Australian Government

MURRAY–DARLING BASIN AUTHORITY

2014–15 Basin Annual Environmental Watering Priorities

Overview and technical summaries

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Murray–Darling Basin Authority

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The Murray–Darling Basin Authority acknowledges and pays its respect to the Traditional Owners and their Nations of the Murray–Darling Basin. The contributions of earlier generations, including the Elders, who have fought for their rights in natural resource management, are also valued and respected.

The MDBA recognises and acknowledges that the Traditional Owners and their Nations in the Murray–Darling Basin 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. Further research is required to assist in understanding and providing for cultural flows. The MDBA supports the belief of the Northern Murray–Darling Basin Aboriginal Nations and the Murray Lower Darling Rivers Indigenous Nations that cultural flows will provide beneficial outcomes for Traditional Owners.

The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of Ngarrindjeri elder Tom Trevorrow: 'our traditional management plan was don't be greedy, don't take any more than you need and respect everything around you. That's the management plan—it's such a simple management plan, but so hard for people to carry out.*[1] This traditional philosophy is widely held by Traditional Owners and respected and supported by the Murray–Darling Basin Authority.

[1] Tom Trevorrow (2010) Murrundi Ruwe Pangari Ringbalin 'River Country Spirit Ceremony: Aboriginal Perspectives on River Country'.

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Managing water for environmental benefits

Three strategies have been identified to assist in maximising environmental benefits. These (or similar) strategies are already being used by many river operators and managers. They are detailed here to support implementation of the Priorities and environmental watering in general.

1. Maximise environmental benefits by coordinating and collaborating through effective governance arrangements

Freshwater systems are complex and managers must operate at multiple scales. Coordination and collaboration through effective governance arrangements between water holders, managers and river operators is important in water management to maximise environmental benefits (Cullen et al. 1999; MDBA 2013).

Historically, governance arrangements have developed around individual entitlement portfolio objectives or catchment and regional objectives. The MDBA is promoting governance arrangements in which clear roles, responsibilities and accountabilities are articulated and agreed; thus providing a system-wide approach to environmental water planning and coordinated flow management (MDBA 2013).

Promoting hydrological connectivity

Rivers, wetlands and floodplains that are hydrologically-connected require coordinated water delivery to achieve the best environmental benefits. Connectivity upstream and downstream is called longitudinal connectivity; and connectivity between rivers and their adjacent floodplain is called lateral connectivity. Both forms of connectivity are essential to the viability of freshwater populations, maintaining key ecological processes and riverine health more broadly (Bunn and Arthington 2002; Hermoso et al. 2012).

Longitudinal connectivity allows movement of biota along river networks and is important for reproduction and dispersal (Hermoso et al. 2012). It can be achieved through in-stream pulse flows and flow variability. Lateral connectivity between the river channel and adjacent floodplains, wetlands and lakes can occur when water levels are high in the river; or when they are connected through the operation of weir pools (see section: *Maximise environmental benefits through the use of all water*). This ensures movement of aquatic species, carbon and nutrients between river channels and floodplains, wetlands and lakes; improving the productivity of the entire freshwater system (Hermoso et al. 2012).

Achieving lateral and longitudinal connectivity requires water holders, managers and operators to view freshwater ecosystems as an integrated whole. This is only possible through governance arrangements that allow for coordination and collaboration in the planning and delivery phases of environmental watering. It is recommended that longitudinal and lateral connectivity are incorporated during annual planning and water delivery within and between catchments (Barmuta et al. 2011; Hermoso et al. 2012).

Isolated floodplains, wetlands and lakes can provide an important component of the broader functional network of freshwater ecosystems. These systems provide opportunities for animals to rest, feed or breed at various sites across the landscape (Hermoso et al. 2012). Water delivery to such sites to achieve environmental outcomes also requires a coordinated management approach.

Implementation

Coordination and collaboration during annual water planning and delivery is essential to ensure environmental water priorities are agreed to and implemented across management levels and areas. This strategy encourages environmental water holders, managers and river operators to identify water management opportunities by coordinating and collaborating through the establishment of effective governance arrangements. These arrangements need to be established to ensure annual water planning and delivery are aligned and tracked against long-term planning and objectives at catchment, state, and Basin scales.

Successful coordination and collaboration between stakeholders can overcome critical water management challenges, identify a broad range of solutions, and enable ownership of outcomes (Stiftel and Scholz 2005). There are many cases where river operators and managers are already coordinating and collaborating within and between catchments during annual planning and/or during environmental water delivery.

Planning

Annual environmental water planning occurs throughout water management areas, and across catchments and state boundaries. Each management level and area has different stakeholders, environmental priorities, delivery constraints, objectives, accountabilities and approval processes.

State annual environmental water plans and seasonal watering plans, and the Commonwealth Environmental Water Office's annual water-use options should be integrated with river operations planning. This will enhance the capacity of river operations plans to achieve the environmental objectives articulated in environmental water plans through the use of consumptive water (MDBA 2013) (see section: *Maximise environmental benefits through the use of all water*). Governments have begun to articulate environmental objectives into river operations planning; however, it is acknowledged that there is some way to go (MDBA 2013).

Water delivery

Operational advisory groups allow river operators, managers and holders of environmental water to be in touch with on-ground conditions. This assists effective decision-making by access to the most up-to-date information. These groups facilitate collaboration and coordination during an environmental watering event; and allow river operators, managers and holders of environmental water to manage events adaptively. They enable the best environmental outcomes to be achieved, the mitigation and management of risks, and guidance in the use of all water (see section: *Maximise environmental benefits by managing water in harmony with natural cues*). These groups are not usually part of formal governance structures and rely on soft institutional arrangements. As implementation of watering arrangements mature, it is envisaged that the role of operational groups will become more formalised.

2. Maximise environmental benefits through the use of all water

All water in the Murray–Darling Basin river system, regardless of whether it is held or planned environmental water, or water intended for consumptive use, has the potential to improve the ecological condition of aquatic environments and the plants and animals that depend on them.

Flow variability is critical to ecosystem functions and biodiversity maintenance in the Murray–Darling Basin and is a defining hydrological characteristic of arid and semi-arid rivers (Bayley 1995; Arthington and Balcombe 2011). Natural flow variability supports lateral connectivity, habitat diversity, biological processes, and initiates fish spawning and migration.

There are several options to improve environmental outcomes through the management of all water:

1. creating flow variability by pulsing the delivery of consumptive, operational and environmental water (planned and held) from dams and weir pools
2. managing bulk water transfers for environmental outcomes
3. delivering environmental water in conjunction with consumptive water to increase flow heights
4. raising and lowering of weir pool levels.

Other options relevant to this strategy include transparent operations for water storages and the protection of unregulated peaks. These are discussed in further detail in the section: *Maximise environmental benefits by managing water in harmony with natural cues*.

Pulsed deliveries to increase flow variability

Pulsed water delivery is an innovative way to increase flow variability. The National Water Commission has identified that pulsing the delivery of water to users in harmony with natural flow variability provides a major opportunity to achieve ecological benefit. Pulsing can reduce the negative environmental impacts of river regulation. Environmental benefits achieved through pulsed flows include:

1. flushing of sediment, saline water and algal blooms
2. enhanced riparian habitat
3. reduced bank notching (which can occur from holding flows at fixed heights)
4. restoration of lateral connections between rivers and floodplains
5. recharged wetlands, restored food webs and conditions that stimulate animal migration, reproduction and recruitment
6. creation of beneficial disturbance which is critical to riparian ecology (Watts et al. 2009)
5. strengthened resilience of the system so as to cope with future dry periods.

Managing bulk water transfers for environmental outcomes

In catchments where there is more than one water storage, bulk water transfers are used to top-up downstream storages from storages upstream. Water managers are trialling ways to transfer this water so as to maximise environmental benefits. For example, the Mitta Mitta River in Victoria is used to transfer water from Dartmouth Dam to the Hume Reservoir on the Murray River. Normally when water is transferred, the Mitta Mitta can be flowing at full channel capacity for many months, causing serious degradation to the river. In 2008–09, water managers trialled the pulsing of flows in the Mitta Mitta to harmonise with a more natural flow regime. In response to the trials, the diversity and abundance of biofilm increased. Biofilm is a mix of algae, bacteria and fungi growing on gravels in the river bed and an indicator of river health. This example demonstrates that there are opportunities for managers to achieve environmental benefits from river operations by exploring the flexibility in existing river operating rules.

Delivering consumptive water and environmental water concurrently

Ecologically-important medium and high flow peaks (lost from the system through river regulation) can be achieved by combining environmental water with consumptive deliveries. In the Macquarie catchment in 2012–13, water managers and river operators worked together to achieve environmental outcomes for the Macquarie Marshes that would not have been possible with environmental allocations alone. In some valleys channel and valve capacity may limit the extent of environmental outcomes that can be achieved with this strategy.

Weir pool manipulation

In normal operation weirs hold water at fairly constant levels. This permanently inundates nearby naturally ephemeral wetlands; and greatly reduces flow variability in the river upstream of the weir (in the weir pool). Weir pool manipulations raise and lower the height of water in the weir. This restores wetting and drying phases in wetlands close to the river, provides connections between permanent water bodies and temporary wetlands, and can expose shallow-water habitats and mudflats (Ecological Associates 2013). Weir pool manipulation can also improve operational flexibility and allow more efficient water management.

Implementation

Not all environmental objectives are compatible, and implementation of the strategies outlined here should not take precedence over achieving primary environmental outcomes.

3. Maximise environmental benefits by managing water in harmony with natural cues

Why are natural cues important?

A natural cue may be a change in water levels, river flows, water temperature, or carbon and nutrient input as a result of local rainfall or a flood upstream. When a natural cue occurs, ecological processes such as frog breeding, fish spawning and waterbird nesting are more likely to be triggered and sustained. A natural cue may also result from the *absence* of rain and flows, triggering ecological processes necessary for the survival of biota during a drying phase — such as fish movement to refuge waterholes. Dams, weirs and other structures in streams and on floodplains, and water abstractions, may interrupt and alter flow patterns and affect water quality; and consequently affect the success of these triggers.

Environmental water released in conjunction with a natural event is more effective, as less is needed to achieve the desired flow and ecological responses. Such strategic releases also improve the extent of inundation and increase the capacity for triggering events such as bird breeding. They can also make better use of productivity gains from upstream flooding. These productivity gains result from inundation of floodplain soils and plant material; and can include plant and invertebrate propagules, increased carbon and nutrients, and the eggs and larvae of fish and other organisms spawned at upstream sites (Wallace et al. 2011; Baldwin et al. 2010). Higher flows earlier in the season can also help prevent or reduce the severity of possible black water events. Put simply, if natural cues are followed, there will be a much greater chance that the expected biological response will occur.

This strategy does not exclude the need to sometimes provide flows in areas or at times without a natural trigger. This might be necessary where habitats or natural populations are degraded, have lost resilience or may experience catastrophic loss.

Altered flow patterns reduce natural cues

A river's natural flow regime is a result of the seasonal pattern of rainfall; the timing, frequency and duration of events; and the variability of water level change (Richter et al. 1996; Poff et al. 1997; Olden and Naiman 2010 and Poff et al. 1997). River management practices in some rivers of the Murray–Darling Basin have reduced natural cues by altering components of the natural flow regime.

Seasonal inversion of flows

The timing of flow events and the drying interval between flows is a key determinant driving natural cues in many rivers, and underpins the diversity and persistence in freshwater biota (Resh et al. 1988; Biggs, Nikora and Snelder 2005). The reversed seasonality of flows has caused a loss of wetland and floodplain productivity; lost and altered habitats; changes in aquatic species composition (including invasion by alien species); and reduction in health, area and diversity of riparian, floodplain and wetland vegetation (Kingsford and Johnson 1998; Gerhke and Harris 2001; Bunn and Arthington 2002). To mitigate these negative impacts, the delivery of water alone is insufficient to trigger an ecological response. The timing and pattern of flow must also be addressed when planning for environmental water delivery.

Altered water quality reduces natural cues

The capture and storage of water in dams and large weirs alters the temperature, salinity, pH and oxygen content of the stored water. It also reduces nutrients and limits populations of critical microorganisms that are dispersed from upstream sites (Burford et al. 2011). Such alterations continue to characterise stored water even once it is released. The release of this water in the absence of an unregulated flow event reduces the ability of freshwater biota to recognise and respond to natural cues.

It is ecologically favourable to provide flows with either all, or a mix of water properties that favour spawning, recruitment, growth and persistence of freshwater biota. These can be physical (temperature, plant material, nutrient concentration) or chemical (dissolved oxygen).

Implementation

Looking to natural triggers and cues to guide environmental water use is possible under all resource availability scenarios. In wet to very wet years, responding to natural events may mean filling the gaps in the hydrograph, or extending the recession (or tail) of a flow event so that flows more closely mimic a natural pattern. In drier years it may be possible to build upon a smaller event to achieve a higher peak flow, so as to maintain refuge habitat or mitigate adverse events such as black water.

Examples are illustrated below to demonstrate this overarching strategy and facilitate its adoption throughout the Basin. They represent a subset of examples of innovative water management practices.

Translucent/transparent operating practices – maintaining seasonally appropriate flows

Storage operational practices known as 'translucent' and 'transparent' flows permit small to medium inflow events to be passed directly through water storages. Translucent flows allow a proportion of inflows to be passed though storages; and the less frequent practice of transparent flow operations allows all inflows to be passed. This maintains the same or similar hydrograph shape to a natural flow. Existing translucent and transparent flow operating practices provide important opportunities for environmental water holders to protect and restore some elements of seasonal flow variability.

The opportunity to manage airspace differently – reinstating natural flow variability

Airspace refers to the difference between the actual volume of water being held in a storage; and the total volume that the storage can hold (full supply level). Airspace is managed to protect the structural integrity and safety of the storage; to limit flood damage to downstream communities; and to ensure downstream water demands for irrigation, production and communities are met. The operational objective is to effectively fill the storage to full supply level (FSL). When the storage reaches FSL, inflows are not captured and are instead passed immediately downstream.

Under current practices, if a storage is well below its FSL, then a high-flow event (including its peak flow) may be fully captured with no significant proportion released as outflow (Figure 1). However, once FSL is reached all floodwaters entering from upstream may then be passed through the storage with very little difference between inflow and outflow rates. This release pattern is more aligned with a natural flow pulse, and would achieve environmental outcomes triggered by natural cues.

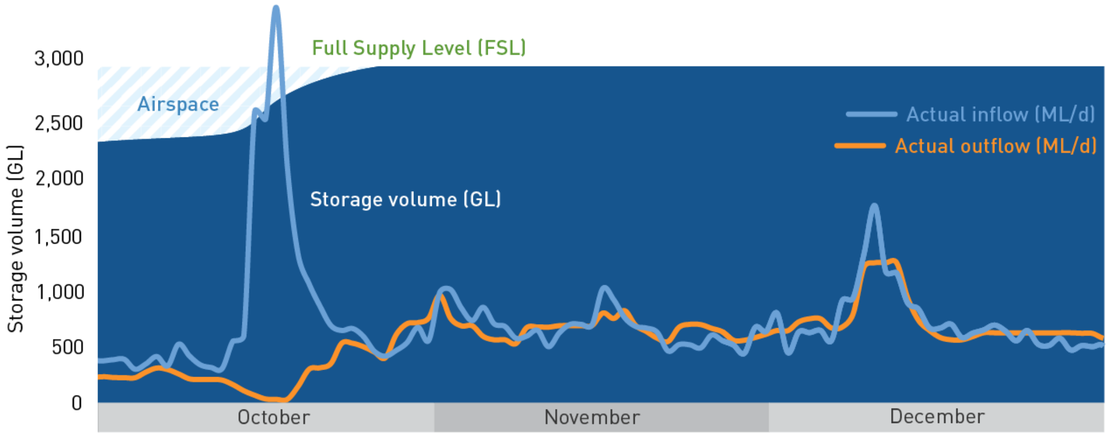

Figure 1 Theoretical example of current airspace management practice

Opportunities exist to allow a proportion of inflows to pass directly downstream of dams under certain scenarios. For example, water managers/river operators could have allowed a proportion of the high-flow event to pass through the storage at timing that was seasonally appropriate (Figure 2). This release pattern would have satisfied orders by any entitlement holder and achieved seasonally appropriate flows for the environment. This can only be pursued in instances where it is certain that future flows will fill a storage and maintain supply for other users. A new choice could involve environmental water being used to underwrite the risk that the storage does not fill to the same capacity.

