) and unspecked hardyhead (*Craterocephalus fulvus*)).

Group 5: Generalists - alien species (e.g. carp - *Cyprinus carpio*).

The flow attributes that benefit each functional group are detailed in *NSW DPI (2015)*.

Some functional groups have a particularly strong association with parts of the flow regime. For example:

- Flow dependent specialists need flow freshes for a number of life-cycle requirements including to generate spawning responses, aid in larvae drift, and to undertake moderate to large-scale migrations (e.g. hundreds of km).
- Some in-channel specialists such as Murray cod also have important flow related requirements, such as requiring stable flows to allow for nest development and spawning.

Access to habitat including in-channel benches, large-woody debris (snags), deep pools, and wetlands is important for fish (*NSW DPI 2015*). The *NSW DPI (2015)* project mapped in-stream habitat, including benches and snags along more than 1,100 km of the Barwon–Darling River between Walgett and Wilcannia. This enabled the relationship between flows at a representative gauge in the river and fish habitat to be developed to describe how habitat access increases with increasing flow rate. The river between Walgett and Wilcannia was split into four reaches as described by Boys and Thoms (2006), with each reach having a representative gauge. An example of the relationship between snag and bench inundation for the Brewarrina to Bourke reach and the flow at the Bourke gauge is provided in Figure 10.

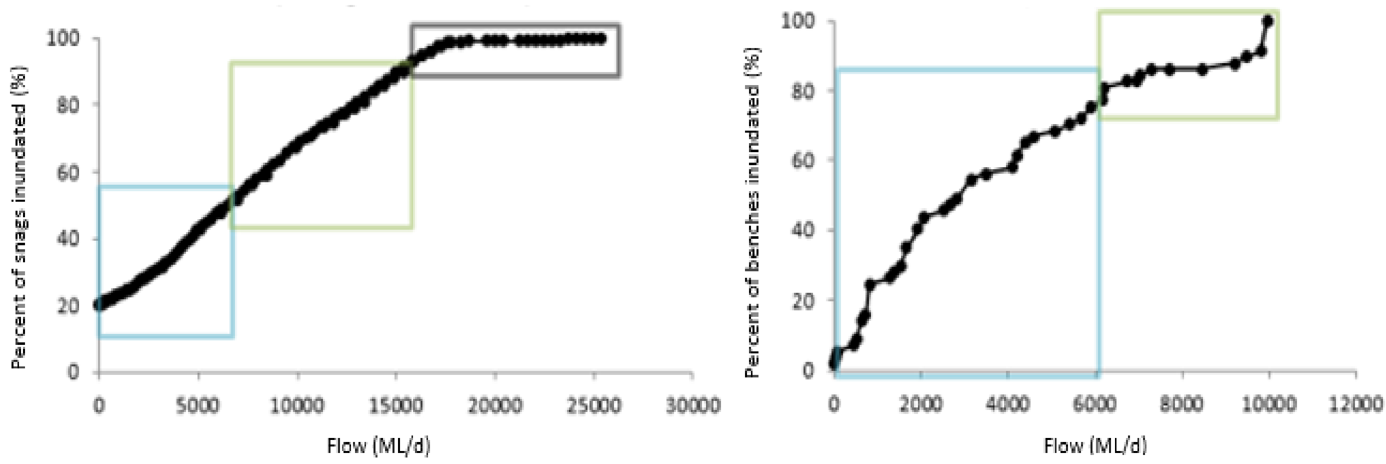

Figure 10: Example of the percentage of snags (left) and benches (right) inundated with increasing flow measured at Bourke, for the Brewarrina to Bourke reach. Boxes represent indicative flow components: moving left to right: small fresh (blue), large fresh (green) and bankfull (grey).

Other lines of evidence to complement *NSW DPI (2015*) were considered when developing site-specific flow indicators for longitudinal connectivity in the Barwon–Darling river system UEA, as is discussed below.

Carbon and nutrient input into rivers drives nutrient spiralling and productivity (Thorp and Delong 1994; Thoms 2003). Periodic inundation of in-channel benches allows debris, sediment, carbon and nutrients to become incorporated into different river system food webs and drives the productivity of the river system (Sheldon and Thoms 2006; Southwell 2008; Foster and Cooke 2011). The extent that nutrients get taken up into the food webs depends on the bioavailability of the nutrients (Baldwin 1999), the amount of nutrients already present within the river (Westhorpe et al 2010), and light availability within the water column given the typically high turbidity (*Woods et al 2012*).

A variety of flows is integral to the structure and diversity of the aquatic communities, including fish, in the Murray–Darling Basin (Baumgartner et al. 2013; Rolls et al. 2013). Variable flows allow aquatic animals to access a diversity of environments. For example, research in the Barwon–Darling River shows variable flows are needed to inundate snags that are important for fish as they can provide habitat, protection from predation and have been demonstrated to be an important breeding location for many species such as Murray cod (Boys et al. 2005; *Boys et al. 2013*).

The provision of opportunities for dispersal, including by short lived aquatic species, is important for maintaining healthy populations. Jenkins and Boulton (2003) showed that recruitment of microinvertebrates into floodplain lakes along the Darling system had a large influence on the composition of the community in the broader river system. Invertebrate dispersal has been shown to be facilitated by drift of flowing water (Bilton et al. 2001), as has the dispersal of larvae of fish species such as golden perch and silver perch (*NSW DPI 2015*).

Flows can also trigger larger scale movement and migration of some fish species. Research in the northern basin has shown that some fish use connecting flows between waterholes to travel large distances (Puckridge et al. 1998; Balcombe et al. 2007). Reynolds (1983) studied upstream migration patterns of golden perch and silver perch in the River Murray, and studied large-scale movements by golden perch of over 1,000 kilometres in response to rises in water level. These upstream migrations were only made by mature fish, and appeared to be a reproduction strategy as the buoyant eggs subsequently drifted downstream. Species such as Murray cod, golden perch and silver perch commonly migrate to flowing water habitats as juveniles and to spawn (Saddlier et al. 2008; Koehn et al. 2009; Mallen-Cooper and Zampatti 2015). Additional research on fish migration in the Moonie River demonstrates that changes in water level and water temperature are important cues for the movement of golden perch and freshwater catfish (*Marshall et al. 2016*).

Barriers, such as weirs, in the river can limit the movement and dispersal opportunities of aquatic species. There are 15 major weir structures along the main stem of the Barwon–Darling system upstream of Menindee Lakes to the Macintyre junction at Mungindi (NSW DPI 2007b; *Nichols et al. 2012; NSW DPI 2015*). An example is the weir at Bourke (Figure 11). These structures have varying levels of impact on aquatic species including fish, with some structures drowning out more frequently than others to provide suitable fish passage and open up reaches of river for fish movement opportunities. The location of the major fish barriers and the flow magnitudes estimated to drown them out is shown in Figure 12. From this, it can be seen that the drown-out flow at Bourke of 10,000 ML/d is an important magnitude of flow for providing longitudinal connectivity through much of the Barwon–Darling river system UEA, from Walgett to Menindee.

Figure 11: Bourke Weir on the Darling River: an example of significant barrier to fish passage on the Darling River (Photo: Adam Sluggett, April 2015)

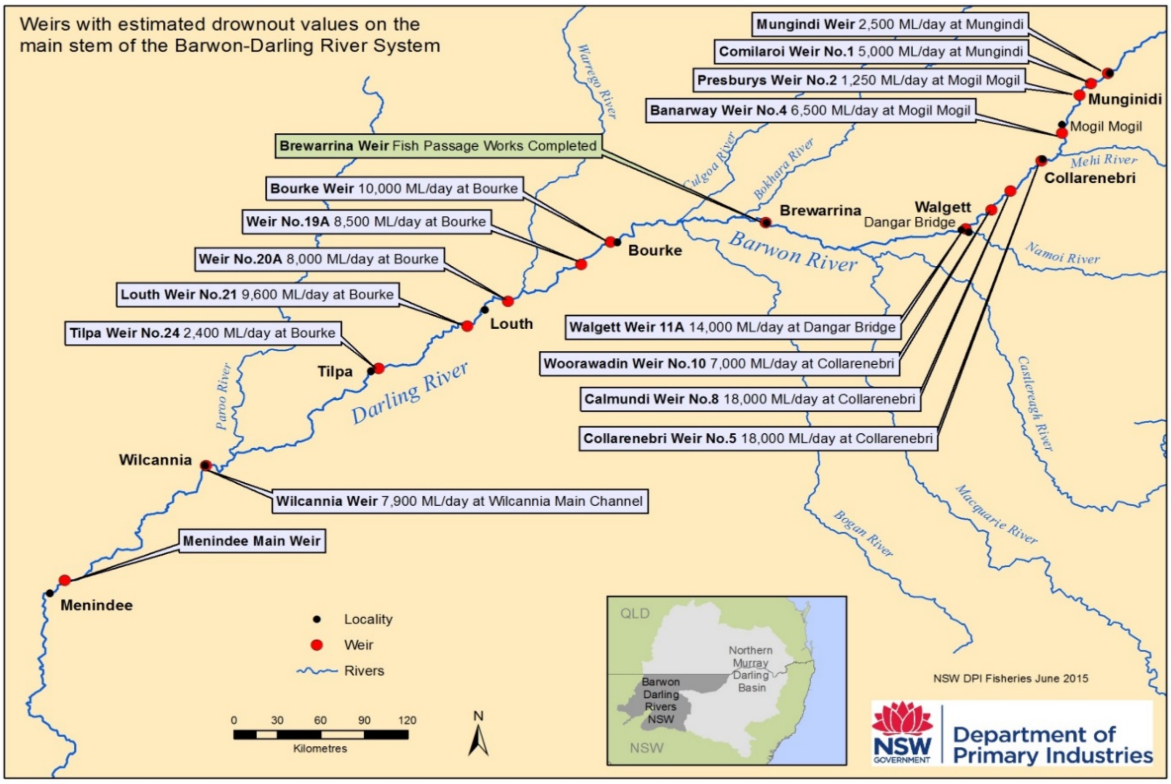

Figure 12: Location of 15 major fish passage barriers on the main stem Barwon–Darling river system UEA, highlighting estimated drown out values and the corresponding gauge for each structure as identified in Cooney (1994) (source: *NSW DPI, 2015*). The Brewarrina fish passage was recently completed to provide improved passage at lower flows in the river between Walgett and Bourke

5.1.2 Site-specific flow indicators

Seven site-specific flow indicators are specified for longitudinal connectivity in the Barwon–Darling river system UEA. Site-specific flow indicators were proposed by *NSW DPI (2015)* after primarily considering the needs of fish, and were generally accepted by the MDBA.

The indicators have been grouped into two flow components: small in-channel freshes that occur in most years (three indicators), and larger in-channel freshes that occur every few years (four indicators).

Small in-channel freshes

Indicator: Minimum of 1 flow event of 6,000 ML/d in the Darling River at Bourke for 14 consecutive days any time of the year for 90% (low uncertainty) to 80% of years (high uncertainty).

Magnitude: The flow magnitude of 6,000 ML/d at Bourke was selected to provide movement opportunities for fish and improved access to in-channel habitats along the Barwon–Darling (*NSW DPI 2015).* This flow would inundate 60% of snags and 90% of the benches mapped between Walgett to Brewarrina, and around 50% of the snags and 80% of benches mapped between Brewarrina and Bourke (Figure 13). Where barriers do not inhibit movement, this flow would enable fish to move short distances. For example a flow of 6,000 ML/d at Bourke provides fish movement opportunities between Brewarrina and Bourke, and into tributaries such as the

Culgoa River, and between Bourke and the next weir downstream towards Louth (Weir 19A), noting that the weir at Bourke remains a barrier to fish passage at this flow.

Duration: The 14 day duration at Bourke is the median duration for flow events under the without development model.

Timing: Improved habitat access and nutrient spiralling is considered to provide benefits to fish throughout the year and the flow indicator can therefore be met at any time.

Frequency: For the Darling River at Bourke, *NSW DPI (2015)* proposed that a small fresh should occur in most years, with a low uncertainty frequency of 90% of years and a high uncertainty frequency of 80% of years. This frequency range aims to provide regular opportunities for recruitment of fish and aims to provide sufficient food sources for aquatic biota.

Indicator: Minimum of 1 flow event of 6,000 ML/d in the Darling River at Louth for 20 consecutive days from August to May for 70% of years (low and high uncertainty)[10].

Magnitude: A flow of 6,000 ML/d at Louth inundates key snag habitat between Brewarrina and Tilpa. This habitat is important for fish such as Murray cod that are prevalent in this area (*NSW DPI 2015)*. The flow indicator describes a small in-channel fresh that would provide fish with breeding opportunities.

Duration: This duration is to provide spawning and recruitment opportunities for both the flow dependent and in-channel specialist functional groups. A duration of 20 days may also facilitate larvae drift to downstream areas which can occur over long distances for up to 20 days post spawning in intermittent systems (*NSW DPI 2015*).

Timing: The timing for this flow indicator is August to May. The two coldest months of the year are excluded because fish responses are expected to be subdued (Reynolds 1983; Mallen-Cooper et al. 1995). The timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (August to December) and the other native fish species in the northern basin[11]. The timing has not been limited to the months when spawning occur, but instead limited to the period when water temperatures are warm enough[12] that fish are known to move, which can be important for fish conditioning and dispersal.

Frequency: A single frequency requirement of 70% of years was specified for this indicator. This frequency is based on knowledge of life-cycles of Murray cod and freshwater catfish and aims to provide sufficient opportunities for fish movement and recruitment (*NSW DPI 2015*).

[10] There are two site-specific flow indicators for which the low uncertainty frequency is set equal to the high uncertainty frequency for the Barwon–Darling river system UEA. If these flow events occur more frequently than the frequency requirement, there is a high likelihood of achieving the associated ecological targets. If these flow events occur less frequently there is a high likelihood that the associated ecological targets will not be achieved.

[11] NSW DPI (2015) provides more detail about the spawning season, temperature and method for fishes in the northern basin.