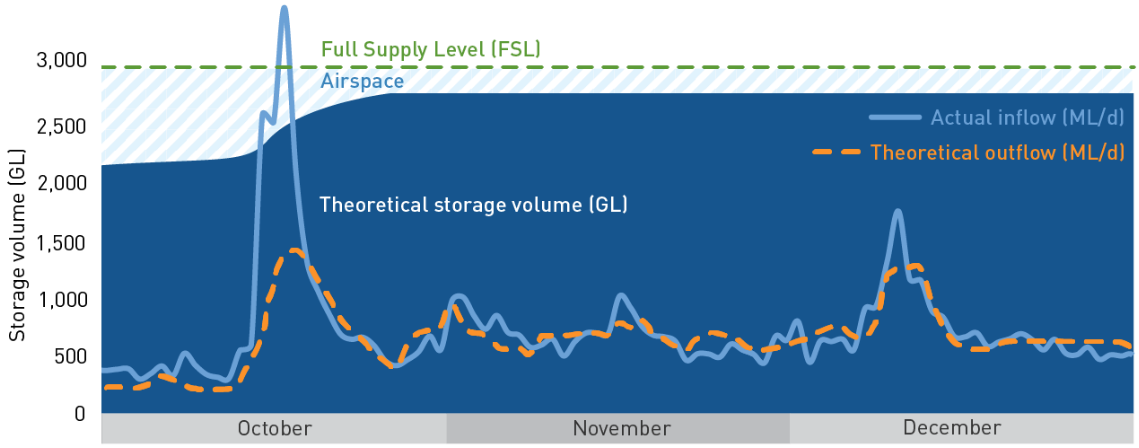

Figure 2 Theoretical example of airspace management that provides a higher flow event in October in the river below the dam

Managing unregulated rivers – maintaining and extending low, medium and high flow events

Unregulated rivers are defined by those without large public storages to capture and re-regulate water. In some of these rivers, a large volume of water is extracted directly from the river and is often stored in large private reservoirs. Protection of flows from extraction by event and season can restore some natural variability of flows — including peak flows — to augment periodic flooding of refuge sites, reconnect pools and improve water quality.

Managing unregulated rivers for the environment can be achieved by purchasing entitlements and leaving flows in-stream. Other strategies may be required to protect flows from extraction — through 'shepherding' arrangements or temporary purchase of water access licenses. While it is best that unregulated flows are left in-stream, there may be some occasions where there would be value in purchasing already diverted water (i.e. held in on-farm storages) for use back in-stream.

Managing unregulated inflows in regulated rivers – retaining high quality water in the system

Water in regulated rivers includes outflows from storages, inflows from regulated and unregulated tributaries and flow events created by rainfall downstream of major storages. By protecting these naturally-occurring inflows from extraction or re-regulation, the chemical and physical properties necessary to trigger ecological processes are improved within the river system.

This can be achieved by meeting environmental flow orders through unregulated inflows that have not been diverted into storage, or by delivering water from storages at the same time as unregulated inflows. The maximisation of these opportunities depends upon effective governance arrangements being in place (see section: *Maximise environmental benefits by coordinating and collaborating through effective governance arrangements*).

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Overview of the 2014–15 Basin Annual Environmental Watering Priorities

What are Basin Annual Environmental Watering Priorities?

The purpose of the Basin annual environmental watering priorities (the Priorities) is to influence regional environmental watering towards Basin-wide ecological outcomes and to promote coordinated environmental watering between environmental water holders and managers. All watering in the Murray–Darling Basin for environmental benefit, including watering that uses both held and planned environmental water, is to be undertaken having regard to the Priorities.

The Priorities are not an exhaustive list of all-important environmental assets and functions throughout the Basin; and do not preclude other watering priorities identified by environmental water holders and managers at the regional level.

Setting the scene for the 2014–15 Priorities

Preceding dry conditions (Figure 3), together with the average rainfall outlook for the next three months (June–August 2014) (Figure 4); mean that the status of the Basin is 'dry'. The Bureau of Meteorology estimates that there is a greater than 70% chance that an El Niño will develop during the 2014 winter. El Niño is often associated with below-normal rainfall across large parts of southern and inland eastern Australia. The Bureau advises that it is too early to determine the strength of this potential El Niño. If the longer-term outlook remains dry, the Priorities accommodate these drier conditions (refer Basin *Environmental Watering Outlook for 2014–15*). Real-time management of environmental water will be undertaken according to specific conditions in each catchment.

The Bureau of Meteorology's rainfall outlook for the next three months indicates average to slightly drier than average conditions throughout the Murray–Darling Basin (Figure 4).

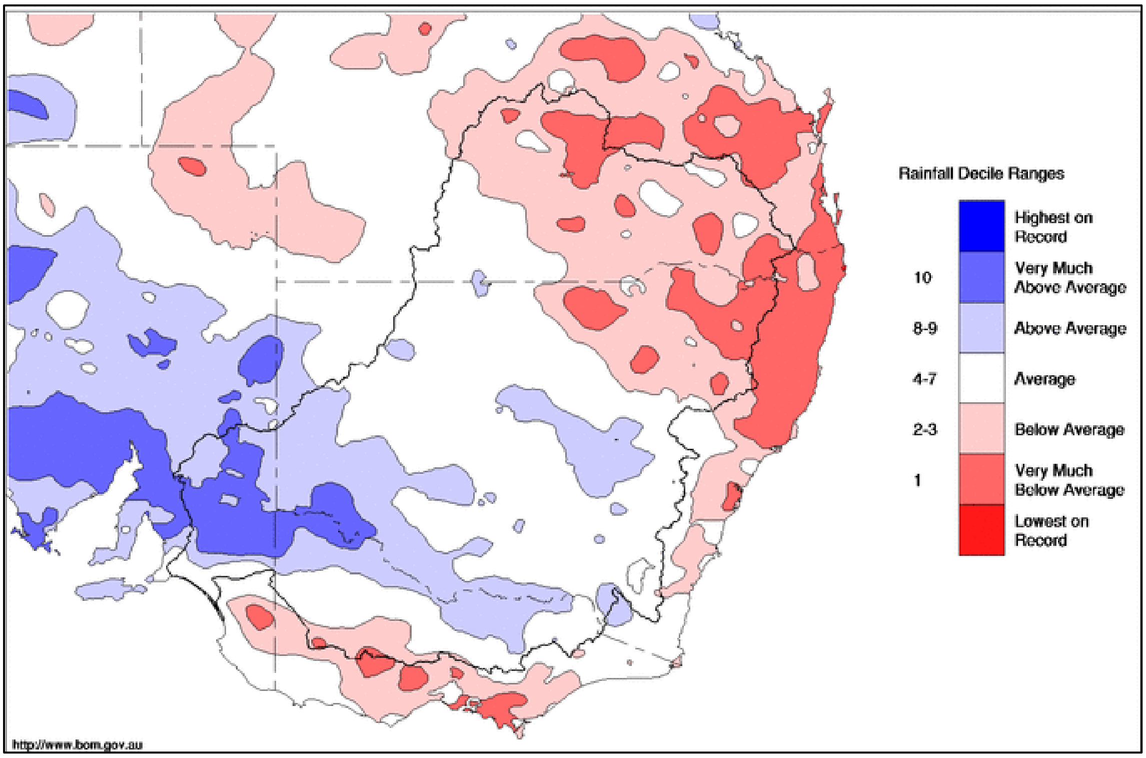

Figure 3 Map of the Basin showing rainfall outlook for June to August 2014

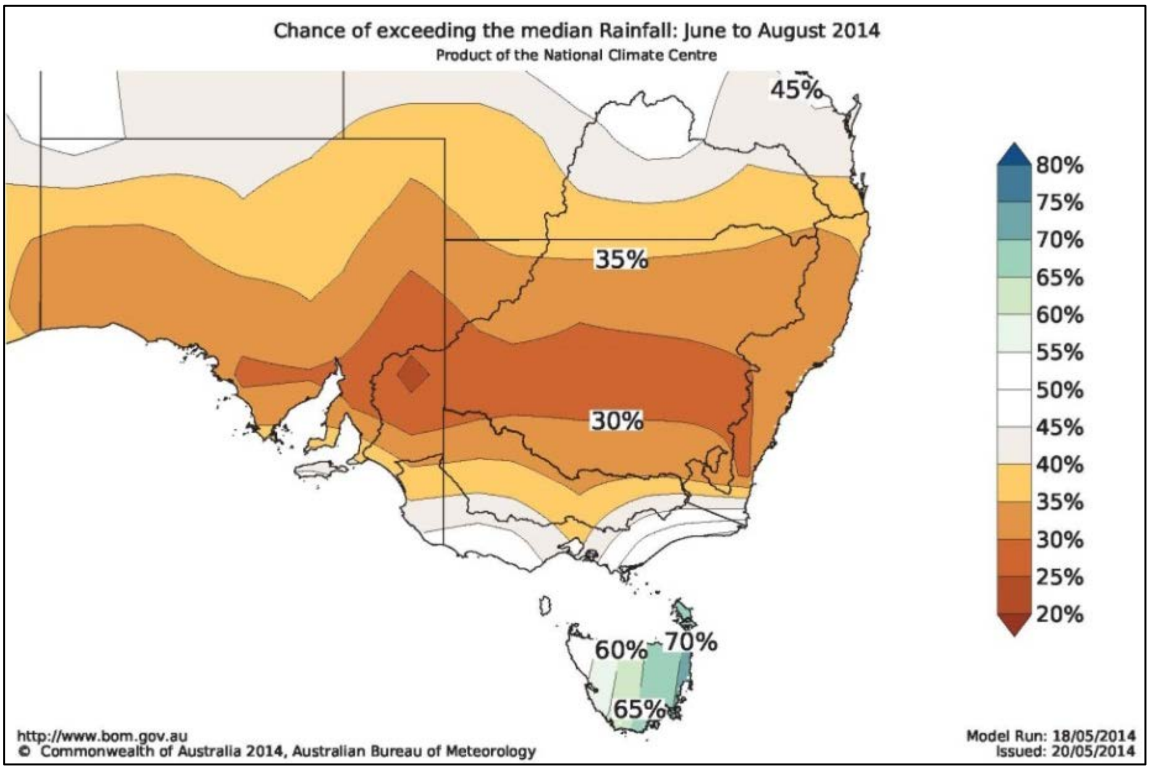

Figure 4 Chance of exceeding median rainfall in the Murray–Darling Basin: June to August 2014 (www.bom.gov.au)

Given the lower than average rainfall in most of the Basin since June 2012 conditions, current climate forecasts and likely water availability, the Priorities for 2014–15 focus on broad management outcomes that are aligned to the moderate to dry resource availability scenarios (Table 1). These are aimed at maintaining ecological health and ecosystem resilience throughout the Basin.

However, because of the highly variable nature of climate and river flow across the Basin, real-time management of environmental water will be undertaken according to specific conditions in each catchment.

Table 1 Management outcomes for each resource availability scenario

	Resource availability scenario: Very Dry	Resource availability scenario: Dry	Resource availability scenario: Moderate	Resource availability scenario: Wet–Very Wet
Management outcomes	− Avoid critical loss of species, communities, and ecosystems. − Maintain critical refuges. − Avoid irretrievable damage or catastrophic events. − Allow drying to occur, where appropriate, but relieve severe unnaturally prolonged dry periods.	− Support the survival and viability of threatened species and communities. − Maintain environmental assets and ecosystem functions, including by allowing drying to occur consistent with natural wetting-drying cycles. − Maintain refuges.	− Enable growth, reproduction and small-scale recruitment for a diverse range of flora and fauna. − Promote low-lying floodplain–river connectivity. − Support medium-flow river and floodplain functions.	− Enable growth, reproduction and large-scale recruitment for a diverse range of flora and fauna. − Promote higher floodplain-river connectivity. − Support high-flow river and floodplain functions.

Three strategies have been identified for managing environmental water to improve environmental outcomes:

1. maximise environmental benefit through the use of all water
2. maximise environmental benefits by coordinating and collaborating through effective governance arrangements
3. maximise environmental benefits by managing environmental water in harmony with natural cues.

The strategies are inherently linked (Figure 5). For further information refer to the supporting rationales for the strategies.

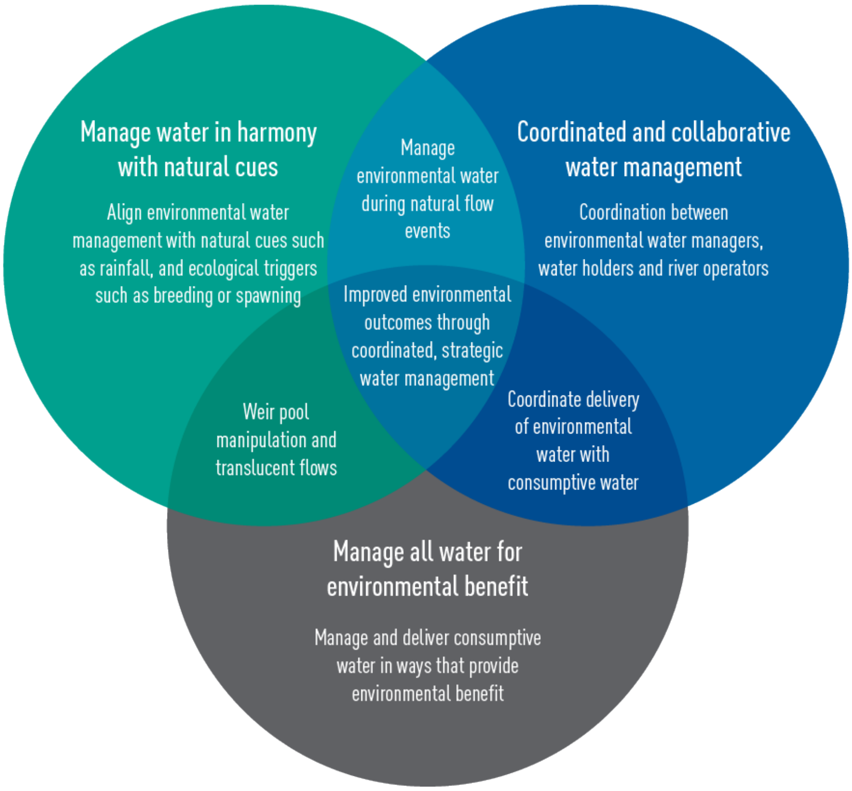

Figure 5 The linkage between the strategies for managing environmental water

The Priorities for 2014–15

The Priorities for 2014–15 are focussed around three themes:

- connecting rivers and floodplains
- supporting in-stream functions
- enhancing and protecting refuge habitat.

Seven Priorities have been developed for 2014–15. All Priorities are supported by a rationale outlining the expected outcomes, matters of interest and practical issues relating to implementation.

The Priorities have not attempted to prioritise the watering needs of all the ecological assets and functions throughout the Murray–Darling Basin. Rather, the Priorities reflect those considered to be of Basin significance (noting that environmental watering is already occurring successfully throughout much of the Basin at the local and regional scale; and that state priorities will guide watering for each water resource plan area). The state governments, Commonwealth and the MDBA have built infrastructure under The Living Murray program to assist with the delivery of environmental water at sites including Gunbower Forest, Koondrook–Perricoota Forest, Hattah Lakes and Chowilla Floodplain. The MDBA has chosen not to identify these sites in the 2014–15 Priorities, but acknowledges the importance of commissioning (test-running) these structures as soon as possible.

Connect rivers and floodplains

Protecting and restoring the connection between rivers with their floodplains is fundamental for maintaining the health of floodplain vegetation and for supporting ecosystem functions within aquatic ecosystems. Connecting rivers to their floodplains is also vital for the protection and restoration of declared Ramsar wetlands and for supporting species listed under international migratory bird agreements.

Given the moderate to dry predictions for water availability, the following areas are considered to be at a high risk of ecosystem decline if watering does not occur in the 2014–15 water year.

1. **Gwydir Wetlands:** Improve the condition and maintain the extent of wetland vegetation communities in the Gwydir Wetlands (including Ramsar sites) by restoring hydrological connectivity and a flow regime that meets ecological requirements (relisted Priority).

2. **Mid-Murrumbidgee wetlands:** Improve the condition of wetland vegetation communities in the mid-Murrumbidgee wetlands through a winter or spring fresh (relisted Priority).

Support in-stream functions

Maintaining longitudinal hydrological connectivity is vital to protect, restore and enhance the health of in-stream and end-of-system aquatic ecosystem functions. Longitudinal connectivity through in-stream pulse flows and flow variation is important for linking aquatic habitats and aquatic species and communities along the length of a river.

Given the moderate to dry predictions for water availability, the following Priorities will achieve environmental benefits at multiple ecological sites and functions. This will assist the transfer of nutrients and biota and will support the recovery of native aquatic fauna and flora. Improved in-stream function will enhance the ecological outcomes when rivers and floodplains are connected.

3. **Macquarie River:** Improve native fish habitat within the Macquarie River below Burrendong Dam, by restoring a more natural flow regime and managing cold water pollution.

4. **Connectivity in the River Murray System:** Improve riparian, littoral and aquatic vegetation (e.g. *Ruppia tuberosa*) and native fish populations, by increasing ecosystem connectivity through coordinating water delivery in the River Murray system.

5. **Winter flows for fish in the southern Basin:** Improve survival, recruitment and condition of native fish populations, by providing winter flows to tributaries and creeks of the River Murray and through the barrages to the Coorong.

Enhance and protect refuge habitat

In response to the drying trend exhibited over the past 18 months, it will be important in the coming water year to support the resilience of aquatic habitats through targeted watering of refuge areas and protection of natural inflows. Providing flows to priority refuge areas will promote the persistence of high quality habitats during moderate or dry scenarios, as well as providing connectivity between such habitats during natural flows. This is important to promote viability and to facilitate the survival of biota under moderate-to-dry conditions.

6. **Native fish in the northern Basin:** Improve survival of native fish populations by enhancing and protecting dry period refuge habitat in the northern Basin.

7. **Waterbird refuge:** Maintain waterbird habitat, including refuge sites and food sources, to support waterbird populations across the Murray–Darling Basin. Support waterbird breeding where feasible.

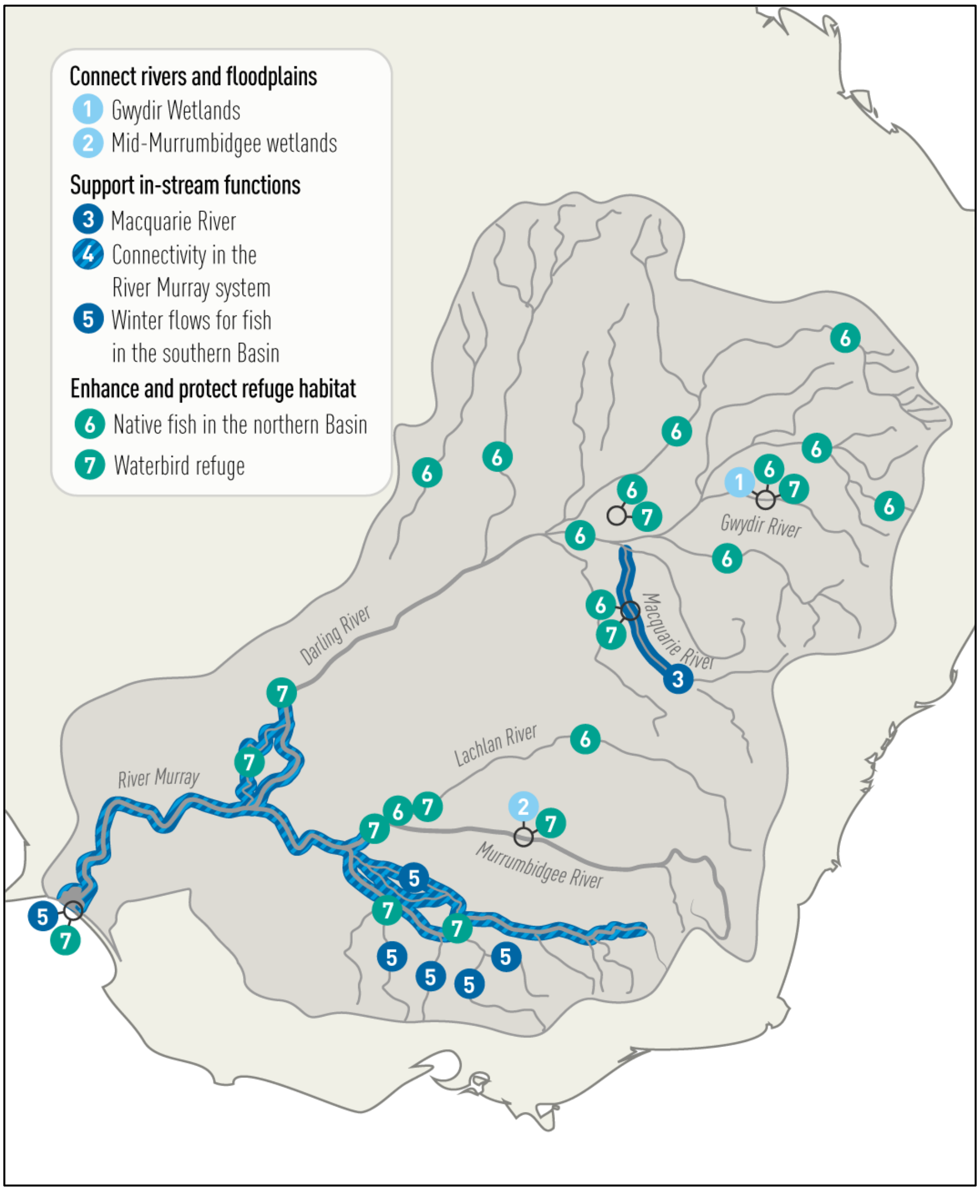

Figure 6 Geographic representation of the Priorities for 2014–15

Basin-wide Environmental Watering Strategy

In the future the Basin-wide annual watering priorities will be guided by the Basin-wide environmental watering strategy (the Strategy) which will be published in November 2014.

The purpose of the Strategy is to guide the management of environmental water at a Basin scale and over the long-term so as to achieve the objectives of the environmental watering plan. To achieve this purpose, the Strategy will describe:

- important environmental outcomes to be achieved
- strategies for the management and use of environmental water to achieve long-term outcomes
- governance, roles and responsibilities for environmental water management
- an explanation as to how the Priorities are identified.

Outcomes of particular importance to Aboriginal people

Environmental degradation of rivers, wetlands and aquifers has had detrimental effects on the lifestyles and wellbeing of Aboriginal people. Involvement and engagement with the management of environmental flows provides an opportunity for Aboriginal people to sustain and strengthen their connection with rivers and improve the condition of Country. In turn, it allows managers of environmental water to improve environmental outcomes by building upon the local knowledge of Aboriginal communities.

Healthier rivers and wetlands are of particular importance to Aboriginal people. This means more diverse fish populations and greater numbers of native fish, more opportunities for harvesting products from native vegetation, and increased bird breeding and abundance of other wetland-dependent animals. These outcomes align strongly with those being sought through environmental watering.

Connect rivers and floodplains: Gwydir Wetlands

Basin Annual Environmental Watering Priority

Improve the condition and maintain the extent of wetland vegetation communities in the Gwydir Wetlands (including Ramsar sites) by restoring hydrological connectivity and a flow regime that meets ecological requirements.

Expected benefits

It is anticipated that restoring hydrological connectivity in the Gwydir Wetlands will restore a flow regime and will contribute to the following benefits:

- improve the condition and extent of permanent and semi-permanent wetland vegetation communities
- maintain habitat suitable for colonial waterbird breeding
- protect and restore endangered ecological communities
- contribute to restoration of the ecological character of the Ramsar sites
- promote lateral and longitudinal connectivity between wetlands–floodplains–river
- enable growth, reproduction and recruitment for a range of permanent and semi-permanent wetland vegetation
- maintain wetland refuges and adequate soil moisture in core wetland to allow improved biotic response to water deliveries
- assist the recovery of the wetland plant marsh club rush, a critically endangered ecological community.

Why is this of Basin significance?

The Gwydir Wetlands were a Basin annual environmental watering priority in 2013–14. They remain a priority because:

- while some environmental watering occurred in Mallowa Creek, Carole Creek and the Mehi River, only minimal water was delivered to the Lower Gwydir Wetlands
- in March 2014, fire affected 1,600 hectares of the area's important wetland vegetation communities, including the endangered marsh club rush
- rainfall in the catchment was below average during 2013–14
    - while rain in March initiated some recovery, watering is required to support continued regeneration.

Significance of the site

The Gwydir catchment is in the north-west of New South Wales. Copeton Dam is the largest regulated water storage in the catchment. The dam supplies water for consumption on the Gwydir River (including the Mehi River, Carole Creek, Gil Gil Creek, and Moomin Creek) and replenishment flows to the Lower Gwydir, Gingham Watercourse, and Mallowa Creek.

The Gwydir Wetlands lie in the downstream reaches of the Gwydir River, west of Moree in northern New South Wales (see Figure 7).

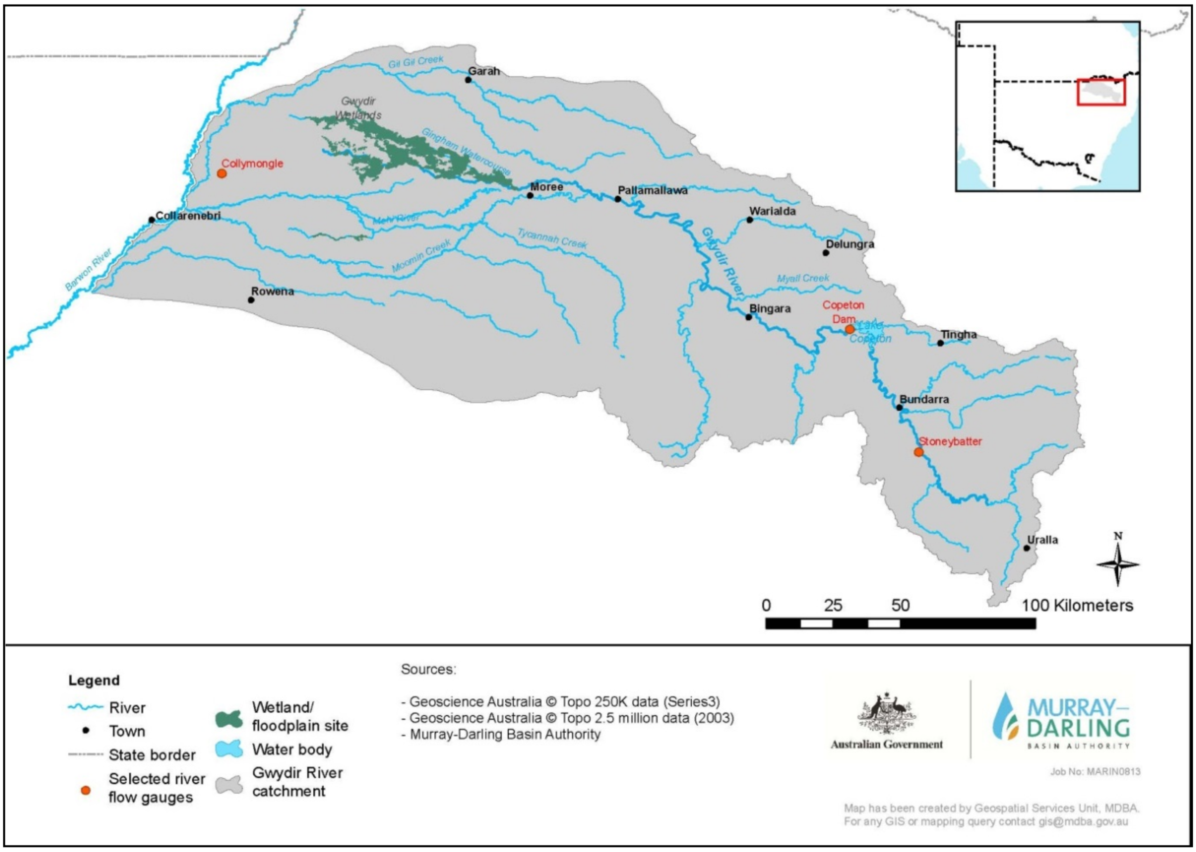

Figure 7 Map of the Gwydir catchment

The Gwydir Wetlands are a mosaic of wetland types, ranging from semi-permanent marshes and waterholes to floodplain woodlands. These wetland types include nationally and internationally important wetlands; with four sites listed as internationally significant under the Ramsar Convention. Three of these sites are privately owned and the largest is a nature reserve and managed by the NSW Government.

The Gwydir Wetlands are a major site for waterbird breeding in Australia (Morse 1922; McCosker 1996). They are recognised as a refuge for waterbirds in dry times, and for supporting some of the largest waterbird breeding colonies recorded in Australia (Green and Bennett 1991). There have been 75 waterbird species recorded in these wetlands (Spencer 2010). They include species listed as threatened both in New South Wales and nationally, and species listed on the Japan–Australia Migratory Bird Agreement, China–Australia Migratory Bird Agreement and Republic of Korea–Australia Migratory Bird Agreement (Spencer 2010). Records of major breeding events date to the 1920s when the Gwydir Wetlands were thought to hold the largest heronry in New South Wales with hundreds of thousands of breeding birds (Morse 1922). A separate Priority has been identified for 2014–15. This more fully develops the theme of possible watering to support waterbird populations in the Gwydir and other Basin wetlands.

The Gwydir Wetlands are also notable for having one of the largest known stands of the marsh club rush in New South Wales (Green and Bennett 1991; McCosker and Duggin 1993). The marsh club-rush sedgeland is a Critically Endangered Ecological Community under the New South Wales Threatened Species Conservation Act (1995), and was affected by fire in 2014.

Condition of environmental assets and functions

Recent condition

From 2010 to 2013 the northern Murray–Darling Basin experienced a series of floods after receiving significantly higher than average rainfall. Unregulated flows inundated large areas of the Gwydir Wetlands and small volumes of Commonwealth and New South Wales held environmental water were delivered to core wetland areas. Collectively, these flows allowed some recovery of wetland and floodplain vegetation after the Millennium drought, and supported large numbers of breeding colonial nesting waterbirds (predominantly ibis and egrets). Despite some improvement in wetland condition, wetland and floodplain vegetation communities are still recovering from disturbances experienced in the previous decade, and more recently from fire. Overall, wetland extent continues to decline primarily due to land clearing.

Rainfall in 2013–14 in the Gwydir catchment was below average. Consequently, there was an absence of natural cues to trigger any substantial environmental water delivery to the Gwydir Wetlands. Environmental watering has occurred in the broader Gwydir catchment, including:

- Mallowa Creek – environmental water was delivered to support the health of Mallowa wetland vegetation, improve the overall condition of the creek system, and also to promote fish movement and nutrient and carbon cycling
- Mehi River and Carole Creek – environmental water was delivered to support fish movement; and to stimulate carbon and nutrient cycling and primary production.

Historical impacts and past condition

The natural flow regime in the Gwydir catchment has been significantly altered by river regulation and increased water consumption. Since 1976 (when Copeton dam was commissioned) there has been a 75% increase in the average length of time between flood events; and a 64% increase in the maximum length of time between flood events (a rise from 7 to 11.5 years). The reduction in flood frequency means that the average annual flooding volume has been reduced by 42% (CSIRO 2007a). These changes have contributed to the stressed ecological condition of the wetlands (CSIRO 2007a), and the poor condition and health of floodplain soils.