[12] generally greater than 15° Celsius

Indicator: Minimum of 2 flow events of 6,000 ML/d in the Darling River at Wilcannia for 7 consecutive days any time of the year for 60% (low uncertainty) to 45% (high uncertainty) of years.

Magnitude: A flow magnitude of 6,000 ML/d at Wilcannia (a small fresh) inundates snags and in-channel benches between Tilpa and Wilcannia. *NSW DPI (2015)* mapping showed this area contains a greater amount of these habitat features than areas upstream (Figure 13).

As a result of inundation of the benches, carbon and nutrients released into the river can increase nutrient spiralling which fuels aquatic food webs. This improves food availability for fish and other aquatic biota and can improve recruitment success.

Two flow events in a year at Wilcannia is typical of flows in this part of the Darling River. Two events are characteristic of the system due to high flows typically occurring in both summer and winter. These two flow events would allow for improved in-channel food supply and greater opportunities for small-scale movement (Southwell 2008; Foster and Cooke 2011).

Duration: A duration of seven days is considered sufficient for abiotic processes such as the release of carbon and other nutrients from inundated benches. This duration would also provide some opportunity for the dispersal and movement of aquatic species.

Timing: This flow indicator is associated with movement opportunities for fish and in-stream nutrient spiralling. Flows of this magnitude would provide these benefits to fish and aquatic biota throughout the year and can therefore be met at any time.

Frequency: The low uncertainty frequency of 60% of years and the high uncertainty frequency of 45% of years are considered appropriate for providing increased productivity benefits to the river system's food web (*NSW DPI 2015*).

Large in-channel freshes

Indicator: Minimum of 1 flow event of 10,000 ML/d in the Darling River at Bourke for 14 consecutive days from August to May for 80% (low uncertainty) to 60% (high uncertainty) of years.

Magnitude: A flow of 10,000 ML/d at Bourke describes a large in-channel pulse that would provide improved movement and breeding opportunities for flow dependent fish. This flow is expected to provide for fish movement between Walgett and Menindee (approximately 1,100 km). Opportunities for large-scale movement is of particular importance for fish such as golden perch and silver perch that are known to travel long distances (Hutchison et al. 2008; Reynolds 1983). Researchers have demonstrated that a flow with similar attributes in the Moonie catchment triggers movement of golden perch and freshwater catfish (*Marshall et al. 2016*). A flow of 10,000 ML/d also provides increased access to habitat, as it inundates two thirds of snags, and most benches. This flow also inundates some of the low lying wetlands between Walgett and Menindee (Brennan et al. 2002).

Duration: The indicator of 10,000 ML/d at Bourke has a minimum duration of 14 days. This is considered a typical duration for a flow event of this magnitude under the without development model scenario.

Timing: The timing for this flow indicator is August to May. The two coldest months of the year are excluded because fish responses are expected to be subdued (Reynolds 1983; Mallen-Cooper et al. 1995). The timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (August to December) and the other native fish species in the northern basin[13]. The timing has not been limited to the months when spawning occur, but instead limited to the period when water temperatures are warm enough[14] that fish are known to move, which can be important for fish conditioning and dispersal.

Frequency: This flow indicator has a low uncertainty frequency of 80% of years and a high uncertainty frequency of 60% of years. This frequency range aims to improve opportunities for distribution and mixing of populations of fish and other aquatic species (*NSW DPI 2015*).

The increase in opportunities for fish to move through the river system and potentially into other catchments is anticipated to significantly benefit flow dependent specialists. The traits of fish to move in response to flows in the northern basin are well documented with species studied including spangled perch, golden perch, silver perch and Hyrtl's tandan (*Marshall et al. 2016*; *Boys et al. 2013*; Hutchison et al. 2008).

Indicator: Minimum of 2 flow events of 10,000 ML/d in the Darling River at Bourke for 20 consecutive days from August to May, with a minimum peak of 15,000 ML/d for five days, for 35% (low uncertainty) to 25% (high uncertainty) of years.

Magnitude: Two 10,000 ML/d events are stipulated at Bourke in one year. This is intended to improve the chance for successful recruitment of fish species (*NSW DPI 2015*). Two events in one year is more likely to provide sufficient food and habitat resources necessary for recruitment than a single event (*NSW DPI 2015*). Two flow events around 10,000 ML/d at Bourke is also a common feature of the Barwon–Darling River system.

Duration: A duration of 20 days is to provide spawning and recruitment opportunities for both the flow dependent and in-channel specialist functional groups (*NSW DPI 2015*). A duration of 20 days may also facilitate larvae drift to downstream areas which can occur over long distances for up to 20 days post spawning in intermittent systems (*NSW DPI 2015*).

Timing: The timing for this flow indicator is August to May. The two coldest months of the year are excluded because fish responses are expected to be subdued (Reynolds 1983; Mallen-Cooper et al. 1995). The timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (August to December) and the other native fish species in the northern basin[15]. The timing has not been limited to the months when spawning occur, but instead limited to the period when water temperatures are warm enough[16] that fish are known to move, which can be important for fish conditioning and dispersal.

Frequency: The frequency range associated with the two 10,000 ML/d flow events for 20 day flow indicator at Bourke (35% of years with low uncertainty to 25% of years with high uncertainty) reflects a need for spawning and recruitment flow events in two to three years per decade for the

[13] NSW DPI (2015) provides more detail about the spawning season, temperature and method for fishes in the northern basin.
[14] generally greater than 15° Celsius
[15] NSW DPI (2015) provides more detail about the spawning season, temperature and method for fishes in the northern basin.
[16] generally greater than 15 degrees Celsius

flood dependent specialists and two to five years per decade for in-channel specialists, which reflects biological requirements including life span and age at sexual maturity (*NSW DPI 2015*).

Indicator: Minimum of 1 flow event of 21,000 ML/d in the Darling River at Louth for 20 consecutive days from August to May for 40% of years (low and high uncertainty).

Magnitude: The flow indicator describes a large in-channel pulse that would provide fish with opportunities for large-scale movement and improve the chance for successful recruitment of fish species by optimising food and habitat resource availability. A flow of 21,000 ML/d at Louth provide fish with opportunities for large-scale movement and improved access to in-channel habitats. These flows inundate more than 95% of snags and in-channel benches between Brewarrina and Wilcannia. Inundation of in-channel habitats improves availability of food resources that promote conditioning for fish of all life stages (e.g. larvae, adult) that can aid in successful recruitment (*NSW DPI 2015*).

Flows of around 20,000 ML/d also inundate riparian areas and wetlands. These areas are important habitats for aquatic biota including fish. Inundation of riparian areas and wetlands can provide an increase in food supply and provide spawning and nursery habitats for aquatic biota (*NSW DPI 2015*). Research in the Barwon–Darling catchment by Brennan et al. (2002) on wetland commence-to-flow rates showed that a flow rate of 20,000 ML/d at Bourke, Louth and Wilcannia inundated between 15% and 60% of the wetlands along the river, depending on their location along the river system between Mungindi and Menindee.

This indicator aims to provide improved conditions for the in-channel specialist functional group, such as Murray cod, through improved opportunities for re-colonisation, breeding and habitat access, including fish recruitment.

Duration: This flow indicator has a minimum duration of 20 days. This duration is to provide spawning and recruitment opportunities for both the flow dependent and in-channel specialist functional groups. A duration of 20 days may also facilitate larvae drift to downstream areas which can occur over long distances for up to 20 days post spawning in intermittent systems (*NSW DPI 2015*).

Timing: The timing for this flow indicator is August to May. The two coldest months of the year are excluded because fish responses are expected to be subdued (Reynolds 1983; Mallen-Cooper et al. 1995). The timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (August to December) and the other native fish species in the northern basin[17]. The timing has not been limited to the months when spawning occur, but instead limited to the period when water temperatures are warm enough[18] that fish are known to move, which can be important for fish conditioning and dispersal.

Frequency: The frequency is set at between 60-80% of without development conditions, which provides the preference to have more than two spawning and recruitment opportunities per decade for the in-channel specialist functional group (*NSW DPI 2015*).

[17] NSW DPI (2015) provides more detail about the spawning season, temperature and method for fishes in the northern basin.
[18] generally greater than 15° Celsius

Indicator: Minimum of 1 flow event of 20,000 ML/d in the Darling River at Wilcannia for 7 consecutive days any time of the year for 60% (low uncertainty) to 45% of years (high uncertainty).

Magnitude: A flow of 20,000 ML/d at Wilcannia provide fish with opportunities for large-scale movement and improved access to in-channel habitats (*NSW DPI 2015*). These flows inundate more than 95% of snags and in-channel benches between Brewarrina and Wilcannia. Inundation of in-channel habitats improves availability of food resources that promotes conditioning for fish of all life stages (e.g. larvae, adult) that can aid in successful recruitment (*NSW DPI 2015*).

Flows of around 20,000 ML/d also inundate riparian areas and wetlands. These areas are important habitats for aquatic biota including fish. Inundation of riparian areas and wetlands can provide an increase in food supply and provide spawning and nursery habitats for aquatic biota (*NSW DPI 2015*). Research in the Barwon–Darling catchment by Brennan et al. (2002) on wetland commence-to-flow rates showed that a flow rate of 20,000 ML/d at Bourke, Louth and Wilcannia inundated between 15% and 60% of the wetlands along the river, depending on their location along the river system between Mungindi and Menindee.

This indicator aims to enhance nutrient spiralling from inundation of benches, particularly between Tilpa and Wilcannia (*NSW DPI 2015*). There is the highest number and total area of benches in this 250 km stretch of the Darling River (*NSW DPI 2015*).

Duration: A duration of seven days is considered sufficient for abiotic processes such as the release of carbon and other nutrients from inundated benches. This duration would also provide some opportunity for the dispersal and movement of aquatic species.

Timing: The timing for this indicator is any time of year. Improving food sources and access to habitat for aquatic biota would be beneficial any time of year.

Frequency: The 20,000 ML/d flow indicator at Wilcannia is based on a percentage of the frequency under without development conditions (80% of years with low uncertainty to 60% of years with high uncertainty).

A summary of the basis of each site-specific flow indicator for small in-channel freshes to contribute to longitudinal connectivity in the Barwon–Darling river system UEA is presented in Table 3; and for large in-channel freshes to contribute to longitudinal connectivity is presented in Table 4.

Table 3: Site-specific flow indicators for small in-channel freshes for the Barwon–Darling UEA. In this table, frequency is the percentage of years in which there is the flow event. Frequency range is shown as low uncertainty to high uncertainty

Magnitude: minimum flow (ML/d)	Basis of magnitude	Duration (consecutive days)	Basis of duration	Timing	Basis of timing	Freq. range	Basis of frequency
6,000 (Bourke gauge)	Small scale fish movement between Walgett and Tilpa, and access to over half the snags and three quarters of the in-channel benches	14	The 14 day duration at Bourke is the median duration for flow events under the without development model.	Minimum of 1 event any time of the year	Provides regular short scale movement opportunities and access to preferred habitat	80%—90% of years (with at least 1 event)	To provide regular freshes (close to annual) for maintenance and conditioning of fish populations and other aquatic biota
6,000 (Louth gauge)	In addition to the above, some spawning opportunities for in stream specialists such as Murray cod	20	The 20 day duration is to provide spawning and recruitment opportunities for both the flow dependent and in-channel specialist functional groups. A duration of 20 days may also facilitate larvae drift to downstream areas which can occur over long distances for up to 20 days post spawning in intermittent systems (*NSW DPI 2015*).	Minimum of 1 event between Aug— May	Fish response expected when the water temperature exceeds the critical temperature threshold (15°)	70% of years (with at least 1 event)	Based providing more than two spawning and recruitment opportunities per decade for the in-channel specialist functional group
6,000 (Wilcannia gauge)	Promote in-stream nutrient spiralling: provide inundation of 90% of mapped in-channel benches	7	A duration of seven days is considered sufficient for abiotic processes such as the release of carbon and other nutrients from	Minimum of 2 events any time of the year	Two events in a year increases nutrient spiralling; common for this type of flow to occur more than once per year	45%—60 of years (with at least 1 event)%	Based on estimated frequency for increased productivity benefits to river ecosystem

Magnitude: minimum flow (ML/d)	Basis of magnitude	Duration (consecutive days)	Basis of duration	Timing	Basis of timing	Freq. range	Basis of frequency
	between Tilpa and Wilcannia		inundated benches. This duration would also provide some opportunity for the dispersal and movement of aquatic species.				