Historically, the Gwydir Wetlands covered an area of around 220,000 hectares (Green and Bennett 1991). However, within the Lower Gwydir and Gingham Channel, the Millennium drought, altered water regime and changed land use have reduced the area of the wetlands by 85% (Bowen and Simpson 2009). From 1997 to 2011 the area of land opportunistically cropped in the Gwydir Wetlands is estimated to have increased by more than 70,000 hectares (EcoLogical 2012). Consequently there has been significant decline in health and extent of both semi-permanent and floodplain wetland within the Gingham and Lower Gwydir Watercourses (Bowen and Simpson 2009).

Remnant wetland areas in the Gwydir are largely fragmented by areas of land developed for cultivation. Dry land cropping and other intensive agriculture in the Gwydir Wetlands has reduced wetland habitat and affected hydrological connectivity by limiting the movement of floodwaters throughout the system. Many of the cropped areas are in and around the natural flow paths and in some instances are protected by flood levee banks which affect water distribution. The loss of wetland habitat and changes to flow distribution threatens both the ecological values and ecological function of the Gwydir Wetlands.

Given the historical reduction in the extent of the Gwydir Wetlands there is a significant risk of further wetland loss if flood pathways and a more natural flow regime are not reinstated.

Matters of interest

Natural flow regimes

Natural inundation timing for the Gwydir Wetlands is linked to rainfall in the upper catchment. November to March and June to July are the main periods of high inflows (NSW DECCW 2011; EcoLogical 2012). Increased wetland plant growth is associated with spring–summer floods and warm moist soils — which provides optimal conditions for germination and seed growth. Winter floods are important for replenishing soil moisture and establishing suitable conditions for plant growth in the warmer months (CEWO 2012a).

Late winter and spring floods also enable adult fish to feed and grow before they spawn (Humphries et al. 2002). Native fish species in the Gwydir Wetlands and Lower Gwydir River are typically triggered to spawn by an increase in flow and water temperatures during spring and early summer (Spencer 2010; NSW DECCW 2011). Flows that target in-channel habitat in September to October coincide with the spawning period of Murray cod and freshwater catfish (Wilson et al. 2009).

Presently in the Gwydir there are temporal limitations on environmental watering in the Gwydir Wetlands. Farming activity restricts environmental watering for large parts of the year (EcoLogical 2013). These limits on the seasonality of environmental watering present challenges to supporting the ecological assets and functions.

Implementation

Restoring connectivity and more natural flow regimes in the Gwydir catchment is important to improving the condition and extent of permanent and semi-permanent wetland vegetation communities. Because of the high volume of water in environmental accounts, it is anticipated that this Priority could be met across the full range of Resource Availability Scenarios.

The provision of held environmental water in combination with small to moderate unregulated base flows and freshes would support the natural inundation of floodplains and wetlands, promote connectivity between wetlands, support vegetation recovery, and improve recruitment opportunities for a range of waterbird and native aquatic species in the Gwydir Wetlands. As inundation of the Gwydir Wetlands is linked to rainfall in the upper catchment, the provision of environmental water could be delivered in response to natural cues (See Strategy: *Maximise environmental benefits by managing water in harmony with natural cues*). However, the absence of a natural cue should not preclude watering core wetlands as it did in 2013–14. Watering of the core wetlands is vital in 2014–15 as these communities require water in the majority of years, and a prolonged period of inundation between five and six months is desired.

The Resource Availability Scenario may change over the course of 2014–15 as the season progresses and new allocation announcements are made. Likewise, the scale of hydrological connectivity and inundation will vary with the different inflow scenarios. In wet to very wet scenarios, unregulated flow will achieve Basin Annual Environmental Watering Priority in 2014–15 (the Priority). In moderate to dry scenarios, a combination of unregulated flow and held environmental water could be delivered to contribute to achieving the Priority. In very dry scenarios, held environmental water will be required to achieve this priority. Continued planning and stakeholder consultation in 2014–15 should assist with the implementation of this priority in 2014–15.

Maximising outcomes

Re-establishing natural flow paths is necessary to reconnect important habitat of the Gwydir Wetlands. As discussed above, there are physical and temporal barriers to restoring connectivity and reinstating a flow regime that meets ecological requirements. Close cooperation with individual landholders will be required to understand the opportunities and resolve barriers at a property level.

The priority actions listed in the Constraints Management Strategy for the Gwydir catchment include the development and analysis of inundation maps and flow pathways to identify potentially affected land and infrastructure. The MDBA will work with the local community and jurisdictions to identify mitigation strategies with the aim of providing an enduring solution to some of the current constraints for future environmental watering activities.

Another factor limiting the capacity of held environmental water to meet this Priority is channel capacity during peak water demand periods. In these periods consumptive orders are high and can dominate available channel capacity. If environmental water holders chose not to access channel capacity so as to lessen competition for capacity with consumptive orders, this will limit the ability of held environmental water to contribute to the objectives of this Priority.

As impediments to delivering held environmental water are mitigated, river operators and environmental water holders/managers will increase the range of outcomes targeted under this Priority. This will improve the condition of the Gwydir Wetlands in the future.

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Connect rivers and floodplains: Mid-Murrumbidgee Wetlands

Basin Annual Environmental Watering Priority

Improve the condition of wetland vegetation communities in the mid-Murrumbidgee wetlands through a winter or spring fresh.

Expected benefits

It is anticipated that a winter–spring fresh in the mid-Murrumbidgee will contribute to the following benefits in 2014–15:

- maintain and improve the health of inundation–dependent vegetation communities in the mid-Murrumbidgee wetlands, by providing opportunities for growth and recruitment
- support watering of adjacent low-lying wetlands to promote mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter)
- support native vegetation communities' recovery from drought
- increase habitat for fish, frogs, birds and turtles
- maintain and improve condition of the ecosystems in the Yanco Creek system.

Why is this of Basin significance?

The mid-Murrumbidgee wetlands were a Basin annual environmental watering priority in 2013–14. They remain a priority because:

- delivery of environmental water to meet the 2013–14 priority was unable to be achieved through a coordinated environmental flow event. This was in part because of unresolved stakeholder concerns about potential third-party impacts
- despite a small number of individual watering actions being conducted at selected wetlands, at a system level the condition of vegetation (particularly semi-aquatic vegetation) in the mid-Murrumbidgee wetlands continues to decline due to a lack of inundation.

Significance of the site

The mid-Murrumbidgee wetlands are an assemblage of lagoons and billabongs located on the floodplain of the Murrumbidgee River between Wagga Wagga and Carrathool (Figure 8). The mid-Murrumbidgee wetlands are good examples of inland river and lagoon wetlands; of which a selection is listed in *the Directory of Important Wetlands of Australia* (Environment Australia 2001). These wetlands support the functioning of the Murrumbidgee River — one of the longest rivers in the Murray–Darling Basin — by providing an important input of carbon and nutrients as well as important habitat for fish, frogs, turtles and birds.

The mid-Murrumbidgee wetlands support many rare and threatened fauna species, including the Environment Protection and Biodiversity Conservation Act 1999 listed endangered trout cod, the vulnerable southern bell frog and numerous bird species. The wetlands also support internationally listed migratory species such as the cattle egret, eastern great egret, glossy ibis, Latham's snipe and the white-bellied sea-eagle (MDBA 2012b).

Condition of environmental assets and functions

As demonstrated in Figure 9, the Murrumbidgee River went through an extended period of low flows between the years 2000 and 2010, resulting in minimal lateral connectivity between the mid-Murrumbidgee wetlands and the Murrumbidgee River. The critical threshold for connection for a number of low-lying wetlands is a flow of 26,850 megalitres per day (ML/d) at Narrandera (MDBA 2012b), with many more wetlands requiring larger flows to be connected. Figure 9 demonstrates that a large proportion of mid-Murrumbidgee wetlands did not naturally connect with the Murrumbidgee River throughout the period 2000–2010, with only a small number connecting in 2005. The prolonged period of low flows was followed up in 2010–11 and 2012 by consecutive years of high flows, resulting in widespread inundation and lateral connectivity. During 2013–14 flows were considerably lower with no high to moderately high flows.

In 2009, after many years of low flows, the condition of the mid-Murrumbidgee wetlands was considered critical and declining (SKM 2011). While the subsequent high-flow events improved the condition of the wetlands, they are still in a recovery phase (Wassens et al. 2012). Semi-aquatic vegetation cover in the mid-Murrumbidgee wetlands is still relatively low compared to 2000–2004 levels. Recovery is particularly slow within wetlands which have experienced an extensive dry period, such as those that remained dry between 2000 and 2010 (Wassens et al. 2012).

Under modelled ‘without development’ conditions, wetlands with ‘commence to flow’ rates of 26,850 ML/d would have a maximum dry period of five years (MDBA 2012a). However, the majority of these wetlands experienced 10 years without inundation. To assist in recovery it is important to build upon the high flows of 2010–2012 to improve resilience. This will ensure these wetlands can withstand future dry periods and provide refuge habitat. This is particularly important given dry periods are predicted by the Bureau of Meteorology; and opportunities to water these wetlands may be limited in future years.

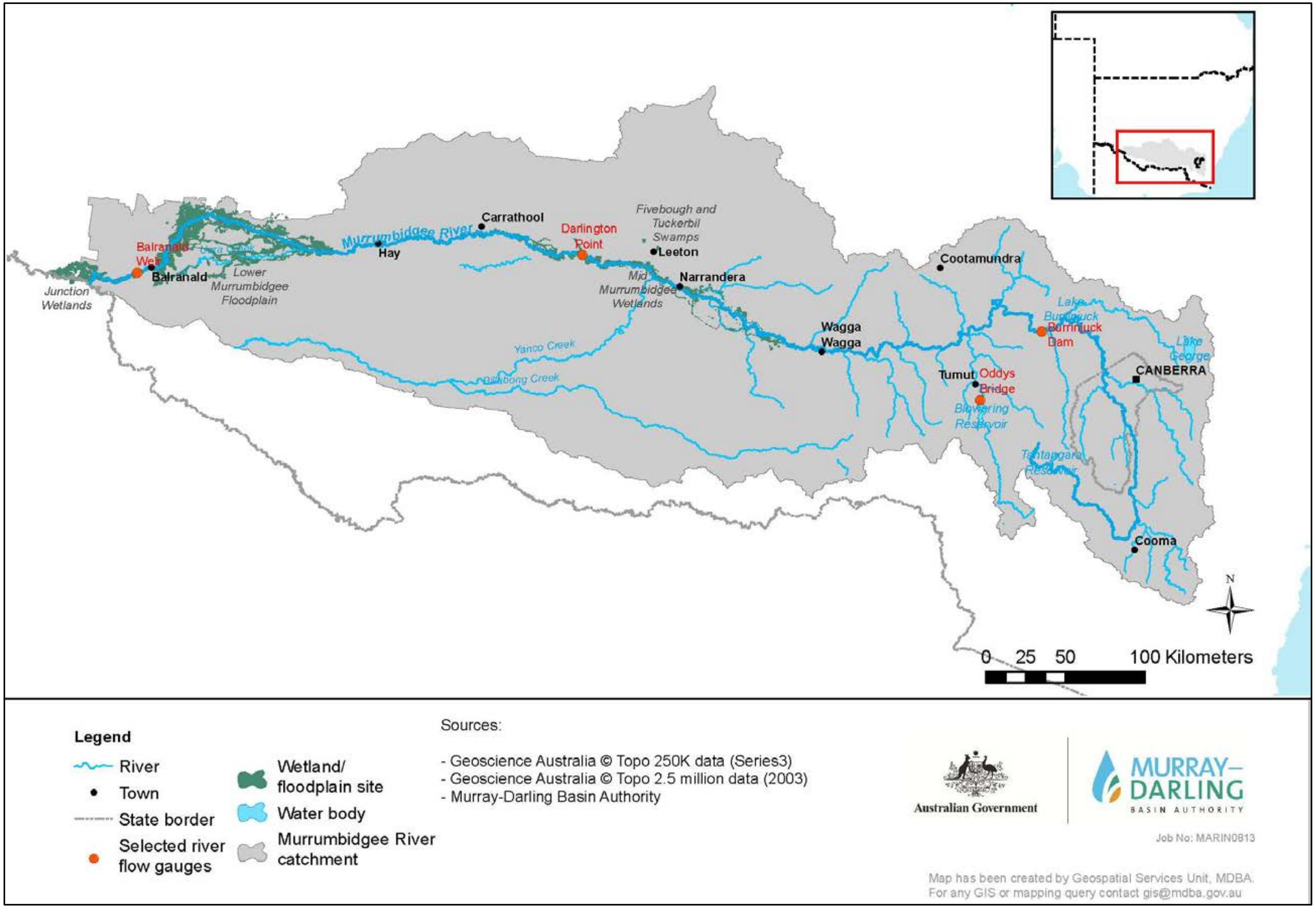

Figure 8 Map of the Murrumbidgee catchment

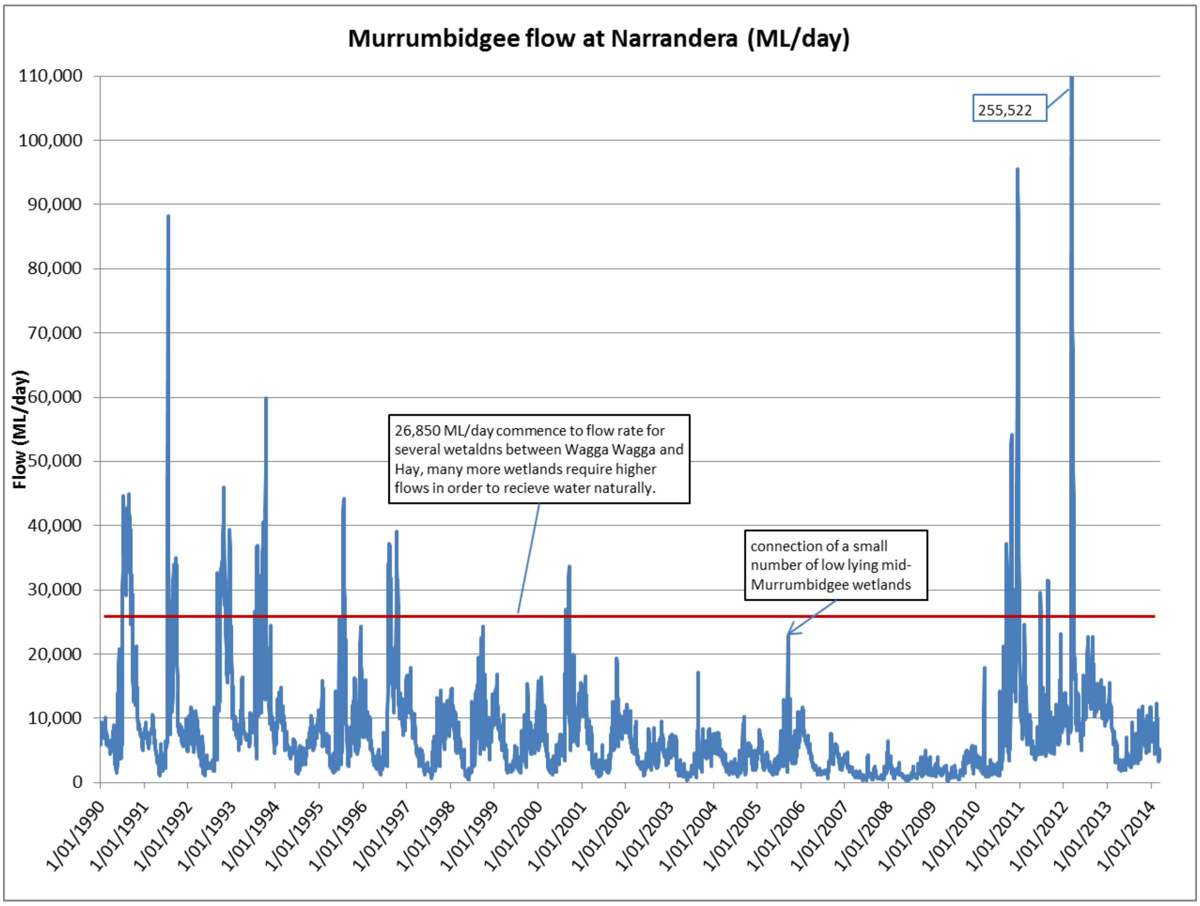

Figure 9 Flow rates of the Murrumbidgee River at Narrandera from 1990 to March 2014, including critical thresholds for wetland inundation.

Note: The rating table for Narrandera is currently under review and likely to change. As such, the flow rate required to fill wetlands may change.

Matters of interest

Semi-aquatic vegetation

Slow recovery of the semi-aquatic vegetation in the mid-Murrumbidgee wetlands is an important consideration. Healthy and diverse semi-aquatic vegetation helps to maintain water quality and provides important habitat for waterbirds and frogs — including the 'vulnerable' southern bell frog. The long-term persistence of semi-aquatic vegetation is dependent upon the maintenance of a viable seed bank, which can be affected by:

- time since the seed bank was last replenished. The viability of seed declines over time (Casanova and Brock 2000), with seed banks progressively depleting if the wetland remains dry for longer than about six years (Roberts and Marston 2011). The replenishment of the seed bank can be influenced by:
  - watering and the hydrologic pathways for dispersal of seeds and propagules (Roberts and Marston 2011). For instance, connectivity by floodwater facilitates dispersal and re-colonisation of wetlands by semi-aquatic species (Sheldon et al. 2002)
  - the condition of plants and their ability to produce seed and germinate
- disturbances, such as grazing and cultivation (Tuckett et al. 2010)
- hydrologic characteristics of a wetland filling event (e.g. depth, duration and oxygen) (Casanova and Brock 2000).

Given the above, a watering event in 2014–15 that connects wetlands with the Murrumbidgee River will increase the likelihood of semi-aquatic vegetation recovery and improve seed banks; thus improving the resilience of semi-aquatic vegetation in the Murrumbidgee Valley.

Consideration should also be given to opportunities to implement other wetland management strategies to help maximise outcomes, including grazing management strategies.

Implementation

Ability to meet the Priority under changing resource availability scenarios

Prevailing conditions throughout the water year will determine the extent to which this Priority can be achieved; and how it is achieved. At the time of preparing this Priority, the Resource Availability Scenarios (RAS) outlook for 2014–15 range from moderate to dry for the Murrumbidgee River system, with a potential drying trend.

Under a dry scenario it is anticipated there will be enough environmental water to support this Priority — should an event occur upon which to build. However, there is likely to be reduced occurrence of natural higher flows, and fewer opportunities to build on a natural flow event to achieve or extend inundation. With reduced water availability under this scenario (and therefore potentially lower water levels in Burrinjuck Dam) there may also be reduced outlet capacity.

Wetter conditions (i.e. moderate to wet scenarios) will increase the likelihood of being able to achieve this Priority. There would be more flow events which could provide more opportunities to build on natural events. In addition to this, wetter conditions may also provide a natural flow event large enough to meet the Priority without the addition of environmental water. Increased water availability and higher levels in Burrinjuck Dam would also provide greater outlet capacity.

There are multiple constraints to delivering higher regulated flows in the Murrumbidgee Valley. The delivery of environmental water needs to be consistent with the rules outlined in the Water Sharing Plan for the Murrumbidgee Regulated River Water Source. Continued planning and stakeholder consultation in 2014–15 should assist with the implementation of this priority in 2014–15. However, depending on conditions, inundation through lateral connectivity may not be possible for all wetlands.

Other opportunities

Providing a winter or spring fresh to the mid-Murrumbidgee wetlands may also assist in maintaining condition and contribute to the resilience of the wetlands in the Yanco Creek system. It also has potential, should the fresh occur in winter, to contribute to meeting the Priority: *'Improve survival, recruitment, and condition of native fish populations by providing winter flows to tributaries and creeks of the River Murray and through the barrages to the Coorong*'.

Flows from the Murrumbidgee River have been identified as an important contributor to environmental outcomes in the mid to lower reaches of the River Murray. Therefore this Priority for outcomes within the Murrumbidgee should also be considered in conjunction with the Priority: '*Improve riparian, littoral and aquatic vegetation (i.e. Ruppia tuberosa) and native fish populations by increasing ecosystem connectivity through coordinating water delivery in the River Murray' system;* and other environmental outcomes in the southern-connected Basin.

Consideration should be given to coordinating flows to water the ‘Junction wetlands’. These are a group of creeks and wetlands located on the western side of the Murrumbidgee River at its confluence with the River Murray (Figure 8). Watering of this group of wetlands requires concurrent high flows in both the Murray River (flows of 10,000 ML/d at Barham) and the Murrumbidgee (flows of 5,000 ML/d downstream of Balranald weir) (SKM 2011). While there is relatively little known about the ‘Junction wetlands’ they are known to support a number of rare and threatened species (SKM 2011) and have experienced similar conditions to the mid-Murrumbidgee wetlands (in that they received flows during 2010–2012; and no flows between 2000 and 2010). Consequently, the condition of the wetlands and creeks is still recovering.

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Support in-stream functions: Macquarie River

Basin Annual Environmental Watering Priority

Improve native fish habitat within the Macquarie River below Burrendong Dam by restoring a more natural flow regime and addressing cold water pollution.

Expected benefits

It is anticipated that restoring a more natural flow regime and addressing cold water pollution (the release of cold water from dams) within the Macquarie River will contribute to the following benefits:

- provide the first opportunity (since Burrendong Dam was completed in 1967) for native fish to recolonise and recruit in the Macquarie river downstream of Burrendong Dam
- enable growth, reproduction and recruitment for a diverse range of aquatic fauna
- support mobilisation, transport and dispersal of sediment, nutrients and organic matter
- support the habitat requirements of native fish and other native species; including frogs, turtles and invertebrates
- improve the condition and extent of emergent, submerged and riparian vegetation communities.

Why is this of Basin significance?

This is important at a Basin-scale because:

- Burrendong Dam on the Macquarie River is one of the first major dams in the Murray–Darling Basin to be modified with infrastructure (a cold water curtain) to mitigate the impacts of cold water pollution
- release of water from Burrendong Dam could promote re-colonisation of native fish in the 300 km reach below the dam wall and generate significant local benefits
- the benefits are expected to be far reaching and flow through to the Macquarie Marshes and the wider northern Basin
- cold water pollution has a major impact on native fish and riverine health. It is estimated to affect up to 3,000 km of river channels in the Basin (Gehrke et al. 2003).

Significance of the site

The Macquarie River is a large, regulated river in the Murray–Darling Basin in central west New South Wales; with a catchment of approximately 75,000 square kilometres. The river rises on the western side of the Great Dividing Range south-east of Bathurst, and flows for approximately 500 kilometres north-west before flowing through the Macquarie Marshes and joining the Barwon–Darling River in northern New South Wales. The Macquarie River traverses a range of landscapes, from upland hills and slopes to the floodplains and wetlands in its northern reaches. The Macquarie River's main tributaries enter the river upstream of Narromine; with most entering upstream of Burrendong Dam. Burrendong Dam was finalised in 1967. It is the Macquarie's largest water storage (DWR 1991) and the fifth largest in NSW. Prior to flowing into the Barwon–Darling River, the Macquarie River flows through and feeds the Ramsar-listed Macquarie Marshes (Figure 10).

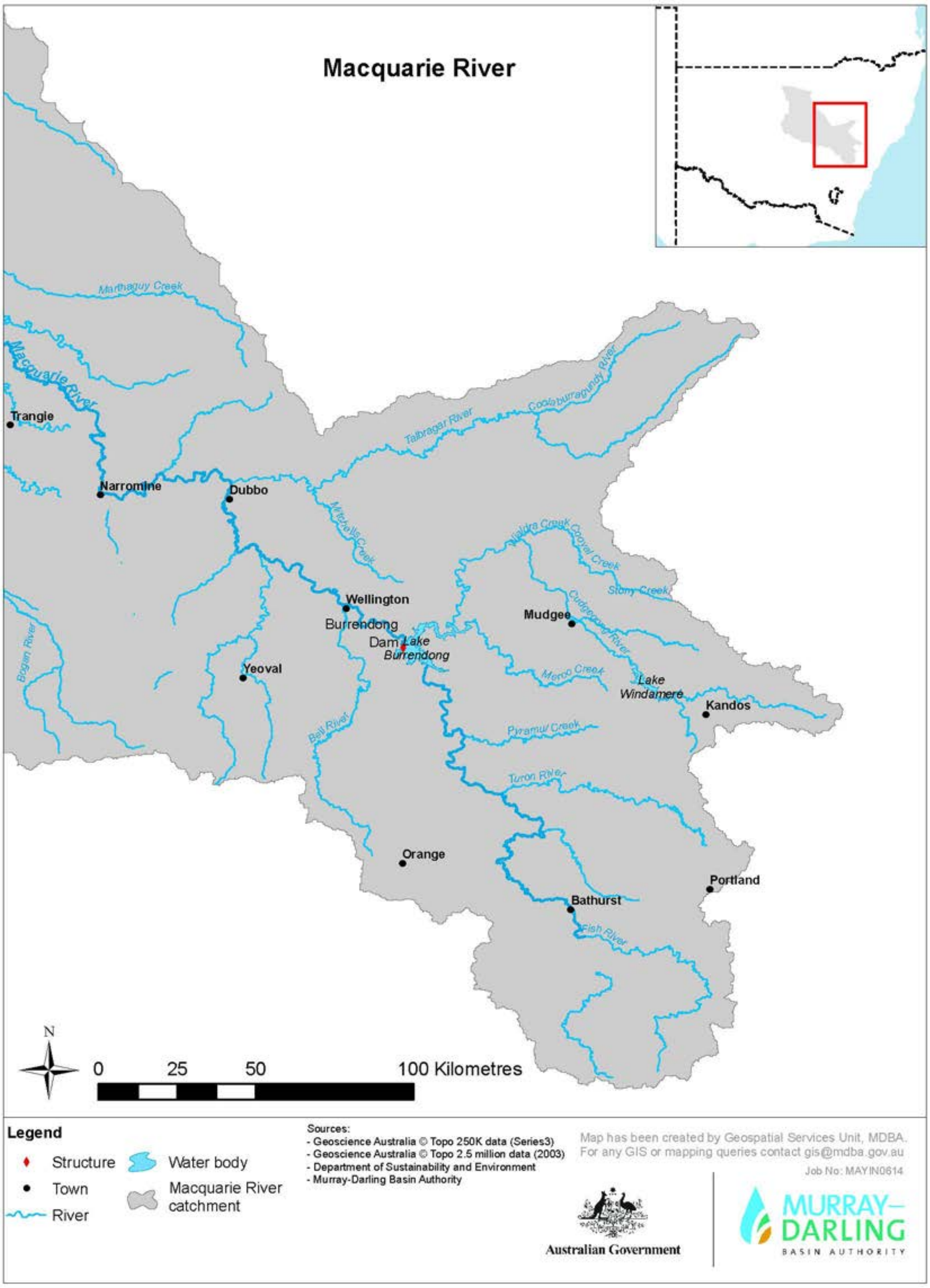

Figure 10 Macquarie River downstream of Burrendong Dam

The Macquarie River is listed as an endangered ecological community under the NSW Fisheries Management Act 1994. It supports several fish species, some of which are listed under the Environmental Protection Biodiversity and Conservation Act 1999 (Cth). These include: Murray cod, trout cod, and freshwater catfish. It sustains a diversity of riparian and floodplain vegetation, including habitat for a range of threatened and migratory bird species — some of which are also listed under international migratory bird agreements (Japan–Australia Migratory Bird Agreement and China–Australia Migratory Bird Agreement).

Matters of interest

Cold water pollution

The construction of large dams and the release of water from the colder parts of water storages significantly reduces water temperature in rivers downstream (Walker 1985). River temperatures downstream of a large dam can be reduced by as much 16° C. During the spring/summer period the reduction is usually 8–10° C lower than natural temperatures (Lugg and Astle unpublished; Sherman 2000). The negative effects of cold water often persist up to 200 km downstream, and in some cases as much as 400 km downstream of a dam (Preece 2003).

Temperature is the most important factor in the development and growth of fish (Astles et al. 2003). It influences metabolism, respiration, feeding, reproduction, larval development and migratory behaviour of native fish (Astles et al. 2003). The effects of cold water pollution on fish have been summarised by Cottingham et al. (2007) and include failure to spawn; reduced survival of eggs and larvae and decreased growth rate. Cold water pollution also reduces rates of primary production and bacterial activity in river systems.

Condition of the Macquarie River

Measured and modelled flow data in the Macquarie River have found significant changes to the natural flow regime as a result of river regulation. These changes include reduced moderate to high flows and end-of-system flows, an increase in the period between large flows, and a reduction in the number of small flows and permanent low flows in previously intermittent streams (CSIRO, 2008; Jenkins and Wolfenden, 2006; Grimes, 2001). In addition to changes in flow regime, there have been significant changes to water quality in the Macquarie River, most notably in water temperature. Cold water released from Burrendong Dam has depressed summer temperatures immediately downstream by 10–11°C. In addition, the natural temperature regime of the river has been altered for up to 300 km downstream of the dam (Sherman, 2000; Harris, 1997; Acaba et al., 2000; Burton and Raisin, 2000b).

The work conducted by Astles et al. (2003) at Burrendong Dam demonstrated that cold water pollution can have an acute impact upon juvenile fish in a relatively short period of time; and seriously threaten survival. Research by NSW Fisheries at Burrendong Dam demonstrated greatly improved growth and survival rates of silver perch in water of a natural temperature (Astles et al. 2003; Lugg and Copeland 2014).

The significant changes to the flow regime coupled with the cold water impacts of Burrendong Dam have had a significant negative impact on the ecology and the condition of the Macquarie River. Figure 11 demonstrates the temperature impacts downstream of Burrendong Dam and their incompatibility with native fish breeding.

The Sustainable Rivers Audit 2 (SRA 2) rated the Macquarie river ecosystem in very poor health over the period of 2008–2010; and ranked the river third last amongst the SRA valleys in terms of ecosystem health (Davies et al. 2012). SRA 2 concluded that '*the fish community was in extremely poor condition. Many expected species were absent. Much of the native species richness has been lost and alien species contributed over 70% of the biomass in samples'*.

Cold water releases have also been associated with the 'loss of silver perch, Murray cod, rainbowfish and bony herring from the Macquarie River for up to 300 km downstream from Burrendong Dam' (NSW DPI 2013).