Table 4: Site-specific flow indicators for large in-channel freshes for the Barwon–Darling UEA. In this table, frequency is the percentage of years in which there is the flow event. Frequency range is shown as low uncertainty to high uncertainty

Magnitude: minimum flow (ML/d)	Basis of magnitude	Duration (consecutive days)	Basis of duration	Timing	Basis of timing	Freq. range	Basis of frequency
10,000 (Bourke gauge)	Trigger opportunity for large-scale fish movement (Walgett to Wilcannia) through drown out of barriers; improved access to ideal habitat (two thirds of snags, most benches and a few wetlands)	14	The 14 day duration at Bourke is the median duration for flow events under the without development model.	Minimum of 1 flow event between Aug—May	Provide at least one opportunity outside the two coldest months	60%—80% of years (with at least 1 event)	To improve mixing of populations (genetic diversity) and improved conditions for breeding, especially for flow dependent specialist fish
10,000 (Bourke gauge)	In addition to above, provides peak of 15,000 ML/d for five days, considered sufficient to cue flow dependent specialist fish breeding	20	The 20 day duration is to provide spawning and recruitment opportunities for both the flow dependent and in-channel specialist functional groups. A duration of 20 days may also facilitate larvae drift to downstream areas which can occur over long distances for up to 20 days post spawning in intermittent systems (*NSW DPI 2015*).	Minimum of 2 flow events between Aug—May	Consistent with spawning season of flow dependent fish, with second flow event enhancing recruitment	25%—35% of years (with at least 1 event)	Ideal spawning and recruitment opportunities in about 3 out of 10 years; linked to biological requirements of flow dependent specialist fish
21,000 (Louth gauge)	In addition to above, provides access to all snags in the Bourke to Louth reach to support in-	20	The 20 day duration is to provide spawning and recruitment opportunities for both	Minimum of 1 flow event	Consistent with spawning season of flow dependent fish, with second	40% of years (with at	Based on providing more than two spawning and recruitment

Magnitude: minimum flow (ML/d)	Basis of magnitude	Duration (consecutive days)	Basis of duration	Timing	Basis of timing	Freq. range	Basis of frequency
	channel specialist breeding, and access to an increased number of anabranches and wetlands		the flow dependent and in-channel specialist functional groups. A duration of 20 days may also facilitate larvae drift to downstream areas which can occur over long distances for up to 20 days post spawning in intermittent systems (*NSW DPI 2015*).	between Aug—May	flow event enhancing recruitment	least 1 event)	opportunities per decade for the in-channel specialist functional group
20,000 (Wilcannia gauge)	Extensive inundation of in-channel benches to support nutrient spiralling, food supply and habitat access	7	A duration of 7 days is considered sufficient for abiotic processes (e.g. release of carbon and other nutrients from inundated benches). This duration would also provide for the dispersal and movement of aquatic species.	Minimum of 1 flow event any time of the year	Considered to provide benefits to fish and aquatic biota any time of year	45%—60% of years (with at least 1 event)	Based on a percentage of the frequency under without development conditions

5.2 Lateral connectivity (with the floodplain)

Floodplains are an important component of river systems. Many, if not all, of the species that live in rivers depend in some way on the river connecting with its' floodplain (Mussared 1997). Flooding flows that punctuate dry spells and inundate floodplains are an essential component of dryland river systems. When rivers overflow and floodwaters extend across the floodplain there is an exchange of nutrients which replenishes the floodplain and river, and a dispersal of seeds and organisms (Thorp et al. 2008). This process is important for the lifecycle needs of fauna including fish, waterbirds, and other aquatic organisms (Balcombe et al. 2007; Leigh et al. 2010).

Periodic inundation is important for the health of the river system and the floodplain (Thorp et al. 2008). Floodwaters inundate a diverse suite of environments, including wetlands and floodplain vegetation communities such as forests, woodlands and grasslands (Figure 4). Wetlands, creeks and anabranches provide foraging habitat for bird species (Wen et al. 2011). Fish move into the anabranches and wetlands that are inundated with floodwaters to feed in these nutrient-rich areas, and many small bodied fish use these habitats to breed (*Nichols et al. 2012, NSW DPI 2015*). Other animals including amphibians and reptiles also depend on areas of the river banks and floodplain (*DSITIA 2013*, Ayers et al. 2004). Floodwaters are also important for triggering events that are important for river-floodplain food webs (e.g. Jenkins and Boulton, 2003).

A diversity of out-of-channel flows (lateral connectivity) is needed to connect different parts of the floodplain system and have a range of environmental benefits. These are described below.

5.2.1 Summary of available evidence

New information gathered through the Northern Basin Review includes: hydrological analysis undertaken by the MDBA; inundation mapping (*MDBA 2016*); vegetation mapping (*Eco Logical Australia 2016*); and a review of knowledge on waterbirds (*Brandis and Bino 2016*). Other evidence considered included: commence-to-flow relationships for key wetlands (Brennan et al. 2002; SKM 2009); and research on the Talyawalka–Teryaweynya system near Wilcannia (e.g. Withers 1996; Jenkins and Briggs 1997; DEWHA 2010).

Through hydrological analysis using observed gauge data, flow attenuation relationships were calculated between gauges along the Darling River from Bourke to Wilcannia (*MDBA 2016*). This analysis took into account flow travel time between gauges. The observed flows in the Darling River at Bourke, Louth and Tilpa were estimated to be within 3% of each other for flows between 30,000 ML/d and 60,000 ML/d. However, the flows at Wilcannia diverged substantially from those at Bourke (within the same flow band) above a flow of 30,000 ML/d at Bourke, as shown in

. This is due to flows breaking out into wetlands and anabranches between Bourke and Wilcannia, thereby bypassing the Wilcannia gauge. For example, flows into Talyawalka–Teryaweynya wetland and anabranch system just upstream of Wilcannia re-join the Darling River well downstream of Wilcannia at Menindee (Jenkins and Boulton 2003). The commence-to-flow of Talyawalka Creek is approximately 30,000 ML/d at the Wilcannia gauge (Cooke and He 2007).

Table 5: Relationship between flow at Bourke and the estimated flow at Wilcannia

Flow at Bourke (ML/d)	Estimated flow at Wilcannia (ML/d)
20,000	19,000
30,000	25,000
40,000	28,000
50,000	30,000
60,000	30,000

MDBA (2016) describes the method used to assess which flow rates breach the river banks and the approximate proportion of floodplain inundated. The method uses an existing archive of Landsat imagery between 1987 and 2014, comprising thousands of individual images which have been classified for the presence of water on the floodplain. The inundation represented in these images was analysed for 10 individual hydrologically-distinct flood zones extending from Bourke to Wilcannia, and plotted against flow gauged on the date when the satellite image was taken.

This produces relationships between actual gauged flow in the river and the resulting area inundated for those flood zones, providing an idea of the inundation extent resulting from actual flow events that have occurred since the mid-1980s (*MDBA 2016*). For the less frequent higher flow rates, there were only a few flood images available to assess inundation patterns. This means the relationships drawn for larger flow events are not as strong and limits the ability to accurately predict flow/inundation relationships for different overbank flow rates. Nevertheless, this inundation analysis provides improved knowledge on large-scale floodplain inundation behaviour. An example of areas inundated by flows at the Bourke gauge on particular days is given in Figure 13 (*MDBA 2016*).

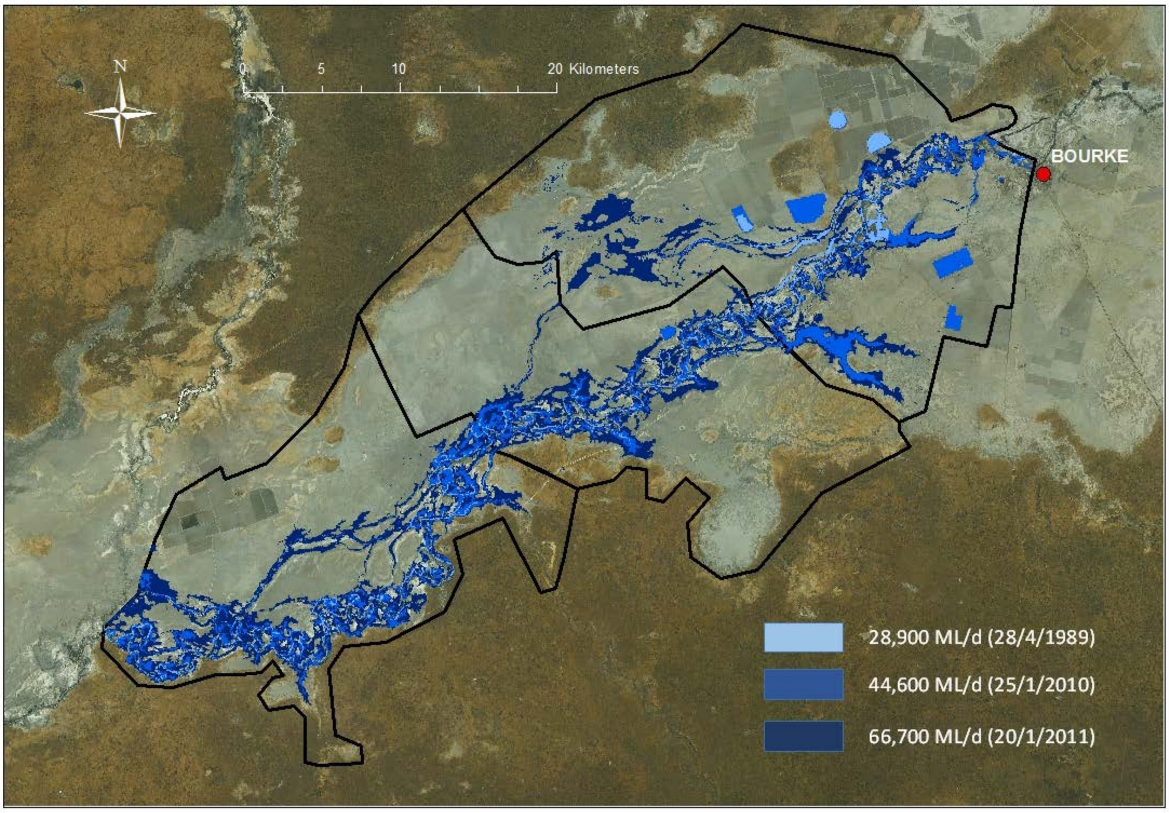

Figure 13: Example of floodplain areas inundated downstream of Bourke associated with flows measured at Bourke

The vegetation community composition on a floodplain varies according to flood frequency and position. A stylised example of where different vegetation communities are likely to be located on the floodplain of the Barwon–Darling river system UEA was given earlier in Figure 4.

Knowledge of the presence of vegetation on the Darling floodplain forms another line of evidence when developing indicators for lateral connectivity. Different vegetation communities will have greater or lesser access to water sources depending on their location. The riparian zones that fringe the creeks and rivers of the Darling River are dominated by river red gum (*Eucalyptus camaldulensis*) and coolibah (*E. coolabah*) forests with a range of shrub, reed and grass species such as lignum shrubs (*Duma florulenta*), Downs nut-grass (*Cyperus bifax*) and rat's tail couch (*Sporobolus mitchelli*) forming an understory (*Eco Logical Australia 2016*; *Sheldon et al. 2014*). Lignum and cane grass (*Eragrostis australasica*) are prevalent in wetland habitats (SKM 2009). Vegetation at higher elevations on the floodplain is predominantly a mixture of coolibah and floodplain grasslands (*Eco Logical Australia 2016*). New vegetation community mapping was undertaken along the Darling River as a part of the Northern Basin Review (*Eco Logical Australia 2016*). This mapping has helped identify the extent and location of floodplain vegetation communities in the region.

The areas of inundation previously described were intersected with vegetation maps using methods discussed in *(MDBA 2016)*. While this was a significant improvement in the science, a number of factors led to an underestimate of areas of vegetation inundated[19]. Hence the areas reported here represent a lower limit - that is, 'at least' a certain proportion of a vegetation community is inundated at a given flow (Table 6). The most recent vegetation mapping undertaken by *Eco Logical Australia (2016)* provides a current understanding of which vegetation communities occupy different areas of the riparian and floodplain zones. This, combined with recent inundation mapping forms the best available information with which to estimate the area of vegetation communities inundated under each existing flow indicator.

Table 6: Relationship between flows at Bourke gauge and proportion of selected vegetation inundated (MDBA 2016)

Flow at Bourke (ML/d)	Percentage of river red gum inundated between Bourke and Louth	Percentage of coolibah and floodplain grasslands combined inundated between Bourke and Louth
30,000	At least 55%	At least 5%
45,000	At least 70%	At least 10%
65,000	At least 85%	At least 30%

Water requirements (in the form of overbank flows) for four of the dominant floodplain vegetation species found along the Barwon–Darling system were summarised from Roberts and Marston (2011). These were reviewed by a group of vegetation ecologists for the northern basin (*Casanova 2015*), and the results are provided in Table 7. The table summarises the average overbank flow requirements of a plant in average condition for vigorous growth and regeneration, and the critical interval between overland flow events to maintain vigour.

[19] The method used to detect water from the satellite images either cannot pick up, or tends to underestimate, the presence of water in heavily vegetated areas (especially wetlands) and in areas of vegetation smaller than the resolution of the data (25 x 25 metre cells). This increases uncertainty in the derivation of reliable flow/inundation relationships, but the work produces robust results when considering large-scale flow patterns and particularly the flow rates at which significant inundation breakouts occur in the landscape.

Table 7: Water requirements (frequency, timing, depth) for the four most common flood-dependent species summarised from Roberts and Marston (2011). This data represents the best available general knowledge from across the Murray–Darling Basin and was reviewed in *Casanova (2015)*. The table summarises the overland flow requirements of a plant in average condition for vigorous growth and regeneration, and the critical interval between overland flow events to maintain vigour

Species	Water regime requirements
River red gum	**For vigorous growth:** Flooding about every one to three years for forests, about every two to four years for woodlands, depth not critical, variability is preferable, timing best in spring—summer **For regeneration:** Flood recession in spring or later, follow-up flood for establishment, depth 20—30 cm, but longer is tolerated **Critical interval:** Flooding after about three years for forests, five to seven years for woodlands, longer intervals lead to loss in condition
Lignum	**For vigorous growth:** Frequency about every one to three years for vigorous growth, three to five years to sustain, seven to 10 years for persistence, depth not critical (< 1m), timing not critical (natural flow patterns should be followed if possible). **For regeneration:** Depth not critical, timing in autumn—winter, follow-up flooding nine to 12 months after germination likely to assist establishment. Flooding once every 12 to 18 months during first three years desirable, depth to 15 cm, before or during summer. **Critical interval:** Flood every five to seven years, although rootstock can survive up to 10 years.
Black box	**For vigorous growth:** Frequency every three to seven years, depth not critical, timing probably not important (natural flow patterns should be followed if possible) **For regeneration:** Following flood recession or in run-off areas after rainfall, timing in spring—summer, additional moisture in first or second year likely to be beneficial **Critical interval:** Trees may survive 12 to 16 years, but in poor condition with diminished capacity to recover
Coolibah	**For vigorous growth:** About every 10 to 20 years, but could be as little as seven years, depth not critical, timing not expected to be important **For regeneration:** Likely to be on flood recession or in run-off areas after rainfall, timing not critical, additional moisture in the first summer likely to improve establishment **Critical interval:** Not known, possibly 10 to 20 years

Information on wetlands along the Barwon–Darling River is also important when developing indicators for lateral connectivity. Wetlands provide a major site of carbon and other nutrient cycling with the river as well as habitat refuges for a range of species (Boulton and Brock 1999). Mapping along the Barwon–Darling River between Mungindi and Menindee in 2002 determined the type and locations of wetlands and assessed the types of flows required to fill wetlands (Brennan et al. 2002). A total of 583 wetlands of various character was recorded, and it was determined that wetlands are typically dominated by anabranches in the upper reaches and larger, complex billabongs and deflation lakes in the lower reaches (Brennan et al. 2002). Flows required to inundate these wetlands vary depending on their location in the landscape, proximity to the main river channel and type (Brennan et al. 2002). These authors indicated that flows in the range of 30,000—50,000 ML/d measured at Bourke will inundate the majority of near-channel and floodplain wetlands along the Barwon–Darling river system UEA.

The Barwon–Darling River was identified as containing key wetland habitats, important for supporting large waterbird numbers and a diverse range of species (*Brandis and Bino 2016*). The region includes several habitat areas that can support large numbers of waterbirds. Up to 74 waterbirds species have been recorded in the Barwon–Darling, with seven species, including two colonial nesting species, recorded breeding at seven wetland sites (*Brandis and Bino 2016*). Particularly significant sites for waterbirds are located in the vicinity of Louth near the confluence of the Warrego and Darling rivers, and near Wilcannia (Talyawalka Creek, Waterloo Lake, Pelican Lake, and Dry Corner Swamp). These are shown in Figure 14. The Talyawalka–Teryaweynya system contains particularly important wetlands that support high waterbird species diversity and high abundance (*Brandis and Bino 2016*).

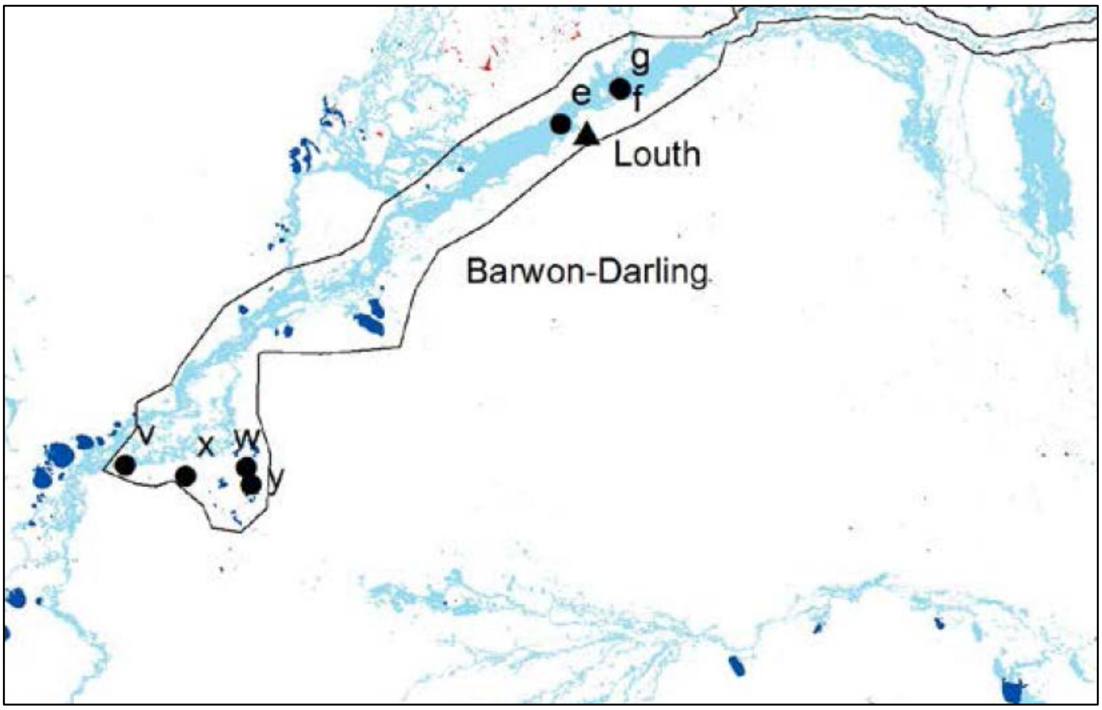

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Figure 14: Location of sites with breeding records along the Barwon–Darling River (wetlands mapping from Kingsford et al. 1999 in *Brandis and Bino 2016*). e, f, g - Darling River sites 1, 2, 3. v - Talyawalka Creek. w - Pelican Lake. x - Dry Corner swamp. y - Waterloo Lake.

5.2.2 Site-specific flow indicators

Four site-specific flow indicators associated with lateral connectivity between the river and the floodplain have been selected. These are connectivity with the riparian zone (including some near-channel floodplain); the inner floodplain; the mid floodplain; and the outer floodplain. The first three of these flow indicators are specified as flows in the Darling River at Bourke, with the remaining indicator specified as a volume (rather than a flow) at the Wilcannia gauge.

No specific time of year has been set for any of the flow indicators to reflect that high flows are dependent on the occurrence of heavy rainfall and will be largely unregulated flow events.

Lateral connectivity with the riparian zone (including some near-channel floodplain)

A riparian zone along the Darling River is shown in Figure 15. The riparian zone and near-channel zone includes river red gum, ephemeral wetlands and lignum communities.

Figure 15: An example of the riparian zone with river red gums lining the Darling River bank. (Photo: Mark Southwell)

Indicator: Minimum of 1 flow event of 30,000 ML/d in the Darling River at Bourke for 24 consecutive days any time of year every 2 (low uncertainty) to 3 years (high uncertainty) on average.

Magnitude: Brennan et al. (2002) found flows around 30,000 ML/d at Bourke start to inundate riparian and near-channel wetlands. A recent analysis of flow/inundation relationships confirms this estimate (*MDBA 2016*).

Flows at around bankfull are important for maintaining geomorphic features within the bed of the river channel, such as sand bars, benches and waterholes (Wilkinson et al. 2004). Maintaining flows around bankfull also provides for riparian vegetation, which can assist in reducing river bank erosion. This flow is also likely to be sufficient for geomorphic processes to re-distribute the fine and mobile sediment within the river channel, maintaining habitats such as pools and benches. Significant sediment movement (i.e. both sedimentation and erosion) has been observed to occur on benches along the Darling River at flows of around this magnitude (Southwell 2008).

Duration: Consistent with past practice (e.g. MDBA 2012), the duration selected was the median[20] duration for a flow of 30,000 ML/d from the without development flow scenario. This median duration is 24 days. It is expected that water would be retained in some wetlands and anabranches for longer than 24 days and be likely to meet the needs of wetland vegetation.

Frequency: A frequency of 2—3 years on average between these flow events was selected, as it is consistent with the flooding requirements to sustain riparian and wetland vegetation such as river red gum forests and lignum (Table 7).

Lateral connectivity with the inner floodplain

An inner floodplain zone along the Darling River is shown in Figure 16. There are river red gums lining the creeks that can be seen in the foreground and coolibah trees on the higher parts of the floodplain.

Figure 16: An example of the inner floodplain zone along the Barwon–Darling River (Photo: Adam Sluggett)

Indicator: Minimum of 1 flow event of 45,000 ML/d in the Darling River at Bourke for 22 consecutive days at any time of year every 3.5 (low uncertainty) to 4 years (high uncertainty) on average.

Magnitude: Through the analysis of observed flow/inundation relationships, flow events of 45,000 ML/d for the Darling River at Bourke would inundate areas of the inner floodplain like that shown in Figure 19. This includes near-channel habitats and floodplain wetlands (*MDBA 2016*). This duration is consistent with work by Brennan et al. (2002) who found flows of around this magnitude across the Barwon–Darling river system UEA are important in connecting the majority of wetlands with the main channel (i.e. inundation of 90% of wetlands).

The majority of river red gum communities between Bourke and Louth would be inundated (Table 6). This flow would exceed the commence-to-flow of channels connecting lakes known to be

[20] The median was chosen as a statistic as it is not biased by very long overbank events which occur occasionally in the Barwon–Darling river system UEA

important for waterbirds, including Poopelloe Lake, Victoria Lake and Eucalyptus Lake in the Talyawalka–Teryaweynya system (Brennan et al. 2002). This flow (and duration) would be sufficient to water river red gum woodlands communities fringing the Talyawalka Anabranch. The recent inundation analysis (*MDBA 2016*) suggests that at this flow at least 10% of coolibah woodlands and floodplain grasslands in the Bourke to Louth region would also be inundated (Table 5).

Duration: Consistent with past practice (e.g. MDBA 2012), the duration selected was the median duration for a flow of 45,000 ML/d from the without development flow scenario. This median duration is 22 days. It is expected that water would be retained in some wetlands and depressions for longer than 22 days and be likely to meet the needs of wetland vegetation.

Frequency: The frequency of 3.5—4 years between flooding events on average is within the range of the watering requirements of river red gum woodlands (Table 7), and is expected to sustain wetland communities including lignum.

Lateral connectivity with the mid floodplain

The mid floodplain zone along the Darling River includes extensive coolibah woodlands. An example is shown in Figure 17.

Figure 17: An example of a coolibah woodland. (Photo: Kelly Marsland)

Indicator: Minimum of 1 flow event of 65,000 ML/d in the Darling River at Bourke for 24 consecutive days at any time of year every 6 (low uncertainty) to 8 years (high uncertainty) on average.

Magnitude: Flows of 65,000 ML/d (measured at Bourke) will inundate a large proportion of the floodplain (*MDBA 2016*). This inundation facilitates the dispersal of organic matter (e.g. seeds, animals, leaf litter), water, nutrients and sediment across the floodplain, creeks and wetlands (Thoms 2003). More than 30% of the floodplain grasslands and coolibah woodlands found at higher elevations become inundated at this flow rate (*MDBA 2016*). This flow also inundates black box woodland communities around the Talyawalka–Teryaweyna system (MDBA 2012).

Duration: Consistent with past practice (e.g. MDBA 2012), the duration selected was the median duration for a flow of 65,000 ML/d from the without development flow scenario. This median duration is 24 days. It is expected that water would be retained in some wetlands and depressions for longer than 24 days and be likely to meet the needs of wetland vegetation.

Frequency: The frequency of 6—8 years is consistent with supporting vigorous growth for black box and is close to the critical interval of river red gum woodlands and lignum (Table 7). Although it is acknowledged that these latter two species may remain alive if inundation occurs less often, their condition is likely to be poor, and more frequent subsequent wetting may be required to improve their health and vigour (*Casanova 2015*).

Lateral connectivity with the outer floodplain

Indicator: A volume of 2,350 GL into Talyawalka Creek within a single flow event at any time of year (measured once flow is above 30,000 ML/d at Wilcannia) for 10% (low uncertainty) to 7% (high uncertainty) of years.

Magnitude: This indicator is associated with filling of lakes in the Talyawalka–Teryaweynya system, as well as inundating wetlands and vegetation communities on the outer Darling floodplain more broadly. A flow into Talyawalka Creek occurs when the flow is in excess of 30,000 ML/d in the Darling River at Wilcannia.

The Talyawalka–Teryaweynya system contains braided channels, interspersed by a series of varying sized lakes and is considered a nationally important wetland/creek system (DEWHA 2010). The lakes and their surrounds are the focus of this indicator. This system supports extensive areas of floodplain vegetation (Jenkins and Briggs 1997) including black box, lignum and grasslands. When inundated, the system's lakes provide foraging habitat for large numbers of waterbirds (DEWHA 2010). In particular, Kingsford et.al (1997) identified Pelican Lake within the system, and the Darling River floodplain near Louth, as places known or predicted to support 20,000 or more waterbirds.

To estimate the minimum volume to inundate the Talyawalka–Teryaweynya system, hydrological analysis of five flood events was undertaken in the original assessment of environmental water requirements (MDBA 2012). The analysis is summarised in Box 8. The minimum volume into Talyawalka Creek to inundate the system was estimated to be 2,350 GL. The minimum peak discharge at Bourke associated with these five observed flow events was 136,000 ML/d and the minimum duration exceeding 65,000 ML/d at Bourke was 31 days. This confirms that flow events that fill the lakes in the Talyawalka–Teryaweynya system exceed the flow indicator specified for the mid floodplain of 65,000 ML/d for 24 days.

Box 8: Analysis of flow events that inundate the Talyawalka–Teryaweynya system (based on MDBA 2012)

Based on knowledge outlined in Jenkins and Boulton (2003) and Jenkins and Briggs (1997), gauged flows at Wilcannia for 1974, 1976, 1983, 1990 and 1998 flood events were to estimate the minimum inflow volumes required to fill the more frequently inundated parts of the system. The duration and inflow volume required to inundate the lakes are below.

	1974 Event	1976 Event	1983 Event	1990 Event	1998 Event
Number of days in excess of 30,000 ML/d in the Darling River at Wilcannia	57	88	75	141	73
Total volume of flow into Talyawalka system (GL)	2,350	4,450	2,900	5,150	2,800
Peak flow in the Darling River at Bourke (ML/d)	443,798	500,931	160,466	136,158	231,250
Number of days in excess of 65,000 ML/d in the Darling River at Bourke	32	55	35	31	67

Such flows at Bourke would inundate virtually all wetland areas of the Darling floodplain (Brennan et al. 2002) and provide for mass exchange of nutrients, sediment and recruitment and dispersal opportunities for a range of native aquatic animal and plant species.

Inundation at this level, though infrequent, has been shown to be vital for the growth and productivity of floodplain grasslands (*Parsons and Thoms 2013*, Capon 2003). Species which are common to the grassland communities on the Darling floodplain include cane grass, Mitchell grasses (*Astrebla lappacea, Astrebla pectinata*), neverfail (*Eragrostis setacea*) and windmill grass (*Chloris truncata*) (*Eco Logical Australia 2016*). Maintaining these grasslands communities is important for providing terrestrial animal habitat and energy sources for aquatic animals (*Parsons and Thoms 2013*; *Woods et al. 2012*).

Duration: The duration is for the volume to flow into the Talyawalka–Teryaweynya system in one continuous event. Based on the data in Box 8, this is expected to take around 60 days or more.

Frequency: The frequency range is for this event to occur in 10% (low uncertainty) to 7% (high uncertainty) of years. This is consistent with the flooding requirements of vegetation communities including black box trees and lignum shrubs (Table 8).

A summary of the basis of each site-specific flow indicator for lateral connectivity for the Barwon–Darling river system UEA is provided in Table 8.