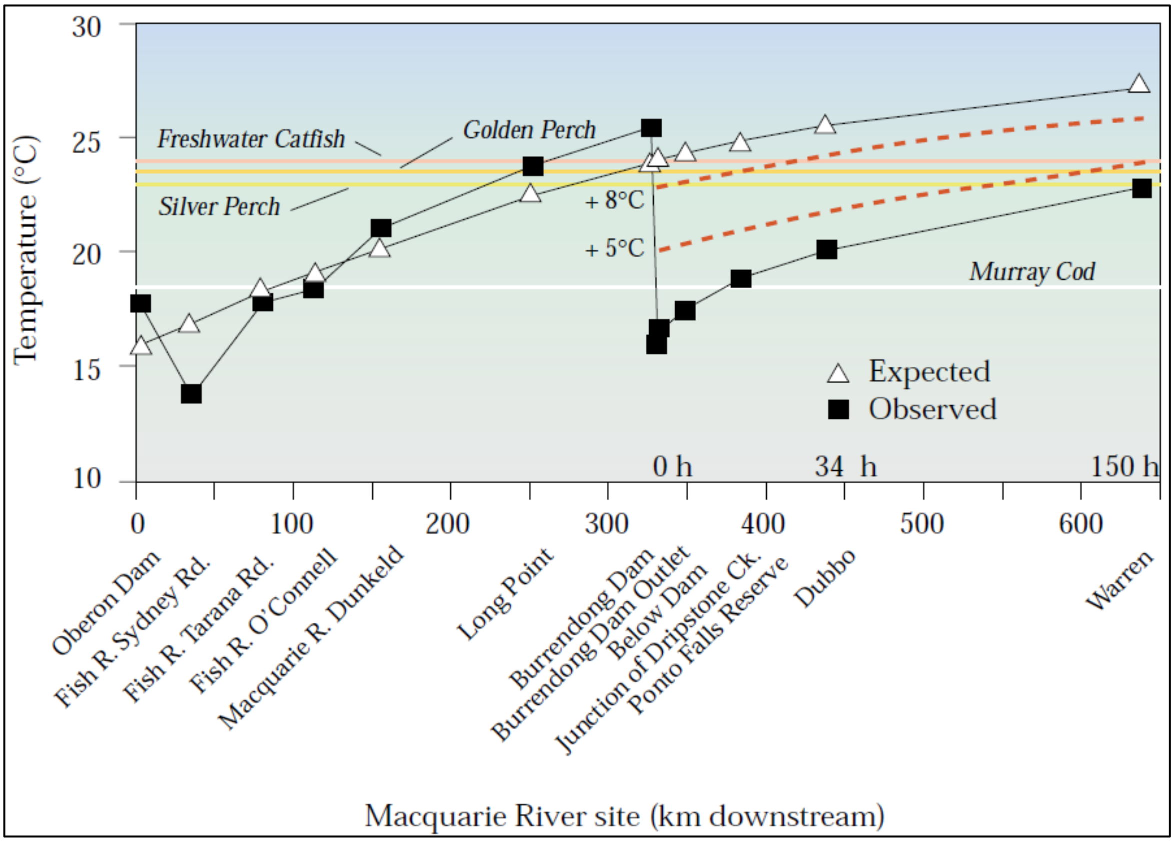

Figure 11 Observed and expected river temperatures above and below Burrendong Dam in relation to temperature requirements for fish breeding (Sherman 2000)

Burrendong Dam was identified as a priority structure for cold water pollution mitigation for New South Wales (Preece 2004). In 2012 construction commenced on a submerged-curtain temperature control structure around the intake tower at Burrendong Dam. Submerged curtains are made of robust, flexible rubber material that extends upwards from the bottom of the dam and surrounds the existing outlet tower (Sherman, 2000). The curtain excludes cold water from the bottom of the dam from passing into the outlet tower; and instead draws the warmer water from the surface of the dam into the curtain for release. It is anticipated that the cold water curtain on Burrendong Dam will be completed in 2014.

Implementation

The presence of the cold water curtain on Burrendong Dam provides a significant opportunity to mitigate the impacts of cold water pollution on the Macquarie River. This is a critical component of restoring a more natural environment in the Macquarie River — and needs to be complemented by releasing a flow regime that will assist with the restoration of the river ecology. All water released from the dam (whether for environmental, consumptive or operational purposes) is now more likely to be within the natural temperature range; and will have increased capacity to improve the ecological condition of the Macquarie River.

It is therefore advised that:

- consumptive water and operational water be released in a way that is mindful of improving environmental outcomes. (see Strategy: *Maximise environmental benefits through the use of all water*)
- environmental water is delivered to target sites in ways that can also maximise environmental benefits in the river. (See Strategy: *Improve survival of native fish populations by enhancing and protecting dry period refuge habitat in the northern Basin* for suggested flow regimes and management to benefit native fish.)

It is anticipated that this Basin annual environmental watering priority could be met across the full range of Resource Availability Scenarios (RAS). However, the scale and nature of watering events will vary with the RAS. In a very dry or dry scenario there will be limited opportunities to achieve high-flow objectives and limited ability to deliver variable pulse flows (see Strategy: *Maximise environmental benefits by managing water in harmony with natural cues*). Regulated river conditions have resulted in a reduced occurrence of low flows, leading to reduced habitat complexity. In drier scenarios there may be opportunities to achieve low flow objectives — such as opportunities to improve habitat conditions for macrophyte vegetation and for fish species that prefer such conditions.

In moderate and wet scenarios there will be a greater capacity to combine held environmental water with an unregulated event or consumptive flows. This will increase the capacity of water managers to target a broader range of in-stream benefits, including providing fish spawning and migration opportunities through drowning out weirs. (See Strategy: *Maximise environmental benefits through the use of all water*, where a case study on the Macquarie illustrates the combination of environmental and consumptive water to improve environmental outcomes.)

Flows from the Macquarie River have been identified as an important contributor to environmental benefits in the Barwon–Darling River in high-flow situations. As such, environmental outcomes within the Macquarie catchment should also be considered in conjunction with other Basin Priorities and in conjunction with outcomes in the Barwon–Darling (see Strategy: *Improve survival of native fish populations by enhancing and protecting dry period refuge habitat in the northern Basin*).

Overcoming cold water pollution across the Basin is a long-term challenge and will require large investments to retrofit current infrastructure. The MDBA encourages the use of cold water pollution mitigation measures such as those implemented at Burrendong Dam. Investigations are underway for options to mitigate cold water pollution from Keepit Dam on the Namoi River; and similar projects are being initiated at other priority dams in New South Wales using a phased approach (State Water 2013).

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Support in-stream functions: Connectivity in the River Murray system

Basin Annual Environmental Watering Priority

Improve riparian, littoral and aquatic vegetation (e.g. Ruppia tuberosa) and native fish populations by increasing ecosystem connectivity through coordinating water delivery in the River Murray system.

Note: For the purposes of this Basin annual environmental watering priority for 2014–15 (the Priority) the River Murray system includes connected tributaries, anabranches, creeks and wetlands of the River Murray, the Lower Lakes and the Coorong and Murray Mouth.

Expected benefits

It is anticipated that increasing ecosystem connectivity through coordinating water delivery in the River Murray system will contribute to the following benefits in 2014–15:

- implementing and maintaining the longitudinal integrity of a pulse along the River Murray would provide pathways for the dispersal, migration and movement of native water-dependent flora and fauna
- movement and breeding of native fish; distribution of plants; sediment transport to the sea; salinity dilution and an open Murray Mouth; carbon and nutrient cycling and recharges groundwater systems
- improved condition and extent of riparian, littoral and aquatic vegetation e.g. moira grass and *Ruppia tuberosa.*

Why is this of Basin significance?

This is important at a Basin scale because:

- coordination across state boundaries, and between governments and environmental water holders and managers is important if environmental benefits are to be achieved in the River Murray system
- the River Murray system is one of the major river systems in the Murray–Darling Basin and has significant rivers, creeks and wetlands that support internationally and nationally listed sites and species
- the occurrence of small to medium floods in the River Murray system has been markedly reduced following river regulation. This element of the flow regime is important for maintaining and restoring floodplain and in-stream communities and will assist with keeping the River Murray flowing to the sea.

Significance of the site

River Murray and its connected anabranches

The River Murray extends from Hume Dam in New South Wales into the Lower Lakes, Coorong and through the Murray Mouth into the Southern Ocean in South Australia (Figure 12). The River Murray connects with other major rivers (e.g. Lower Darling River, Edward–Wakool, Murrumbidgee and Goulburn River), floodplains, wetlands and anabranches (e.g. lower Darling Anabranch).

There are numerous anabranches and creeks of ecological importance to the functioning of a healthy River Murray. These systems support a diverse assemblage of aquatic species and provide vital breeding sites, nurseries, foraging habitat and slack water habitats away from the main river channel — necessary for freshwater fauna to complete their life cycles. These areas also provide key habitat for migratory waterbirds listed under the international Japan–Australia Migratory Bird Agreement and China–Australia Migratory Bird Agreement (MDBC 2006; MDBA 2012a). In addition, national and state listed threatened and endangered species of native fish, vegetation communities, vertebrates and invertebrates are also found in the River Murray system (MDBC 2006; MDBA 2012a).

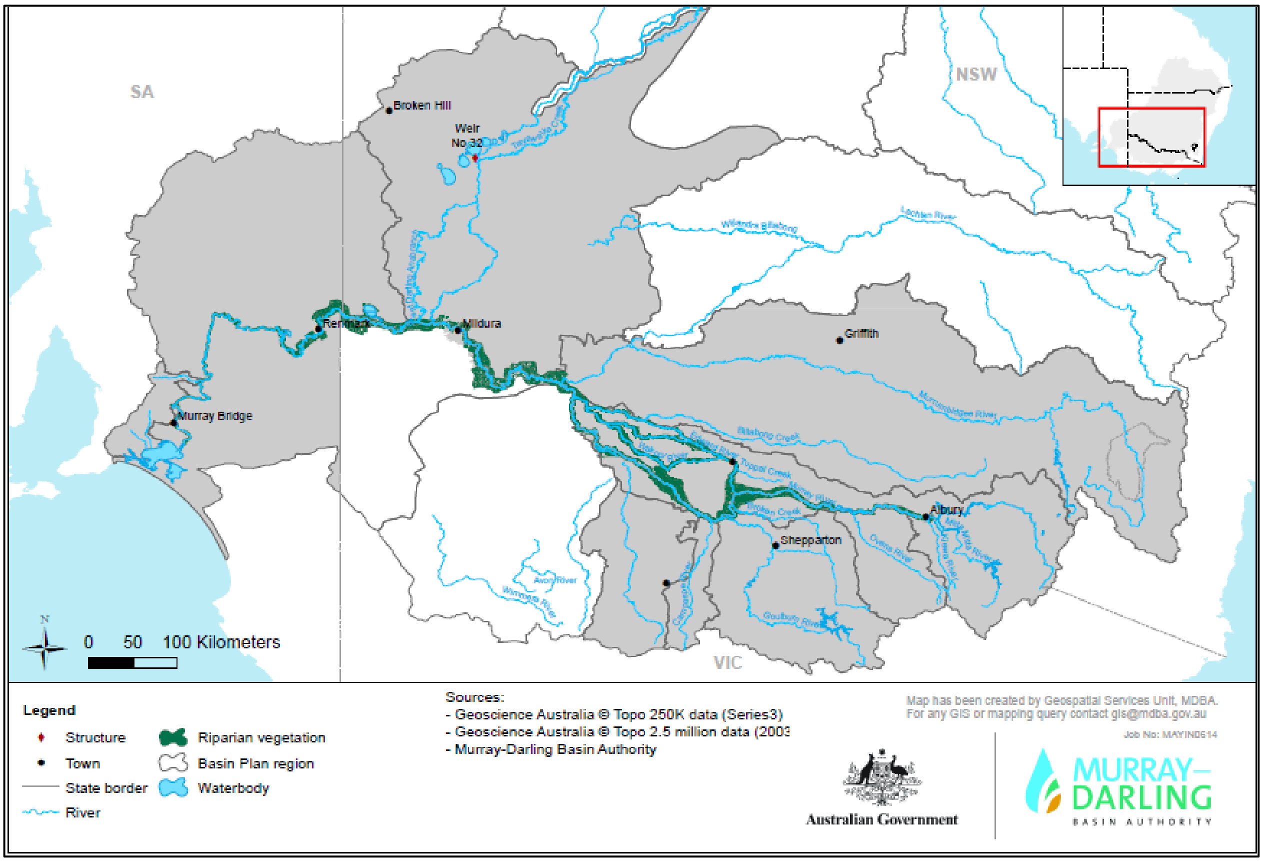

Figure 12 River Murray system

Lower Lakes, Coorong and Murray Mouth

At the lower end of the Murray–Darling system in South Australia, the River Murray passes through Lake Alexandrina and Lake Albert (the Lower Lakes) before flowing through the barrages into the Coorong and finally into the Southern Ocean via the Murray Mouth (Figure 13). The Lower Lakes are broad and shallow, ringed by mudflats and fringing vegetation (Phillips and Muller 2006).

The Coorong, Lakes Alexandrina and Albert comprise one of Australia's largest wetland systems (Brookes et al. 2009) totalling 142,500 hectares. This area was listed under the Convention on Wetlands of International Importance (the Ramsar Convention) in 1985. It is important for migratory fish, provides feeding habitat for international migratory waterbirds; and allows for the export of salt through the Murray Mouth and sediment movement between freshwater and estuarine systems (MDBA 2012b).

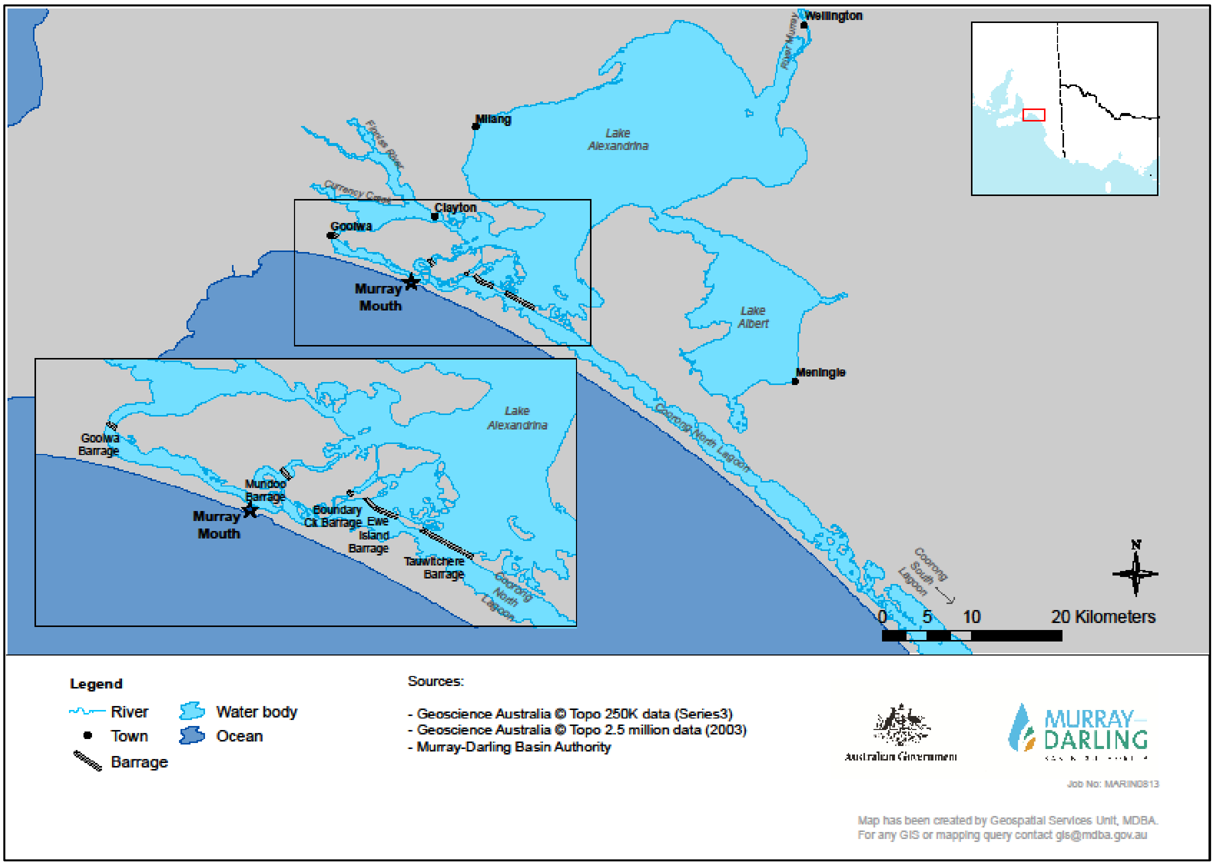

Figure 13 Coorong, Lower Lakes and Murray Mouth

Condition of assets and functions

Environmental water delivered in the River Murray system during 2013–14 aimed to maintain and improve the condition, diversity and extent of floodplain and wetland native plants (e.g. Barmah Forest, Lock 8 and 9 weir pool manipulation) and provide opportunities for breeding and recruitment of fish (e.g. in the Darling Anabranch and Edward–Wakool system), birds and frogs. While this has not led to full recovery, it has helped improve the condition of the system.

Environmental water was also delivered to target *Ruppia tuberosa* (*R. tuberosa*), salinity and water levels in the Coorong; and assisted in stopping sand intrusion into the Murray Mouth. Areas in the River Murray system are still recovering from the Millennium drought and have endured a hot and dry summer during 2013–14.

In 1999, *R. tuberosa* shoots were abundant in the South Lagoon of the Coorong. As a consequence of the reduced flows reaching the Coorong's South Lagoon, *R. tuberosa* was severely affected in both distribution and resilience as a result of the depletion of its seedbank. In 2005, *R. tuberosa* was not recorded at all; and in 2008 it was not found in the South Lagoon (Rogers and Paton, 2009). The 2010–11 floods resulted in some *R. tuberosa* growth in the western-end of the North Lagoon where it had not been previously recorded. This suggested that seed banks of *R. tuberosa* at other sites were not viable (CSIRO 2012; Frahn et al. 2012). While improvements in the population have occurred following the Millennium drought, this species now requires active management through translocation from nearby sites to improve the ability to re-establish populations in the short-term.

Ruppia megacarpa (*R. megacarpa*) used to grow in the North Lagoon, but now it is currently absent from the Coorong (Keith et al. 2013). Expert advice is that the re-establishment of *R. megacarpa* is unlikely under current management arrangements in the short-term. This highlights the ongoing threats to the remnant *R. tuberosa* populations.

Matters of interest

Riparian and littoral vegetation

The riparian zone is the interface between the terrestrial environment and the river or stream (Pusey and Arthington 2003). This zone provides habitats for fish, waterbirds, invertebrates and microalgae; provides a refuge from disturbance; and is often high in biodiversity (Ecological Associates 2010; Pusey and Arthington 2003). Riparian vegetation also provides shade which assists in water temperature regulation; provides bank stability; and intercepts, stores and releases nutrients into the river.

The water–dependent sedge and rush vegetation communities on the edges of wetlands or weir pools (*i.e.* the littoral zone) are important for nesting, breeding and providing shelter habitats for native fish, frogs, waterbirds and macroinvertebrates (Roberts and Marston 2000). They also provide an important source of organic matter into the food web (Ecological Associates 2010). Larger emergent macrophytes such as *Phragmites* and *Typha* provide key habitat for waterbirds and other aquatic fauna (Roberts and Marston 2000). Improving the diversity and health of littoral fringing vegetation creates essential habitat for small-bodied fish species such as Murray–Darling rainbowfish (B Zampatti 2014, pers. comm. 17 April).

Ruppia tuberosa in the Coorong

R. tuberosa provide structural complexity, food and habitat for macroinvertebrates and fish, including the small-mouth hardyhead (Paton and Rogers 2009). Owing to its critical functional role in the Coorong food web, and its structural role in the provision of habitat, *R. tuberosa* is an excellent indicator of ecosystem health, a key indicator species for the Coorong, and an indication of the resilience of the Coorong system (Lamontagne et al. 2012; MDBA 2012b).

A three-year on-ground translocation of *R. tuberosa* into the Coorong South Lagoon was begun by the South Australian Department of Environment, Water and Natural Resources in 2013. The first year of translocation resulted in successful germination and flowering of *R. tuberosa* across 20 hectares of Coorong mudflats (K Ryan 2014, pers. comm. 20 February). A further 42 hectares of mudflats in the Coorong were planted with translocated *R. tuberosa* in early 2014 and the final translocation is expected to occur in 2015.

Salinity levels in the Coorong are influenced by two mechanisms: the water released through the barrages and through tidal exchange with the Southern Ocean. There is also some limited flow into the South Lagoon of the Coorong via the Upper South East Drainage Scheme — which is important for reducing salinity in the South Lagoon.

Native fish

Longitudinal dispersal and connectivity allows for movement of juvenile and adult native fish species in the River Murray system (Department of Environment 2013). Fish dispersal is important both to maintain genetic integrity within species and to provide population resilience against localised catastrophic events — such as hypoxic blackwater events (Koehn et al. 2014).

Implementing flow variability, spring pulses and building on natural flow events is important for native fish in the River Murray (see Principle: *Maximise environmental benefits by managing water in harmony with natural cues*). These flow regimes promote spawning and recruitment of flow-cued spawning species (e.g. silver perch), stimulate the recruitment of circa-annual spawning species (*e.g*. Murray cod and freshwater catfish), and facilitate connectivity between the River Murray and Coorong to promote upstream movement of juvenile congolli. Spring pulses are an important component for juvenile congolli and adult flow requirements are outlined in the Priority: *Improve survival, recruitment, and condition of native fish populations by providing winter flows to tributaries and creeks of the River Murray and through the barrages to the Coorong*. Congolli are diadromous fish (fish that need to spend part of the life cycle in saltwater, and the other part in fresh water), and are restricted to the coastal rivers of South-Eastern Australia (Zampatti et al. 2011; B Zampatti 2014, pers. comm. 17 April).

Ecosystem function

Anabranches and distributary creeks have diverse assemblages of aquatic species and provide vital alternative habitats to the main River Murray. Some of these creeks can be classified as ephemeral streams. The transfer of sediment, nutrient, salt and organic matter through these small creeks into larger river systems such as the River Murray is important for overall ecosystem function (Land and Water Australia 2008).

Nutrient cycling and movement of sediment

Flows in the River Murray provide a mechanism for transporting sediments from various locations within the system to other locations downstream. Releasing and transporting nutrients from sediments is important, as it may increase primary production by increasing access to the nutrients throughout the system. Reinstating variable flow regimes helps move sediments through the system and also allows the sediments to settle out of the water column, lowering turbidity (Thoms 2000). Flow also inundates slack water habitats off the in- channel; which allows for sediments to settle and thus reduced turbidity in these areas.

Over the past 170 years the Murray Mouth has deposited and exported sediment on the landward side (Walker 2001). Flushing flows through the Murray Mouth are important to moderate sand intrusion and keep it open. The Murray Mouth is the only location where water contaminants such as sediments, salt and nutrients can exit the Murray–Darling Basin (South Australian Department of Environment and Heritage 2009).

Groundwater recharge, salinity dilution and export

Diluting salinity and recharging groundwater is important for riverine and floodplain health. Higher river flows result in a larger volume of water within the system — this acts to dilute the concentration of salts within the river and helps move mobilised salt downstream. Higher in-channel flows also provide greater opportunities for groundwater recharge. This has benefits of lowering the salt concentration in groundwater and agricultural environments; and also improving riparian tree health.

Significant places

There are many significant places in the River Murray system (in addition to the River Murray) that sustain riparian and littoral vegetation communities, improve water ecosystem function and are important for the success of native fish populations. Examples of key locations in the River Murray system that will benefit from coordinated environmental watering in the River Murray in 2014–15 include, but are not limited to:

- wetlands influenced by Lock 8 and Lock 9 weir pools (including Carrs Billabong, Capitts and Bunderoo Creeks) in New South Wales
- Edward–Wakool system, to improve water quality and native fish refuge in New South Wales
- Wallpolla Horseshoe wetland and Finnigans Creek (also influenced by the Lock 9 weir pool), to promote wetland aquatic plant diversity and condition in Victoria
- Moira grass plains in Barmah Forest to encourage the establishment of more plants (Victorian Environmental Water Holder 2014)
- Goulburn River, to re-establish lower bank vegetation, the connected wetlands and anabranches in Victoria (Victorian Environmental Water Holder 2014)
- connected wetlands and anabranches (e.g. Bookmark Creek) in the South Australian portion of the River Murray
- the connectivity between the River Murray and Coorong to promote upstream movement of juvenile congolli and flows in the River Murray channel, to support spawning and breeding of Murray cod and golden perch in South Australia.

Also significant are the icon sites managed under The Living Murray (TLM) program (e.g. Gunbower–Koondrook–Perricoota Forests, Hattah Lakes, Chowilla Floodplain and River Murray Channel). The state governments, Commonwealth and the MDBA have built infrastructure under TLM to assist with the delivery of environmental water at the first three of these icon sites. The MDBA has chosen not to identify these sites in the Priorities for 2014–15, but acknowledges the importance of commissioning (test-running) these structures as soon as possible.

Implementation

Prevailing conditions throughout the water year will determine the extent to which this Priority can be achieved and how it is achieved. At the time of preparing the Priority, the Resource Availability Scenarios outlook for 2014–15 range from moderate to dry for the River Murray system, with a drying trend.

In dry and very dry scenarios, riparian and littoral vegetation directly influenced by weirs or regulators will be inundated using base flows and small freshes using both consumptive and environmental water. Under these conditions the provision of flow through to the sea will be a particular focus. In a moderate scenario, flows will inundate low-lying wetlands that are influenced by in-stream variability, connected tributaries and flood runners; the operation of regulators (where they are already in place); and weir manipulation.

Coordination

Coordination is required to ensure that maximum benefits are provided to environmental assets along the length of the River Murray. The majority of flows into the lower River Murray system come from the Upper Murray, Goulburn, Murrumbidgee and Darling Rivers. Flows from the Darling River often occur during times of low flows in the River Murray (because of different rainfall patterns across the Murray–Darling Basin: see Priority: *Improve survival of native fish populations by enhancing and protecting dry period refuge habitat in the northern Basin)*.

Delivery of water (including the rates of rise and fall for peak flow events to the River Murray system) might be constrained by limitations on channel capacity during summer and autumn, due to higher irrigation and consumptive demands. In particular, flow restrictions in the lower River Murray are influenced by the channel capacity below Menindee Lakes in the Lower Darling River; outlet capacity of Lake Victoria; and travel times and re-regulation capacity along the Murray River.

To achieve this Priority, environmental water holders and managers should consider how the water (*i.e.* unregulated and managed water delivery events) can be coordinated between valleys and delivered to increase the connectivity across in-stream, floodplain and wetland environments throughout the River Murray system. (See Strategy: *Maximise environmental benefits by coordinating and collaborating through effective governance arrangements*). This should be done in response to natural cues and with complementary river operations (see Principle: *Maximise environmental benefits by managing water in harmony with natural cues*), and by using all water (see Strategy: *Maximise environmental benefits through the use of all water*).

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Support in-stream functions: Winter flows for fish in the southern Basin

Basin Annual Environmental Watering Priority

Improve survival, recruitment, and condition of native fish populations by providing winter flows to tributaries and creeks of the River Murray and through the barrages to the Coorong.

Expected benefits

It is anticipated that winter flows will contribute to the following benefits in 2014–15:

- in the short term, improved survival and body condition of native fish, particularly juveniles, over the winter period. In the long term, an increased and more resilient native fish population in the southern Basin
- connection between the freshwater and estuarine reaches of the River Murray to facilitate winter spawning migrations of diadromous fish in the Coorong
- reinstatement of winter longitudinal connectivity among creeks, tributaries, the main river channel and the estuary (that has been lost because of river regulation)
- increased reproductive potential of mature large-bodied native fish such as Murray cod, trout cod, and golden perch; by creating flow conditions that increase food resources and consequently build fish body condition and energy reserves prior to the breeding season
- flushing of creeks and tributaries during the cooler winter months to pre-emptively reduce the likelihood of blackwater events during high flows in summer.

Why is this of Basin significance?

This is considered a priority because:

- natural winter flows are currently missing in many tributaries and creeks, and in the estuary of the southern Basin. Returning a portion of the natural winter flows will restore important elements of a more natural flow regime (see Figure 14) to benefit native fish
- native fish in the Coorong and the tributaries and creeks in the southern Basin have important recreational, cultural, and economic significance. Winter flows will help improve these populations and protect their value to benefit people in Basin communities
- the Coorong, and the tributaries and creeks in the southern Basin are of high conservation value for native fish because they contain unique species and populations of nationally-listed and state-listed threatened and endangered species
- healthy and abundant populations of native fish in tributaries and creeks, and in the estuary in the southern Basin, can contribute to populations more broadly throughout the length of the River Murray.

Significance of winter flows in the southern-connected system

The natural seasonal flow regime in the southern Basin is typically characterised by high flows in winter following rainfall, and low flows in summer associated with low rainfall and high evaporation (Figure 14). Native fish in the southern Basin have evolved behaviours and requirements adapted to this natural flow regime (Wallace et al. 2011). Natural winter flows provide optimal food resources that allow juvenile fish to survive the winter period, and enable adult fish to grow and enhance their body condition in the lead up to spawning (Humphries et al. 2002). High winter flows also prepare river substrates and improve the habitat and water quality of deep pools. Collectively, enhanced adult fish body condition and improved in-stream habitats contribute to successful breeding, nesting and juvenile recruitment.

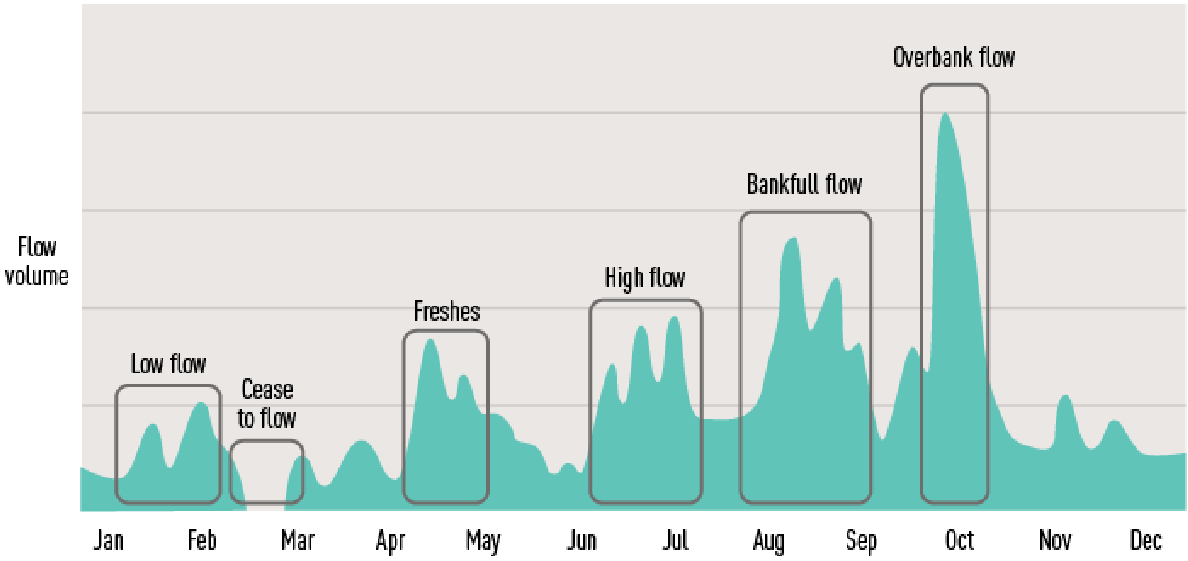

Figure 14 Natural hydrograph of unregulated rivers in the Victorian tributaries of the River Murray

Some unregulated tributaries and creeks in the southern Basin still have high flows in winter and spring (e.g. the Ovens River); however, in most cases water is now extracted in the winter months and released in the summer for irrigation supply. This river regulation has reversed or inverted natural flow seasonality such that high flows now occur during the summer irrigation season and low flows occur during winter (Walker 1985; Thoms and Cullen 1998; Reich et al. 2010). In some reaches downstream of weirs, creeks are almost dry in winter.

Significant community and natural resource management effort has gone into rebuilding the numbers and health of native fish populations in the southern Basin (e.g. *The Native Fish Strategy 2003–2013*; MDBC 2004). Much of this work is compromised during the winter months. Without appropriate winter flows and with many reaches reduced to a series of poor quality pools, native fish suffer high mortality from anglers, predators, disease and competition for limited food. In creeks and tributaries with reduced winter flows, fewer fish survive to adulthood, body condition of mature fish deteriorates, and consequently native fish breeding and recruitment outcomes are significantly reduced.

Reinstating appropriate winter flows in the creeks and tributaries of the southern Basin will create the right environmental conditions for native fish populations to survive and grow; and will ultimately increase the numbers of native fish in the River Murray. Overall, winter flows will support ongoing population recovery of Murray–Darling Basin native fish populations and will increase their resilience.

Sites involved in the Priority

Insufficient winter flows for fish occur to varying degrees in many creeks and tributaries of the southern Basin. Key sites include the Coorong, Lindsay River and Mullaroo Creek, the Loddon River, Gunbower Creek, Little Murray River, Pyramid Creek, the Campaspe River, the Edward–Wakool system, the Yanco–Billabong system, Goulburn River and Broken Creek.