Table 8: Site-specific flow indicators for lateral connectivity for the Barwon–Darling UEA. In this table, frequency is the number of years between watering events. Frequency range is shown as low uncertainty to high uncertainty

Magnitude: minimum flow (ML/d)	Basis of magnitude	Duration (consecutive days)	Basis of duration	Timing	Basis of timing	Freq. range	Basis of frequency
30,000 (Darling River at Bourke)	Inundation of riparian forests, and near-channel and fringing wetlands. The flow is around bankfull, which is important for in-channel geomorphic processes and maintaining habitats.	24	Median duration above this flow under the without development scenario	Any time of year	These flows will be largely unregulated events and can occur at any time of year	2-3 years (average period between events)	Reflects flow requirements for vigorous river red gum forest, and lignum communities in riparian forests.
45,000 (Darling River at Bourke)	Connectivity with inner floodplain including approximately 90% of wetlands.	22	Median duration above this flow under the without development scenario	Any time of year	These flows will be largely unregulated events and can occur at any time of year	3.5-4 years (average period between events)	Frequency based the requirements of vegetation including river red gum woodlands and wetlands, including some habitat within the Talyawalka–Teryaweynya system
65,000 (Darling River at Bourke)	Broad floodplain inundation flows starting to inundate large areas of black box and coolibah woodlands and some grasslands.	24	Median duration above this flow under the without development scenario	Any time of year	These flows will be largely unregulated events and can occur at any time of year	6-8 years (average period between events))	Frequency based on the requirements of vegetation including black box, lignum and red gum
2,350 GL (volume measured once flow is above 30,000 ML/d) (Darling River at Wilcannia)	Minimum volume to fill the lakes more frequently in the Talyawalka–Teryaweynya system based on 5 observed events. This magnitude also inundates wetlands and vegetation communities on the outer Darling floodplain more broadly.	> 60	The duration is tied to a volume of inflow to fill Talyawalka–Teryaweynya system	Any time of year	These flows will be largely unregulated events and can occur at any time of year	7%–10% of years (with at least 1 event)	Frequency based requirements for vegetation including black box and lignum

6 Knowledge gaps

Imperfect knowledge of flow-ecology relationships is a universal challenge in determining the water needs of aquatic ecosystems (Swirepik et al. 2015). As a result of a science review in the northern basin (*Sheldon et al. 2014*) and a number of subsequently commissioned projects (*Brandis and Bino 2016*, *Casanova 2015*, *DSITI 2015*, *NSW DPI 2015*), the scientific evidence underpinning the application of the Environmentally Sustainable Level of Take (ESLT) method has been improved in the Barwon–Darling catchment. However, gaps remain in our understanding. This section draws on the recommendations of the various projects and reviews to describe avenues for further research and investigation that would improve the specification of environmental water requirements in the northern basin.

An assumption of the umbrella environmental asset (UEA) approach is that the provision of adequate flow regimes at individual assets will support the environmental water requirements of the broader set of water-dependent ecosystems (Swirepik et al. 2015). The authors noted that it is not feasible to test this assumption until the environmental water requirements of the broad suite of water-dependent ecosystems were better understood. The key sources of knowledge that will allow this to be tested are identification of floodplain ecosystem types, assessment of the ecological values and water requirements of those ecosystem types, and mapping of floodplain inundation extents at different flows. While some work has commenced (e.g. Brooks et al. 2014 - Australian National Aquatic Ecosystem Interim Classification; Fielder et al. 2011 - Queensland Aquatic Conservation Assessments) the outputs are not consistent in terms of scale or coverage to undertake a northern basin-wide assessment. The MDBA is continuing to invest in these areas of work and the new information is expected to inform future assessments of environmental water requirements across the Murray–Darling Basin.

The determination of environmental water requirements has focused on the relationship between flows and the needs of fish, waterbirds and vegetation — reflecting both the underlying knowledge base and the focus of the new science projects. Rogers and Ralph (2011) and others have identified other species that have particular water requirements — for example, amphibians (e.g. southern bell frog), mammals (e.g. platypus), reptiles (e.g. turtles), macroinvertebrates, and molluscs and crustaceans. The addition of faunal surrogates improves the representation of species inundation requirements (Rogers et al. 2012) and in doing so reduces the risk that some species will not have their water requirements met. Further work is required to develop knowledge of these other species' water needs before this understanding could be integrated into the specification of site-specific flow indicators.

A review of the ESLT method (Young et al 2011) identified the inclusion of key ecosystem functions in the method as a challenge as the relevant knowledge base was more limited than for environmental assets. They recommended including a regionalisation of key ecosystem functions, mapping their importance across the basin, and doing further work to understand the relationships between flow and ecosystem functions. While the conceptual basis for considering ecosystem functions and the role of connectivity have received greater attention in this assessment compared to the original Barwon–Darling environmental water requirement assessment (MDBA 2012), there is still work to be done to be able to implement the more systematic approach proposed by Young et al. (2011).

In addition to the broader knowledge gaps identified above, there are more specific gaps that have been catalogued in the commissioned science projects. A summary of these is provided below.

Brandis and Bino 2016 (Waterbirds)

- Food resource requirements of waterbirds during breeding events
- Pre-breeding habitat requirements of waterbirds
- Quality of nesting habitat for waterbirds
- Movement of waterbirds between wetland sites
- Effect of environmental flows on lignum channel infilling and expansion
- Role of floodplain vegetation in providing food resources for herbivorous waterbird species

Casanova 2015 (Vegetation)

- Information on the basic ecology of *Eucalyptus camaldulensis* (subspecies *acuta*) and all subspecies of *E. coolabah*
- Uncertainty regarding required duration of flooding for most tree species
- Spatial variation in character and condition of vegetation communities both historically and currently
- Information on vegetation community response to flow, especially understory species
- Whether plant species response to flow differs from the same species occurring in the southern basin
- Role of non-flow related factors (e.g. grazing, fire, weeds) in structuring plant communities
- Development of Water Plant Functional Groups to identify water requirements of groups of species
- Identification of ecological thresholds for key plant species
- Identification of stress and recovery pathways of key plant species in response to inundation

DSITI 2015 (Waterholes)

- Additional data on waterhole depths at cease-to-flow to give a better understanding of waterhole persistence throughout the region
- Review the impact of sedimentation on waterholes

NSW DPI 2015 (Fish)

- Undertaking further habitat mapping in systems other than the Barwon–Darling
- Analysis and modelling of flow hydrodynamics in the Barwon–Darling and other northern basin valleys

Glossary

Anabranch - Branch of a river that leaves the main stream and re-joins it downstream.

Antecedent conditions – refers to the moisture conditions in a catchment prior to a flow event.

Bankfull flows - The maximum amount of water a stream channel can carry without overflowing—a key factor in determining the shape of a river.

Baseline – a modelled scenario reflecting the consumptive use, rules, sharing arrangements and levels of infrastructure as at June 2009.

Basin Plan – A plan for the management of water resources of the Murray–Darling Basin under the Water Act 2007.

Hydrological modelling framework - A modelling framework that routes water through all rivers in the basin over a 114 year period of historical inflows (1895—2009) and represents the level of water resource development in 2009.

Environmental watering strategy – A strategy developed under the Basin Plan for the management of environmental water.

Connectivity - the hydrological connections between natural habitats, such as a river channel, adjacent wetland areas and along the length of rivers, including connections above ground (surface water) or below ground (groundwater).

Dry spell - the number of consecutive years without a 'site-specific flow indicator' flow event.

Duration - for flow, the number of days a flow remains at or above the specified magnitude (ML/d); for volume, the period of time flow contributes to meeting the specified quantity of water (one of the hydrologic metrics used to define a site-specific flow indicator).

Ecological targets – the ecosystem components, such as fish, waterbirds, and vegetation at an umbrella environmental asset (UEA) that are targeted by site-specific flow indicators.

Ecological values - is the perceived importance of an ecosystem, which is underpinned by the biotic and/or abiotic components and processes that characterise that ecosystem.

Ecosystem components –parts of an ecosystem at a UEA such as fish, waterbirds, vegetation.

Ecosystem functions - The processes that arise from the interaction of biota with the physical environment and with each other, that maintain the integrity and health of an ecosystem.

Environmental objectives – statements of desired longer term environmental objectives set out in Chapters 5 and 8 of the Basin Plan.

Environmental Science Technical Advisory Group – representatives from state and Federal Government agencies that advised on development of the Northern Basin Review environmental science program.

Environmentally Sustainable Level of Take - the level at which water can be taken from a water resource which, if exceeded, would compromise one of the following:

- key environmental assets of the water resource
- key ecosystem functions of the water resource
- productive base of the water resource
- key environmental outcomes for the water resource.

Functional groups – a classification of fish into northern MDB-specific functional groups based on fish with similar life-cycle requirements for flows: flow dependent specialists, in-channel specialists, floodplain specialists, generalists, generalist alien species.

Flow components - The different parts of river flow that make up a flow regime. They typically include cease-to-flow periods, low flows, freshes, bank-full flows and over-bank flows.

Flow-ecology relationships (short for flow alteration-ecological response relationships) – relationships that correlate measures of ecological condition, which can be difficult to manage directly, to streamflow conditions, which can be managed through water-use strategies and policies.

Flow event – a river flow with particular magnitude, duration and timing characteristics (see hydrologic metrics). The flow defined by a site-specific flow indicator is a flow event.

Flow indicator gauge - These are river gauges within (or close to) a UEA which record flow on a daily basis. Flow requirements of UEAs are expressed at one or more flow indicator gauges.

Flow regime - The description of the characteristic pattern of a river's flow including the quantity, timing and variability.

Frequency - the maximum number of days between flow events; or the percentage of years in which there is at least one flow event of a specified magnitude, duration and timing; or the average period between events; or a maximum return interval (one of the hydrologic metrics used to define a site-specific flow indicator).

Frequency range – the range in frequency from low uncertainty of achieving an ecological target to a high uncertainty of achieving the target.

Freshes - A pulse of water in a river channel, usually caused by heavy rainfall upstream.

High uncertainty - the frequency considered to represent a boundary beyond which there is a high likelihood that the ecological targets associated with a site-specific flow indicator will not be achieved.

Hydrology – The study of the occurrence, distribution and movement of water on, in and above the earth.

Hydrologic metrics – the four metrics that make up a site-specific flow indicator; magnitude, duration, timing and frequency.

Inundation – the movement of water over the land surface, most notably on floodplains but also in river channels with fluctuating flows.

Lateral connectivity – the hydrological connections between watercourses and adjacent floodplains and wetlands that: link a diversity of aquatic environments for feeding, breeding, migration and re-colonisation by native water-dependent species; support the vigour and condition of native vegetation; and facilitate off-stream primary production, and nutrient and organic matter exchange.

Low uncertainty - the frequency considered to represent a high likelihood that the ecological targets associated with a site-specific flow indicator will be achieved.

Longitudinal connectivity – the hydrological connections along watercourses that: link a diversity of aquatic environments for feeding, breeding, dispersal, migration and re-colonisation by native aquatic species; and facilitate geomorphic processes, sediment movement and nutrient spiralling.

Magnitude – either a specified minimum daily flow rate (ML/d); or a volume (ML), which is a specified minimum quantity of inflows over a period of time (and may or may not specify a minimum daily flow) (one of the hydrologic metrics used to define a site-specific flow indicator).

Northern Basin Review – the environmental, social and economic research and investigations being undertaken to review the basis of Sustainable Diversion Limits in the northern Murray–Darling Basin.

Nutrient spiralling - the process whereby nutrients in the water column are assimilated into living organisms, and are subsequently released back into the water via excretion or decomposition — in a repeating process as water flows downstream.

Overbank flows - Flows that spill over the riverbank and onto floodplains.

Refugia (refuges) – places in the landscape that provide habitat for biota to persist during periods of environmental stress — for example, waterholes along a river that provide habitat for native fish and other species to ‘ride out’ dry periods and drought before flows re-connect the system.

Resilience - the capacity of an ecosystem to recover from disturbance or withstand ongoing pressures. It is a measure of how well an ecosystem can tolerate disturbance without collapsing into a different state that is controlled by a different set of processes.

Riparian –The part of the landscape adjoining rivers and streams that has a direct influence on the water and aquatic ecosystems within them.

Site-specific flow indicator – the hydrology indicator used to express a water requirement of one or more ecosystem components (e.g. fish, waterbirds, vegetation) at a UEA.

Sustainable Diversion Limit - the maximum long-term annual average quantities of water that can be taken on a sustainable basis from the basin water resources.

Umbrella environmental asset - an area for which there is relatively rich knowledge with respect to flow-ecology relationships when compared to the broader region within which it sits, and which is used to establish environmental water requirements for a river reach or river system.

Vital habitat – places that provide refugia for native water-dependent biota during dry periods and drought; and places that provide for a diversity of important feeding, breeding and nursery sites for waterbirds including providing conditions conducive to large-scale bird breeding.

Water-dependent ecosystem – An ecosystem that depends on periodic or sustained inundation, waterlogging or significant inputs of water for natural functioning and survival.

Waterholes - places along the channel of a river that retain water during periods of no flow.

Water Act 2007 – Commonwealth legislation to make provision for the management of the water resources of the Murray–Darling Basin.

Water recovery – the program by governments to obtain water for the environment to meet Sustainable Diversion Limits – either through the purchase of water entitlements by willing sellers or by infrastructure investments that improve the operation of off-farm delivery systems and help irrigators improve on-farm water use efficiency.

Without development – A modelled scenario approximating river flows without any dams, weirs or consumptive use – it is a representation of the basin at conditions which approximate its natural state.

Abbreviations

ESLT Environmentally Sustainable Level of Take

MDBA Murray–Darling Basin Authority

ML/d Megalitres per day

SDL Sustainable Diversion Limit

UEA Umbrella Environmental Asset

References

Ayers, D, Mazzer, T and Ellis, M, 2004, 'Reptiles and Amphibians of the Darling Basin', The Darling, pp. 194-231

Balcombe, SR, Bunn, S, Arthington, A, Fawcett, J, McKenzie-Smith, FJ and Wright, A 2007, 'Fish larvae, growth and biomass relationships in an Australian arid zone river: links between floodplains and waterholes', *Freshwater Biology*, vol.52, pp.2385-2398

Baldwin, DS 1999, 'Dissolved organic matter and phosphorus leached from fresh and 'terrestrially' aged river red gum leaves: implications for assessing river-floodplain interactions', *Freshwater Biology*, vol.41, pp.675-685

Baumgartner, L, Conallin, J, Wooden, I, Campbell, B, Gee, R, Robinson, W and Mallen-Cooper, M 2013, 'Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems', *Fish and Fisheries*, vol.15, pp.410-427

Bilton, D, Freeland, J and Okamura, B 2001, 'Dispersal in freshwater invertebrates', *Annual Review of Ecology and Systematics*, vol.32, pp.159-181

Boulton, AJ and Brock, MA 1999, Australian Freshwater Ecology: Processes and Management, Gleneagles Publishing, Glen Osmond

Boys, C, Esslemont, G and Thoms, M 2005, *Fish habitat assessment and protection in the Barwon-Darling and Paroo Rivers*, Fisheries final report series: No. 78, report prepared for the NSW Department of Agriculture, Fisheries and Forestry by the NSW Department of Primary Industries, Port Stephens

Boys, C and Thoms, MC 2006, 'A large-scale, hierarchical approach for assessing habitat associations of fish assemblages in large dryland rivers', *Hydrobiologia*, vol.572, pp.11-31

Boys, C, Southwell, M, Thoms, M, Fowler, A, Thiebaud, I, Alexander, T and Reilly, G 2013, *Evaluation of Aquatic Rehabilitation in the Bourke to Brewarrina Demonstration Reach, Barwon-Darling river system, Australia*, Fisheries Final Report Series: No. 135, NSW Department of Primary Industries, Cronulla

Brandis, K and Bino, G 2016, *A review of the relationships between flow and waterbird ecology in the Condamine–Balonne and Barwon–Darling River Systems*, report prepared for the MDBA by Centre for Ecosystem Science, UNSW, Sydney

Brennan, S, O'Brien, M, Thoms, M and Maher, S 2002, *The physical character and flow criteria for wetlands along the Barwon-Darling river system*, CRC for Freshwater Ecology Technical Report

Brooks S, Cottingham P, Butcher, R and Hale, J 2014, *Murray-Darling Basin aquatic ecosystem classification: Stage 2 report* Peter Cottingham & Associates report to the Commonwealth Environmental Water Office and Murray–Darling Basin Authority, Canberra

Capon, S 2003, 'Plant community responses to wetting and drying in a large arid floodplain', *River Research and Applications*, vol.19, pp.509-520

Casanova, M 2015, *Review of Water Requirements for Key Floodplain Vegetation for the Northern Basin: Literature review and expert knowledge assessment*, report prepared for the MDBA by Charophyte Services, Lake Bolac

Cooke, R and He, H 2007, *Wilcannia-Menindee Flow Modelling, Calibration of IQQM Model for Routing flows from Wilcannia into Menindee Lake*, NSW Department of Water and Energy, Sydney

Cooney, T. 1994, North-west weirs and fish passage report. NSW Department of Water Resources, Technical Services Report No. TS 93.069

DEWHA (Department of Environment, Water, Heritage and the Arts) 2010, Australian wetlands database, information sheet for Talyawalka Anabranch and Teryawynya Creek, viewed 30/3/2016, <http://www.environment.gov.au/cgi-bin/wetlands/report.plwww.environment.gov.au/water/publications/environmental/wetlands/pubs/directory.pdf>

DSITI (Department of Science, Information Technology and Innovation) 2015, *Waterhole refuge mapping and persistence analysis in the Lower Balonne and Barwon–Darling rivers*, Department of Science, Information Technology and Innovation, Brisbane

DSITIA 2013, Review of Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 and Resource Operations Plan, Environmental risk assessment for selected ecological assets, Department of Science, Information Technology, Innovation and Arts, Brisbane

Eco Logical Australia 2016 'Vegetation of the Barwon–Darling and Condamine–Balonne floodplain systems of New South Wales: Mapping and survey of plant community types', prepared for the Murray–Darling Basin Authority.

Fielder, D, Davidson, W and Barratt, P 2011, 'Aquatic Conservation Assessments (ACA), using AquaBAMM, for the wetlands of the Queensland Murray–Darling Basin', Department of Environment and Resource Management, Brisbane

Foster, N and Cooke, R 2011. Barwon–Darling IQQM Analysis – critical flow thresholds for environmental values identified within the Barwon–Darling Water Sharing Plan. NSW Department of Primary Industries, Tamworth

Gehrke, P and Harris, J 2004, 'Fish in the Darling River system', The Darling River. Murray–Darling Basin Commission, Canberra, pp.260-277

Hart, B 2015, 'The Australian Murray–Darling Basin Plan: challenges in its implementation (Part 1)', *International Journal of Water Resources Development*, pp.1-18

Hutchison, M, Butcher, A, Kirkwood, J, Mayer, D, Chikott, K and Backhouse, S 2008, *Mesoscale movements of small and medium-sized fish in the Murray–Darling Basin*, Murray–Darling Basin Commission, Canberra

Jenkins, K and Briggs, S 1997, *Wetland invertebrates and flood frequency on lakes along Teryaweynya Creek*, NSW National Parks and Wildlife Service

Jenkins, K and Boulton, A 2003, 'Connectivity in a dryland river: short-term aquatic microinvertebrate recruitment following floodplain inundation', *Ecology*, vol.84, pp.2708-2723

Kingsford, R, Wong, P, Thomas, R and Wales, N 1997, *Significant wetlands for waterbirds in the Murray-Darling Basin*, NSW National Parks and Wildlife Service

Koehn, J, McKenzie, J, O'Mahony, D, Nicol, S, O'Connor, J and O'Connor, W 2009, 'Movements of Murray cod (*Maccullochella peelii peelii*) in a large Australian lowland river', *Ecology of Freshwater Fish*, vol.18, pp.594-602

Lambeck, RJ 1997, 'Focal species: a multi-species umbrella for nature conservation', *Conservation Biology*, vol.11, pp.849-856

Leigh, C, Sheldon, F, Kingsford, RT and Arthington, AH 2010, 'Sequential floods drive 'booms' and wetland persistence in dryland rivers: a synthesis', *Marine and Freshwater Research*, vol.61, pp.896-908

Mallen-Cooper, M, Stuart, I, Hides-Pearson, F and Harris, J 1995, Fish migration in the River Murray and assessment of the Torrumbarry fishway, 1995 Riverine Environment Research Forum, Canberra

Mallen-Cooper, M and Zampatti, B 2015, Rethinking the Natural Flow Paradigm in the Murray-Darling Basin, Fishway Consulting Services

Marshall, J, Menke, N, Crook, D, Lobegeiger, J, Balcombe, S, Huey, J, Fawcett, J, Bond, N, Starkey, A and Sternberg, D 2016, 'Go with the flow: the movement behaviour of fish from isolated waterhole refugia during connecting flow events in an intermittent dryland river', *Freshwater Biology,* vol.61, pp.1242-1258

MDBA 2011, *The proposed 'environmentally sustainable level of take' for surface water of the Murray-Darling Basin: Methods and outcomes*, 226/11, Murray–Darling Basin Authority, Canberra

MDBA 2012, *Assessment of environmental water requirements for the proposed Basin Plan: Barwon–Darling River upstream of Menindee Lakes*, 41/12, Murray–Darling Basin Authority, Canberra

MDBA 2014, *Basin-wide environmental watering strategy*, 2014, Murray–Darling Basin Authority, Canberra

MDBA 2016, *Floodplain and vegetation inundation using Landsat satellite imagery*, Murray–Darling Basin Authority, Canberra

Mitrovic, S, Oliver, R, Rees, C, Bowling, L and Buckney, R 2003, 'Critical flow velocities for the growth and dominance of *Anabaena circinalis* in some turbid freshwater rivers', *Freshwater Biology*, vol.48, pp.164-174

Mitrovic, S, Chessman, B, Bowling, L and Cooke, R 2006, 'Modelling suppression of cyanobacterial blooms by flow management in a lowland river', *River Research and Applications*, vol.22, pp.109-114

Mussared, D 1997, Living on floodplains, Murray–Darling Basin Commission and CRC for Freshwater Ecology, Canberra

Nichols, S, Berghuis, A, Lay, C and Mallen-Cooper, M 2012, *'Fishway options for weirs of the Northern Murray–Darling Basin*', report prepared for the MDBA by the NSW Department of Primary Industries, QLD Department of Agriculture, Fisheries and Forestry and Fishway Consulting Services

NSW DPI 2007a, *Endangered ecological communities in NSW - Lowland Darling River aquatic ecological community,* Primefact: 173, New South Wales Department of Primary Industries, Port Stephens, NSW

NSW DPI 2007b, *Assessment and prioritisation of weirs for fishway development in the Upper Darling River system*, report prepared for MDBA by the NSW Department of Primary Industries, Port Stephens, NSW

NSW DPI 2012 *Freshwater Fish Research Database. Aquatic Ecosystem Unit*, NSW Department of Primary Industries. Maintained at Port Stephens Fisheries Institute, Taylors Beach

NSW DPI 2015, *Fish and flows in the Northern Basin: responses of fish to changes in flows in the Northern Murray–Darling Basin*, report prepared for MDBA by the NSW Department of Primary Industries, Tamworth

Parsons, M and Thoms, M 2013, 'Patterns of vegetation greenness during flood, rain and dry resource states in a large, unconfined floodplain landscape', *Journal of Arid Environments*, vol.88, pp.24-38

Poff, N, Richter, B, Arthington, A, Bunn, S, Naiman, R, Kendy, E, Acreman, M, Apse, C, Bledsoe, B and Freeman, M 2009, 'The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards', *Freshwater Biology*, vol.55, pp.147-170

Poff, NL and Zimmerman, JK 2010, 'Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows', *Freshwater Biology*, vol.55, pp.194-205

Puckridge, JT, Sheldon, F, Walker, KF and Boulton, AJ 1998, 'Flow variability and the ecology of large rivers', *Marine Freshwater Resources*, vol.49, pp.55-72

Reynolds, L 1983, 'Migration patterns of five fish species in the Murray–Darling River system', *Marine and Freshwater Research*, vol.34, pp.857-871

Roberge, J and Angelstam, P 2004, 'Usefulness of the umbrella species concept as a conservation tool', *Conservation Biology*, vol.18, pp.76-85

Roberts, J and Marston, F 2011, Water regime for wetland and floodplain plants: a source book for the Murray-Darling Basin, National Water Commission, Canberra

Rogers, K and T J Ralph (eds.) 2011, 'Floodplain wetland biota in the Murray–Darling Basin: Water and habitat requirements', CSIRO Publishing, Collingwood, Victoria, Australia.

Rogers, K, Ralph, T J and Saintilan, N 2012, 'The use of representative species as surrogates for wetland inundation', *Wetlands: the Journal of the Society of Wetland Scientists*, 32 (2), 249-256

Rolls, R, Growns, I, Khan, T, Wilson, G, Ellison, T, Prior, A and Waring, C 2013, 'Fish recruitment in rivers with modified discharge depends on the interacting effects of flow and thermal regimes', *Freshwater Biology*, vol.58, pp.1804-1819

Saddlier, S, O'Mahony, J, and Ramsey, D 2008, Protection and enhancement of Murray cod populations. Department of Sustainability and Environment, Victoria' Arthur Rylah Institute for Environmental Research Technical Report Series No. 172

Saintilan, N and Overton, I 2010, Ecosystem response modelling in the Murray-Darling Basin, CSIRO Publishing, Collingwood

Sheldon, F and Thoms, MC 2006, 'Geomorphic In-channel Complexity: the key to organic matter retention in large dryland rivers?', *Geomorphology*, vol.77, pp.270-285

Sheldon, F, Bunn, SE, Hughes, JM, Arthington, AH, Balcombe, SR and Fellows, CS 2010, 'Ecological roles and threats to aquatic refugia in arid landscapes: dryland river waterholes', *Marine and Freshwater Research*, vol.61, pp.885-895

Sheldon, F, Balcombe, S, Capon, S and Hale, J 2014, *Reviewing the scientific basis of environmental water requirements in the Condamine–Balonne and Barwon–Darling: Technical Report*, Murray–Darling Basin Authority, Canberra

SKM 2009, *Environmental values and watering priorities for the Northern Murray–Darling Basin*, Sinclair Knight Merz, Melbourne

Southwell, M 2008, Floodplains as Dynamic Mosaics: Sediment and Nutrient patches in a Large Lowland Riverine Landscape, Riverine Landscapes Research Laboratory, University of Canberra, Canberra

Swirepik, JL, Burns, IC, Dyer, FJ, Neave, IA, O'Brien, MG, Pryde, GM and Thompson, RM 2015, 'Establishing Environmental Water Requirements for the Murray–Darling Basin, Australia's Largest Developed River System', *River Research and Applications* (published online in Wiley Online Library)

Thoms, MC and Sheldon, F 2000, 'Water resource development and hydrological change in a large dryland river: the Barwon–Darling river system Australia', *Journal of Hydrology*, vol.228, pp.10-21

Thoms, MC 2003, 'Floodplain-river ecosystems: lateral connections and the implications of human interference', *Geomorphology*, vol.56, pp.335-349

Thoms, M, Sheldon, F and Crabb, P 2004, 'A hydrological perspective on the Darling River', The Darling, pp.332-347

Thoms, M, Maher, S, Terrill, P, Crabb, P, Harris, J and Sheldon, F 2004, The Darling: Environmental Flows in the Darling River, Murray–Darling Basin Commission, Canberra

Thoms, MC, Southwell, MR and McGinness, HM 2005, 'Floodplain-river ecosystems: Fragmentation and water resource development', *Geomorphology*, vol.71, pp.126-138

Thoms, M and Walker, K 1993, 'Channel changes associated with two adjacent weirs on a regulated lowland alluvial river', *Regulated Rivers: Research and Management*, vol.8, pp.271-284

Thorp, JH and Delong, MD 1994, 'The riverine productivity model: an heuristic view of carbon sources and organic processing in large river ecosystems', *Oikos*, vol.70, pp.305-308

Thorp, JH, Thoms, MC and Delong, MD 2008, The Riverine Ecosystem Synthesis: Towards conceptual cohesiveness in river science, Elsevier, San Diego

Wen, L, Rogers, K, Saintilan, N and Ling, J 2011, 'The influences of climate and hydrology on population dynamics of waterbirds in the lower Murrumbidgee River floodplains in Southeast Australia: implications for environmental water management', *Ecological Modelling*, vol.222, pp.154-163

Westhorpe, DP, Mitrovic, SM, Ryan, D and Kobayashi, T 2010, 'Limitation of lowland riverine bacterioplankton by dissolved organic carbon and inorganic nutrients', *Hydrobiologia*, vol.652, pp.101-117

Wilkinson, SN, Keller, RJ and Rutherfurd, ID 2004, 'Phase-shifts in shear stress as an explanation for the maintenance of pool–riffle sequences', *Earth Surface Processes and Landforms*, vol.29, pp.737-753

Withers, M 1996, *The Talyawalka Creek and associated lakes*, Report to NSW National Parks and Wildlife Service, Sydney

Woods, R, Lobegeiger, J, Fawcett, J and Marshall, J 2012, Riverine and floodplain ecosystem response to flooding in the lower Balonne and Border Rivers, Department of Environment and Resource Management, Queensland

Young, W, Bond, N, Brookes, J, Gawne, B and Jones, G 2011, *Science Review of the estimation of an environmentally sustainable level of take for the Murray–Darling Basin*, report prepared for MDBA by the CSIRO Water for a Healthy Country Flagship, Canberra

Appendix A - Acknowledgement of uncertainty regarding method

There are uncertainties with the Environmentally Sustainable Level of Take method that influence the accuracy of assessments of environmental water requirements. These are discussed in MDBA (2011), and a summary is provided in Box A1.

Box A1: Examples of uncertainties (based on MDBA 2011)

- Regarding the identification of key environmental assets and ecosystem functions - limitations in data, data inconsistencies, and criteria definition.
- Limitations in extrapolating flows from flow indicator gauges to a larger UEA.
- Regarding overbank environmental watering and lateral connectivity, limitations of knowledge on: the nature, extent and condition of wetlands; inundation patterns of various geomorphic features; the water requirements of some biota and vegetation communities, particularly with respect to frequency and duration of flooding.
- The adequacy of the existing knowledge base.
- Assumptions in hydrological models, how well models can reflect the variability of conditions and whether they incorporate policy change, and the potential impact of climate change.

This assessment of environmental water requirements includes consideration of eco-hydrology, which results in the selection of site-specific flow indicators. As a set, the site-specific flow indicators reflect a broad range of flow events and are a practical compromise between understanding the complexity of large eco-hydrological systems, and the need to focus on key flow-ecology characteristics when planning and setting Sustainable Diversion Limits.

In the Environmentally Sustainable Level of Take method, the focus is on linking ecological outcomes associated with the restoration of different flow components. These relationships in reality are impacted by a range of complex and interacting features including antecedent conditions, time lags and other factors that affect ecosystem response over the longer term. Figure 18 below depicts some of the factors at play that influence the health of the riverine environment at different time scales.

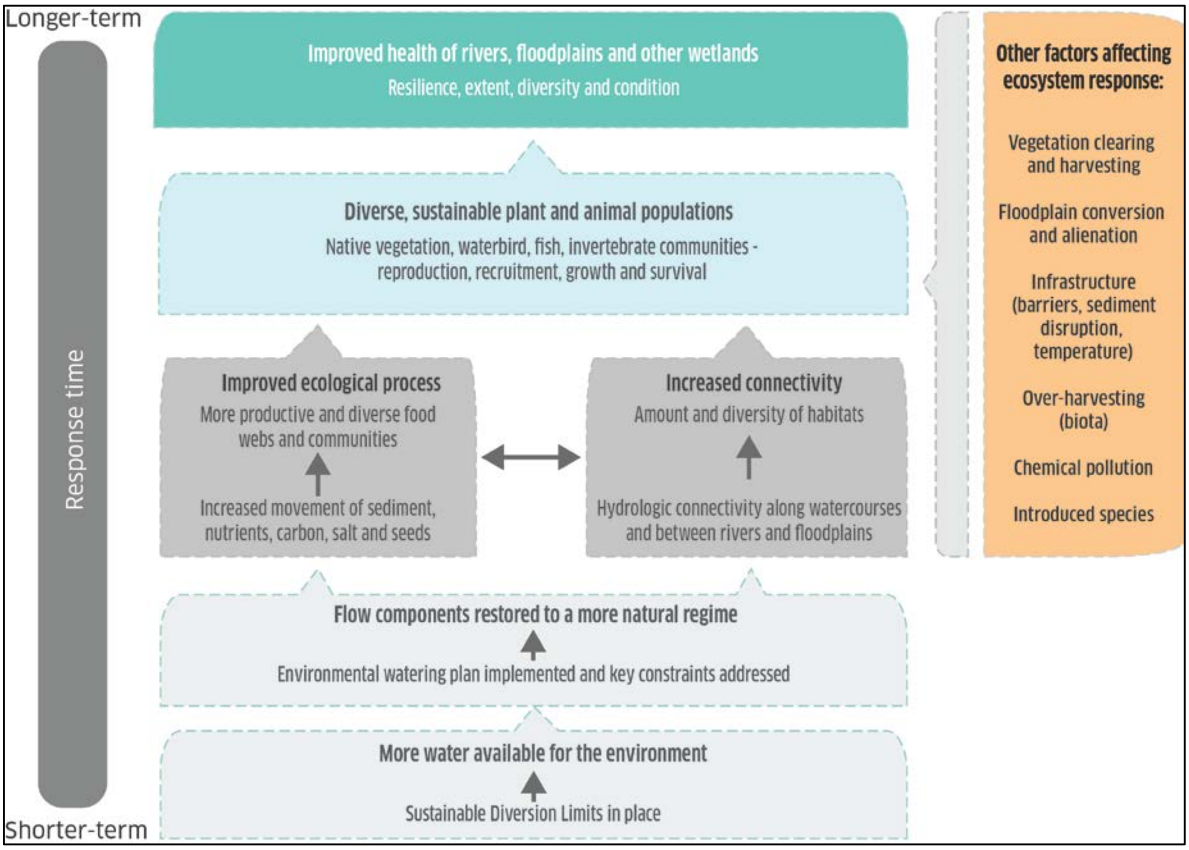

Figure 18 A conceptual diagram showing the various factors influencing the health of rivers, floodplains and wetlands the short and long term.

The following tables show the main logic, key assumptions, and confidence assessments for the flow volumes, duration, timing and frequency for each flow indicator. Confidence is assessed as either 'high' or 'pragmatic'.

- **High confidence** - the decision is based on relevant, recent and specific research and/or work; or multiple lines of evidence support the assumption
- **Pragmatic** - where there aren’t specific studies or pieces of evidence; and hence the decision is based on expert opinion/advice; is consistent with previous work; is consistent with relevant analysis based on modelled baseline and without development flows; and/or is supported by general and relevant scientific understanding.

As a result of further scientific investigations in the future, a more complete picture will emerge of the relative importance of the above complexity and uncertainties at the broad scale of the basin. This, combined with continued monitoring and evaluation will provide information to help adaptively refine the Basin Plan and water resource plans established by the states in the future, through specified review mechanisms in the Basin Plan.

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
6,000 ML/d for 14 days, any time of the year at Bourke. Frequency: 80% to 90% of years	To improve the inundation and availability of key habitat features along the Barwon–Darling River, particularly for large woody debris. To improve the longitudinal connectivity along the Barwon–Darling River, enhancing upstream and downstream migration and movement opportunities for native fish.	High Observed and modelled flow data used to determine a flow size that has a high likelihood of longitudinal connectivity across the Barwon–Darling. This flow would provide benefits for all functional groups of fish through improved habitat availability (*NSW DPI 2015*). This flow would allow regular opportunities for short to moderate migrations in the system through improved longitudinal connectivity between Walgett and Bourke (*NSW DPI 2015*).	Pragmatic The minimum duration of 14 days is linked to the natural hydrology.	Pragmatic The main outcome for the 6,000 ML/day event is regular habitat access and movement opportunities, and it is therefore considered appropriate for the event to occur any time in the year (*NSW DPI 2015*).	Pragmatic This frequency range aims to provide regular opportunities for recruitment of fish and aims to provide sufficient food sources for aquatic biota. Based on expert advice for flows that provide connectivity in dryland rivers of the northern basin. It is not based on site-specific information (other than this small fresh occurring in 98% of years under without development
6,000 ML/d for 20 days, between August and May at Louth. Frequency: 70% of years	To improve the inundation and availability of key habitat features along the Barwon–Darling River, particularly for large woody debris, providing flow regimes that enhance spawning and recruitment opportunities for In-channel Specialist native fish species.	High This flow would provide significant benefit to in-channel specialists such as Murray cod through enhanced access to core aquatic habitat, especially between Brewarrina to Tilpa where Murray cod is known to be prevalent and/or there is a strong loading of woody debris,	Pragmatic The minimum of 20 days duration is based on spawning and recruitment requirements for in-channel specialists, where a stable flow peak for up to 20 days should allow sufficient time for egg hatching and larval drift (NSW DPI 2015).	Pragmatic The proposed timing is August to May (i.e. does not include the two coldest month of the year when fish responses would be reduced). The proposed timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (late winter/spring and	Pragmatic A single frequency requirement of 70% of years was specified to provide regular habitat access and in-channel specialist spawning opportunities and it is considered appropriate for there to be one event in the season (NSW DPI 2015).

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
		including more complex snags (NSW DPI 2015). This flow would inundate approximately 50% of snags on the Barwon–Darling River between Brewarrina and Bourke, and 40% of snags on the Darling River between Bourke and Tilpa (NSW DPI 2015). This flow could also provide other fish related benefits, including improvements in primary productivity and connectivity (NSW DPI 2015). This flow would also provide longitudinal connectivity between Louth and Wilcannia through the drown-out of the weir at Tilpa, which would potentially allow for upstream and downstream movement of all fish species present in the system (NSW DPI 2015).		early summer) and the other native fish species in the northern basin (NSW DPI 2015).	
2 events of 6,000 ML/d for 7 days, any time of the year at Wilcannia.	To improve the inundation of key habitat features that contribute to primary productivity along the Barwon–Darling River,	High This flow event would inundate around 90% of the mapped benches outside the weir pools on the Darling River between	Pragmatic A duration of 7 days is considered sufficient for abiotic processes such as the release of carbon and	Pragmatic Increased food supply and movement opportunities for fish and aquatic biota	Pragmatic The low uncertainty frequency of 60% of years and the high uncertainty frequency of 45% of years are considered

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
Frequency: 45% to 60% of years	enhancing opportunities to improve food supply and body condition for native fish.	Tilpa and Wilcannia. The dual peaks in a season reflects the natural hydrology where multiple events in the year are common for this flow component. The provision of the second peak would promote productivity benefits and the successful recruitment of larvae and juveniles through the provision for dispersal, and access to habitat and suitable prey (NSW DPI 2015).	other nutrients from inundated benches. Observed and modelled flow data used to determine a flow size that has a high likelihood of riverine connectivity across the Lower Balonne.	can be beneficial at any time of year.	appropriate for providing increased productivity benefits to the river system's food web.
10,000 ML/d for 14 days, between Aug and May at Bourke Frequency: 60% to 80% of years	To improve the inundation and availability of key habitat features along the Barwon–Darling River, particularly for large woody debris. To improve the longitudinal connectivity along the Barwon–Darling River, enhancing upstream and downstream migration and movement opportunities for native fish. Providing flow regimes that enhance spawning and recruitment	High This flow is intended to provide improved movement outcomes for all functional groups of fish in the Barwon–Darling; and would provide aquatic connectivity for around 1,100 km along the Barwon–Darling River between Walgett and Menindee (*NSW DPI 2015*). Site-specific hydrological data has been used to describe a flow that provides a river rise of at least 2 m and an average velocity of 0.3 m/s. These flow attributes have been linked to	Pragmatic Based the typical duration for this type of event.	Pragmatic The proposed timing for both 10,000 ML/day flow indicators is August to May (i.e. does not include the two coldest month of the year when fish responses would be reduced). The proposed timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (late winter/spring and early summer) and the other native fish species in the northern basin (NSW DPI 2015).	Pragmatic The frequency range target (if met) would allow for improved distribution and mixing of populations *(NSW DPI 2015*).

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
	opportunities for flow dependent specialist native fish species.	fish movement responses in other catchments. Researchers have demonstrated that a flow with similar attributes in the Moonie catchment triggers movement of golden perch and freshwater catfish (*Marshall et al. 2016*). A flow of 10,000 ML/d also provides increased access to habitat, as it inundates 68—90% of snags between Brewarrina and Bourke, and most benches outside the weir pools between Brewarrina and Bourke (*NSW DPI 2015*). Flows of 10,000 ML/day would also drown out the in-stream barrier structures between Walgett and Wilcannia (*NSW DPI 2015*).			
2 events of 10,000 ML/d for 20 days, between August and May at Bourke. Frequency: 25% to 35% of years	To improve the inundation and availability of key habitat features along the Barwon–Darling River, particularly for large woody debris.	High This flow would provide suitable conditions for habitat access and successful spawning and recruitment for the flow dependent specialists and in-channel specialists; and	Pragmatic The minimum of 20 days duration is based on spawning and recruitment requirements for in-channel specialists, where a stable flow peak for up to 20 days	Pragmatic The proposed timing for both 10,000 ML/day flow indicators is August to May (i.e. does not include the two coldest months of the year when fish	Pragmatic The frequency range associated with the two 10,000 ML/d flow events for 20 day flow indicator at Bourke (35% of years with low uncertainty to 25% of years with high

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
	To improve the longitudinal connectivity along the Barwon–Darling River, enhancing upstream and downstream migration and movement opportunities for native fish. To improve flow regimes that enhance spawning and recruitment opportunities for flow dependent specialist native fish species.	specifically targets successful spawning and recruitment outcomes (NSW DPI 2015). Recruitment of larvae and juveniles is enhanced by the secondary peak event as it provides for dispersal, and access to habitat and suitable prey (NSW DPI 2015).	should allow sufficient time for egg hatching and larval drift (NSW DPI 2015).	responses would be reduced). The proposed timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (late winter/spring and early summer) and the other native fish species in the northern basin (NSW DPI 2015).	uncertainty) reflects a need for spawning and recruitment flow events in two to three years per decade for the flow dependent specialists 2—5 years per decade for in-channel specialists, which reflects biological requirements including life span and age at sexual maturity.
21,000 ML/d for 20 days, between Aug and May at Louth. Frequency: 40% of years	To improve the inundation and availability of key habitat features along the Barwon–Darling River, particularly for large woody debris, providing flow regimes that enhance spawning and recruitment opportunities for in-channel specialist native fish species. To improve the longitudinal connectivity along the Barwon–Darling River, enhancing	**High** This flow would provide significant benefit to in-channel specialists such as Murray cod through enhanced access to core aquatic habitat, especially between Brewarrina to Tilpa where Murray cod is known to be prevalent and/or there is a strong loading of woody debris, including more complex snags (NSW DPI 2015). This flow would provide significantly improved access to woody debris in this zone,	**Pragmatic** The minimum of 20 days duration is based on spawning and recruitment requirements for in-channel specialists, where a stable flow peak for up to 20 days should allow sufficient time for egg hatching and larval drift (NSW DPI 2015).	**Pragmatic** The proposed timing is August to May (i.e. does not include the two coldest months of the year when fish responses would be reduced). The proposed timing is consistent with existing knowledge of spawning and recruitment requirements for Murray cod (late winter/spring and early summer) and the other native fish species in the northern basin (NSW DPI 2015).	**Pragmatic** This indicator has a frequency requirement of 40% of years this frequency is intended to meet the biological requirements of the targeted in-channel specialists, particularly Murray cod

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
	upstream and downstream migration and movement opportunities for native fish.	including approximately 99% of the snags outside the weir pool between Brewarrina and Bourke, and 95% of snags outside the weir pool between Bourke and Tilpa (NSW DPI 2015). Flows of 21,000 ML/day would however provide system-scale connectivity, allowing access to other northern basin systems and tributaries (NSW DPI 2015).			
20,000 ML/d for 7 days, any time of the year at Wilcannia. Frequency: 45% to 60% of years	To improve the inundation of key habitat features that contribute to primary productivity along the Barwon–Darling River, enhancing opportunities to improve food supply and body condition for native fish. To improve the system wide connectivity along the Barwon–Darling River, enhancing upstream and downstream migration and movement opportunities for native fish.	High The single 20,000 ML/day event would inundate 100% of the mapped benches outside the weir pools between Brewarrina and Wilcannia, whilst also providing some level of floodplain connectivity based on the wetland and anabranch commence to flow (NSW DPI 2015; based on information provided by Brennan, 2002).	Pragmatic A duration of 7 days is considered adequate to enable the release of nutrients, with the majority of releases largely occurring in the first 24 hours of inundation before stabilising (Lowes et al. 2008 in NSW DPI 2015). This duration would also allow fish life history outcomes such as movement and habitat use to be achieved (NSW DPI 2015).	Pragmatic Increased food supply and movement opportunities for fish and aquatic biota can be beneficial at any time of year.	Pragmatic The low uncertainty frequency of 60% of years and the high uncertainty frequency of 45% of years are considered appropriate for providing increased productivity benefits to the river system's food web.

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
30,000 ML/d for 24 days, any time of the year at Bourke (inner floodplain connectivity). Frequency: average period between events of 2 to 3 years.	To inundate riparian and wetland areas.	High Flows at Bourke represent wider floodplain connectivity across the Barwon–Darling. Flows at around bankfull are also important for maintaining geomorphic features within the bed of the river channel, such as sand bars, benches and waterholes (Wilkinson et al. 2004). Brennan et al. (2002) found flows around 30,000 ML/d at Bourke start to inundate near-channel wetlands across the Barwon–Darling. Analysis of flow/inundation relationships by MDBA supports this assessment (*MDBA 2016*). The flow/inundation mapping combined with vegetation mapping shows this flow rate inundates at least 55% of river red gum on the Darling River floodplain downstream of the Culgoa River junction.	Pragmatic It is expected that water would be retained in some wetlands and anabranches for longer than 24 days and be likely to meet the needs of wetland vegetation. The median without development duration has been used to represent the typical inundation of the riparian and near channel areas along the Barwon–Darling River.	Pragmatic These flows will be largely unregulated events and can occur at any time of year	Pragmatic The average flooding frequency requirements of vegetation adopted are an adequate surrogate for maintaining vegetation communities in this zone. Between flooding, vegetation may use a variety of water sources including groundwater. A frequency of 2—3 years on average between these flow events was selected, as it is consistent with the flooding requirements to sustain riparian and wetland vegetation such as river red gum forests and lignum (Roberts and Marston 2011; *Casanova 2015*).
45,000 ML/d for 22 days, any time of the year at	To inundate the inner floodplain and off channel wetlands.	High Flows at Bourke represent wider floodplain connectivity	Pragmatic It is expected that water would be retained in some	Pragmatic These flows will be largely unregulated events and	Pragmatic Frequency stipulated aims to represent the average flooding

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
Bourke. Frequency: average period between events of 3.5 to 4 years.		along the Barwon–Darling Rivers. The majority of river red gum communities between Bourke and Louth would be inundated (*MDBA 2016*). This flow would exceed the commence-to-flow of channels connecting lakes known to be important for waterbirds, including Poopelloe Lake, Victoria Lake and Eucalyptus Lake in the Talyawalka–Teryaweynya system (Brennan et al. 2002). This flow (and duration) would be sufficient to water river red gum woodlands communities fringing the Talyawalka Anabranch. The recent inundation analysis (*MDBA 2016*) suggests that at this flow at least 10% of coolibah woodlands and floodplain grasslands in the Bourke to Louth region would also be inundated.	wetlands and depressions for longer than 22 days and be likely to meet the needs of wetland vegetation The median without development duration has been used to represent the typical inundation of the wetlands within the inner floodplain along the Darling River.	can occur at any time of year	requirements of vegetation. Between flooding, vegetation may use a variety of water sources including groundwater. The frequency of 3.5—4 years between flooding events on average is within the range of the watering requirements of river red gum woodlands, and is expected to sustain wetland communities including lignum (Roberts and Marston 2011; *Casanova 2015*).
65,000 ML/d for 24 days, any time of the year at Bourke.	To inundate parts of the outer floodplain.	High Flows at Bourke represent wider floodplain connectivity	Pragmatic It is expected that water would be retained in some wetlands and depressions	Pragmatic These flows will be largely unregulated events and	Pragmatic Frequency stipulated aims to represent the average flooding requirements of vegetation.

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
Frequency: average period between events of 6 to 8 years.	This infrequent event plays an important role in the overall productivity of the outer floodplain grasslands and the facilitating mass exchanges of, nutrients, sediment and biota between the river and floodplain.	along the Barwon–Darling Rivers. Flows of 65,000 ML/d (measured at Bourke) will inundate a large proportion of the floodplain (*MDBA 2016*). This inundation facilitates the dispersal of organic matter (e.g. seeds, animals, leaf litter), water, nutrients and sediment across the floodplain, creeks and wetlands (Thoms 2003). More than 30% of the floodplain grasslands and coolibah woodlands found at higher elevations become inundated at this flow rate (*MDBA 2016*). This flow also inundates black box woodland communities around the Talyawalka–Teryaweynya system (MDBA 2012).	for longer than 24 days and be likely to meet the needs of wetland vegetation The median without development duration has been used to represent the typical inundation of the mid-to-outer floodplain along the Darling River.	can occur at any time of year	Between flooding, vegetation may use a variety of water sources including groundwater. The frequency of 6—8 years is consistent with supporting vigorous growth for black box and is close to the critical interval of river red gum woodlands and lignum. Although it is acknowledged that these latter two species may remain alive if inundation occurs less often, their condition is likely to be poor, and more frequent subsequent wetting may be required to improve their health and vigour (*Casanova 2015*).
A volume of 2,350 ML/d, any time of the year into Talyawalka creek Frequency: average period between events of 10 to 12 years.	To fill lakes in the Talyawalka–Teryaweynya system, as well as inundating wetlands and vegetation communities on the outer Darling floodplain more broadly.	High A flow into Talyawalka Creek occurs when the flow is around 30,000 ML/d in the Darling River at Wilcannia. Based on work by Jenkins and Boulton (2003) and Jenkins and Briggs (1997) to estimate	High The duration is for the volume to flow into the Talyawalka–Teryaweynya system in one continuous event. Based on the work by, Jenkins and Boulton (2003) and Jenkins and	Pragmatic These flows will be largely unregulated events and can occur at any time of year	Pragmatic Frequency stipulated aims to represent the average flooding requirements of vegetation. Between flooding, vegetation may use a variety of water sources including groundwater.

Flow indicator	Ecological objective(s)	Flow threshold/volume assumptions and evidence	Duration assumptions and evidence	Timing assumptions and evidence	Frequency (target range) assumptions and evidence
		inflow volumes required to inundate Talyawalka creek. Gauged flows at Wilcannia for 1974, 1976, 1983, 1990 and 1998 flood events were used to estimate the minimum inflow volumes required to fill the more frequently inundated parts of the system. Inundation at this level, though infrequent, has been shown to be vital for the growth and productivity of floodplain grasslands (*Parsons and Thoms 2013*, Capon 2003).	Briggs (1997) this is expected to take around 60 days or more.		The frequency is consistent with the flooding requirements of vegetation communities including black box trees and lignum shrubs (Roberts and Marston 2011; *Casanova 2015*).

Appendix B - Contributors

The MDBA took account of the advice and input from the contributors listed below when preparing this document.

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NSW Department of Primary Industries - Fisheries	Victorian Department of Environment, Land, Water and Planning
CSIRO	

Appendix C: 2012 Barwon–Darling site-specific flow indicators

Barwon–Darling ecological targets: Floodplain wetlands and vegetation (Talyawalka–Teryaweynya Creek system)	Flow indicator gauge	Magnitude: flow (ML/d)	Duration (days)	Timing	Frequency Low uncertainty	Frequency High uncertainty
Provide a flow regime which: • ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition • supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds • supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) • supports key ecosystem functions, particularly those related to connectivity between the river and floodplain	Wilcannia	30,000	21	Any time of year	25% (proportion of years event is required)	20% (proportion of years event is required)
	Wilcannia	30,000	30	Any time of year	18% (proportion of years event is required)	15% (proportion of years event is required)
	Wilcannia	2,350 GL (measured at flows above 30,000 ML/d)	N/A	Any time of year	10% (proportion of years event is required)	8% (proportion of years event is required)

Appendix D - Listed species, Barwon–Darling river system

Selection of species for the Barwon–Darling river system relevant to the Basin Plan, schedule 8, criteria 1 and 4

Species	Recognised in international agreement(s) (1)	Environment Protection & Biodiversity Conservation Act 1999 (Cwlth)	Fisheries Management Act 2004 (NSW)	Threatened Species Conservation Act 1995 (NSW)
Birds				
Australasian bittern (*Botaurus poiciloptilus*)				E
Blue-billed duck (*Oxyura australia*)				V
Brolga (*Grus rubicundus*)				V
Caspian tern (*Hydroprogne caspia*)	Yes			
Common sandpiper (*Actitis hypoleucos*)	Yes			
Eastern great egret (*Ardea modesta*)	Yes			
Freckled duck (*Stictonetta naevosa*)				V
Fish				
Freshwater catfish (*Tandanus tandanus*)			E (MDB population)	
Murray cod (*Maccullochella peelii peelii*)		V		
Olive perchlet (*Ambassis agassizii)*			E (MDB population)	
Purple spotted Gudgeon (*Mogurnda adspersa*)			E	
Silver perch (*Bidyanus bidyanus*)		CE	V	
Communities				
Lowland Darling River aquatic ecological community			E	

E = endangered V = vulnerable CE = critically endangered

1 Japan–Australia Migratory Bird Agreement, China–Australia Migratory Bird Agreement, or Republic of Korea – Australia Migratory Bird Agreement.

Appendix E - Frequency statistics

Site-specific flow indicator	Without development^	Low uncertainty^	High uncertainty^	Baseline frequency^	Maximum spell under without development	Maximum spell under baseline
6,000 ML/d for 14 days any time of the year (Bourke)	96%	90%	80%	66%	2 years	3 years
6,000 ML/d for 20 days between August and May (Louth)	91%	70%	70%	58%	2 years	4 years
Two 6,000 ML/d events for 7 days any time of the year (Wilcannia)	77%	60%	45%	42%	5 years	8 years
10,000 ML/d for 14 days between August and May (Bourke)	89%	80%	60%	54%	3 years	6 years
Two 10,000 ML/d events for 20 days between August and May (Bourke)	42%	35%	25%	20%	7 years	12 years
21,000 ML/d for 20 days between August and May (Louth)	54%	40%	40%	32%	4 years	12 years
20,000 ML/d for 7 days any time of the year (Wilcannia)	70%	60%	45%	39%	3 years	8 years
30,000 ML/d for 24 days any time of the year (Bourke)	1.8 years	2 years	3 years	3.9 years	9 years	19 years
45,000 ML/d for 22 days any time of the year (Bourke)	3.3 years	3.5 years	4 years	4.9 years	15 years	29 years
65,000 ML/d for 24 days any time of the year (Bourke)	5.4 years	6 years	8 years	8.7 years	19 years	29 years
2,350 GL once flow is above 30,000 ML/d any time in the year (Wilcannia)	8 years	10 years	12 years	14 years	29 years	29 years

^ - In these four columns, the '%' is percentage of years in which there is a watering event, and the 'years' is the average number of years between watering events.