Winter flows in Gunbower Creek, the Loddon system, the Campaspe system and the Goulburn system can provide important contributions to environmental outcomes in the River Murray. As such, this Priority complements and should be considered in conjunction with the Priority: *Improve riparian, littoral and aquatic vegetation (e.g. Ruppia tuberosa) and native fish populations by increasing ecosystem connectivity through coordinating water delivery in the River Murray system.* Winter and spring flows in Yanco Creek can also complement the Priority*: Improve the condition of wetland vegetation communities in the mid-Murrumbidgee wetlands through a winter or spring fresh.*

A series of case studies on implementation of winter flows at some of the above sites are discussed below.

Coorong barrages

At the lower end of the Murray–Darling system in South Australia, the River Murray passes through Lake Alexandrina and Lake Albert (the Lower Lakes) and then flows through the barrages into the Coorong estuary and finally into the Southern Ocean (Figure 15). Together with the Lower Lakes and Murray Mouth, the Coorong is one of Australia's largest wetland systems (Brookes et al. 2009), totalling 142,500 hectares. It was listed under the Convention on Wetlands of International Importance (the Ramsar Convention) in 1985. The area plays a vital role in the life cycle of migratory fish as it allows for movement between marine, estuarine and freshwater environments.

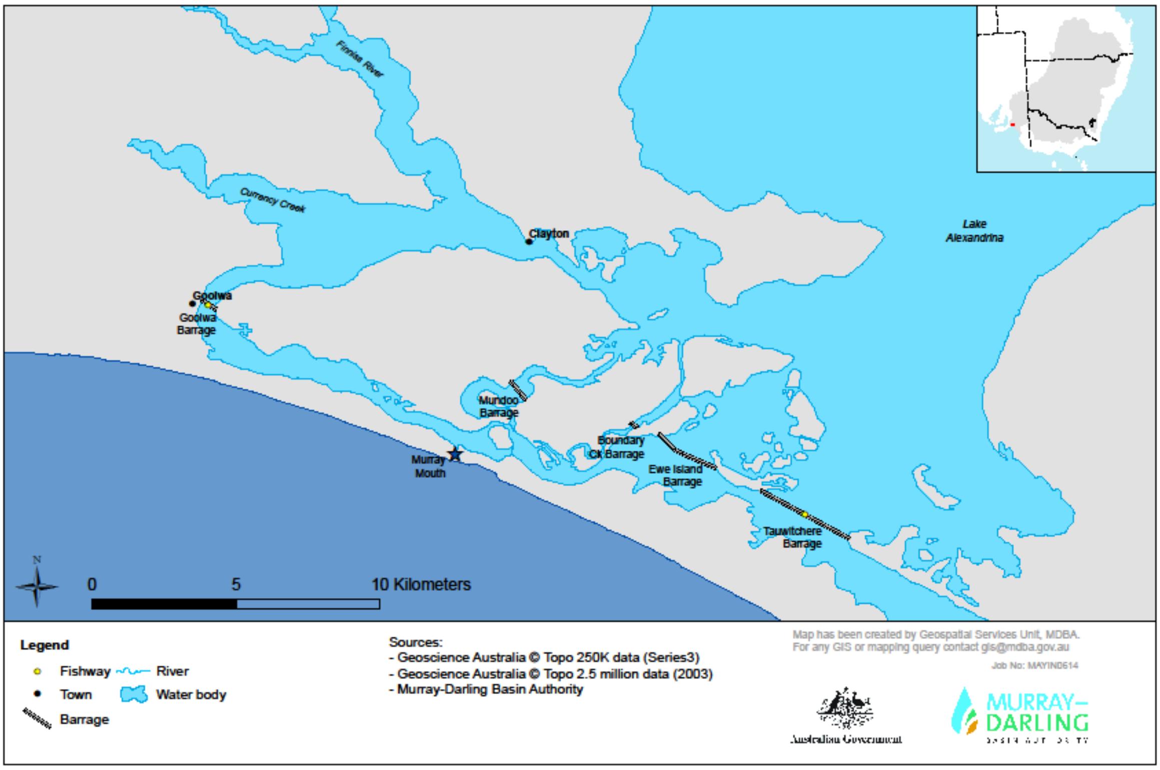

Figure 15 The barrages between Lake Alexandrina and the Coorong in South Australia

The Coorong's estuary is a biodiversity 'hot spot' and provides vital spawning and nursery habitats for diadromous fish (fish that need to spend part of the life cycle in saltwater, and the other part in fresh water). The estuary is also an essential migratory pathway (Baumgartner *et al*. 2014); however, passage between estuarine and freshwater habitats was compromised by the construction of a series of tidal barrages in the 1940s.

Diadromous fish constitute a unique component of the native fish fauna of the Murray–Darling Basin. Five species including the common galaxias, congolli, short-headed lamprey, pouched lamprey and short-finned eel, need to be able to move between freshwater and estuarine/marine environments to complete their life cycles. In late autumn and winter (May–August), reproductively-mature congolli and common galaxias in the River Murray migrate downstream to the estuary/sea to spawn. (Juvenile flow requirements are outlined in the Priority: *Improve riparian, littoral and aquatic vegetation (e.g. Ruppia tuberosa) and native fish populations by increasing ecosystem connectivity through coordinating water delivery in the River Murray system*.) At a similar time, mature lampreys migrate from the sea upstream into the freshwaters of the River Murray. Currently, this fish migration and subsequent spawning and recruitment is compromised in the Coorong because the tidal barrages are often closed during winter to maintain water levels in Lake Alexandrina; and also as a result of historically low entitlement flow to South Australia during this time. (Note that these flows can now be augmented with water available under the Basin Plan reforms.)

Reinstatement of winter flows through the barrages and associated fishways will provide connectivity between the freshwater and estuarine reaches of the River Murray and will facilitate spawning migrations of important diadromous fish species.

Gunbower creek

Gunbower Creek is a 120 km natural floodplain anabranch of the River Murray in north-central Victoria (Figure 16). The creek forms the southwest boundary of Gunbower Island; with the northeast boundary formed by the River Murray. Gunbower Creek is fully regulated via the National Channel and is predominately used as a conduit for delivery of irrigation water. As a result, high water levels are maintained throughout the summer irrigation season and very low water levels characterise winter (Cooling et al. 2001). Flows from Gunbower Creek into the River Murray now only occur during rain rejection events (where water ordered and delivered for agriculture is not extracted from the creek because local rainfall meets watering needs instead) or during environmental watering. This connectivity is recognised as critical to the ecological processes sustaining the Gunbower Island ecosystem (Gippel and Blackham 2002; Rehwinkel et al. 2010).

Anabranches such as Gunbower Creek provide vital migration, spawning, feeding and nursery habitats for native fish (Baumgartner et al. 2014). Gunbower Creek also permits native fish to access the Gunbower Island ecosystem; however, this can only occur when regulators are operated during environmental flow events. Twelve native fish species are found in Gunbower Creek. Four of these are large-bodied threatened species — Murray cod, silver perch, trout cod and freshwater catfish — all of which occur in very low abundance (Rehwinkel and Sharpe 2009a; 2009b). Adult fish are also in low abundance in Gunbower Creek because they cannot access the creek in winter (Stuart and Sharpe 2012).

Restoring longitudinal fish passage along Gunbower Creek in winter is an important component of recovery for native fish populations in the region. Winter flows promote natural productivity in the system, allow for the maintenance of critical fish habitat, and can be used to reduce rapid fluctuations in water levels caused by irrigation demand. Winter flows will create opportunities for large-bodied fish such as Murray cod to enter the Gunbower Creek system to access important food resources and build their body condition prior to mating and spawning in spring (North Central CMA 2014a).

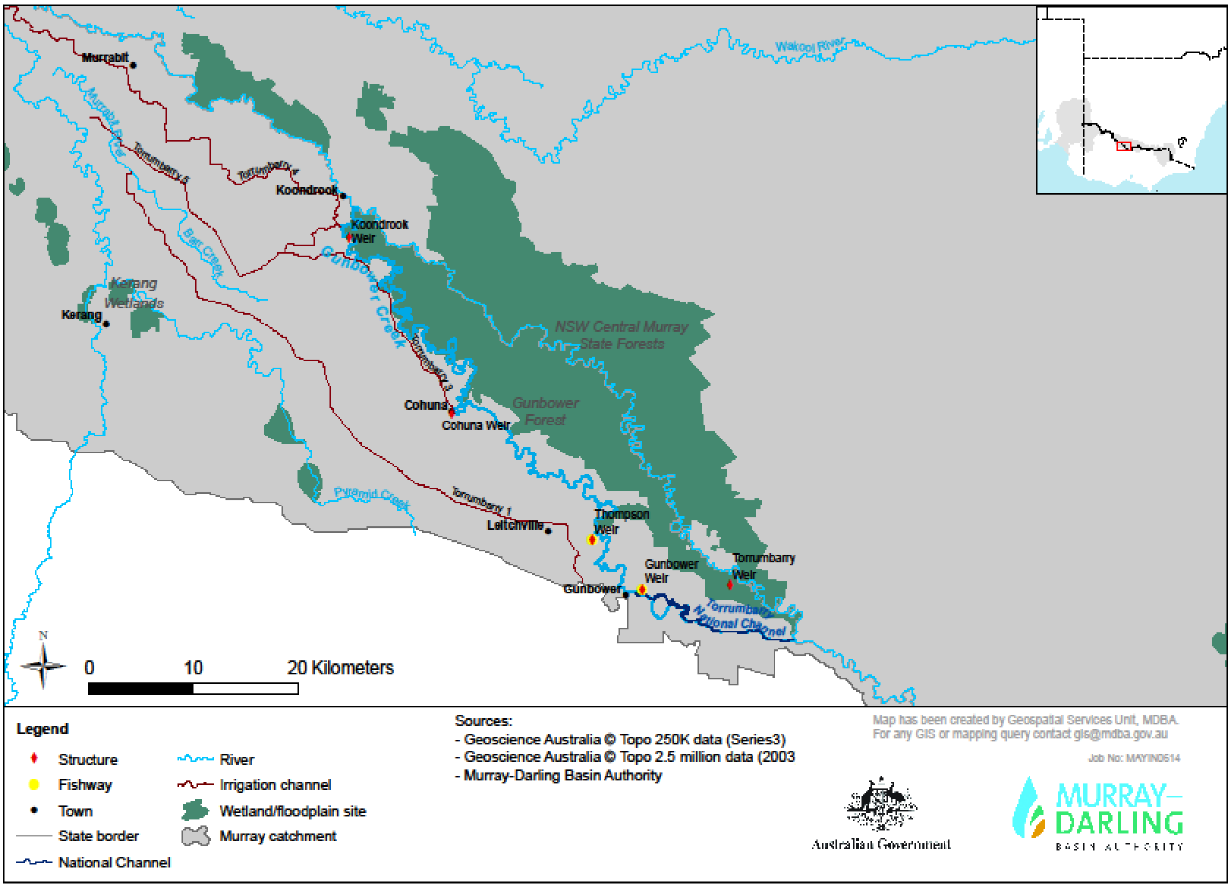

Figure 16 Gunbower Creek in Gunbower Island, Victoria

Loddon River

The Loddon River is a 392 km tributary of the River Murray that flows northward from the Great Dividing Range though central northern Victoria (Figure 17). The river rises above Cairn Curran Reservoir and joins the Murray between Barham and Swan Hill downstream of Torrumbarry Weir. The lower Loddon River encompasses the Ramsar-listed Kerang Wetlands, which provide refuge for migratory waterbirds. The Loddon River supports extensive irrigated pasture, which is enhanced by inter-valley transfers from the River Murray and the Goulburn River (via the Waranga Basin).

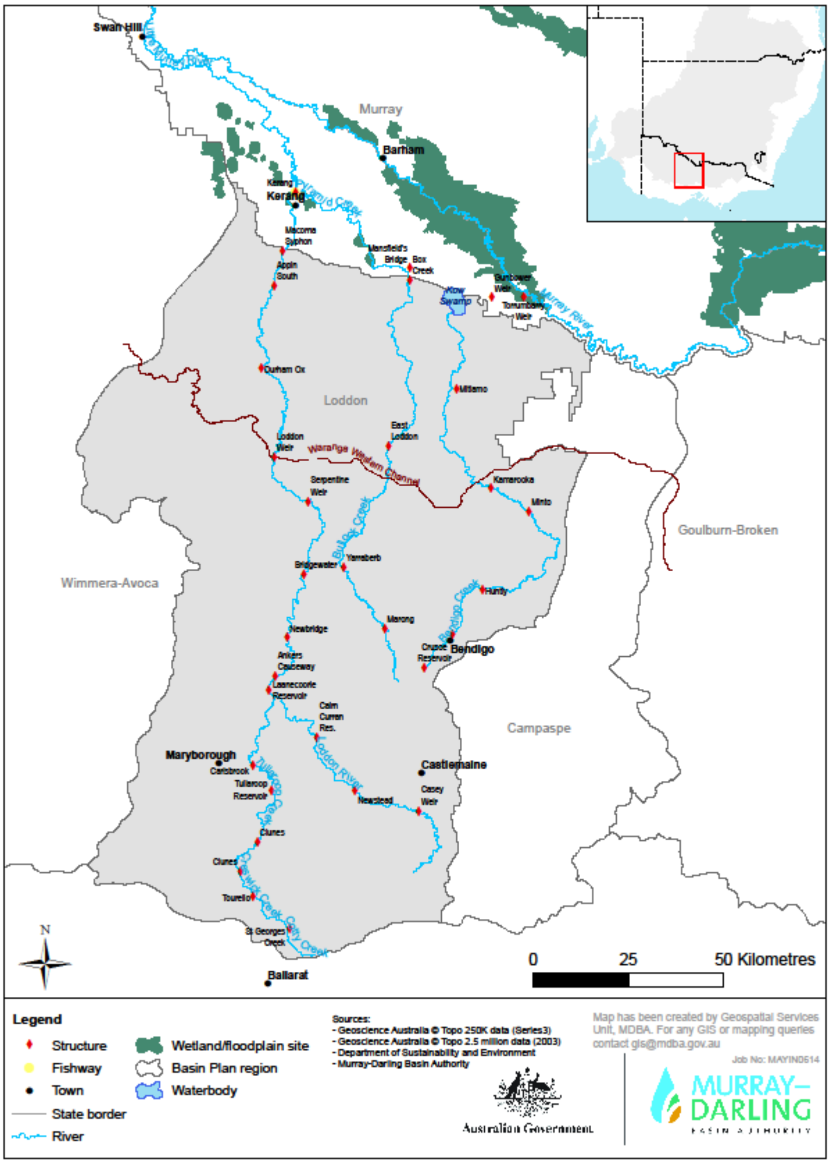

Figure 17 The Loddon River flows north to the River Murray

In 2010 the Sustainable Rivers Audit found the overall ecological health of the Loddon River to be in extremely poor condition (Davies et al. 2012). The river experiences considerable seasonal flow inversion and all reaches have significantly reduced flows in winter (DSE 2008; Davies et al. 2008).

The Loddon River native fish community is in extremely poor condition with significant losses of species and low overall abundance (Davies et al. 2008; 2012). Winter flows in the Loddon River will contribute to mitigating the negative effects of flow inversion on the small native fish populations that remain. In the upper reaches, winter flows will benefit the regionally- important river blackfish; and can also improve in-stream productivity to support Murray cod and golden perch breeding in spring. In the middle reaches, winter low flows can provide important food resources, enhance juvenile survival, build adult body condition and assist fish movement.

Campaspe River

The Campaspe River is a significant tributary of the Murray and extends 150 km from the Great Dividing Range in the south, to the River Murray in the north (Figure 18). Prior to river regulation, the middle and lower reaches of the Campaspe River were characterised by high flows in winter and spring, incised channels, and deep pools providing habitat for native fish (SKM 2006). Today, flow downstream of Lake Eppalock is controlled by weirs; and irrigation and environmental flow releases. The cumulative effects of land clearing, reservoirs, urban development, extensive irrigated agriculture and seasonal flow inversion are reflected in the extremely poor condition of native fish communities, and very poor condition of the river overall (Davies et al. 2012). Despite this, recreational fishing is highly valued in all reaches of the Campaspe River; and a population of Murray–Darling rainbow fish has recently been rediscovered in the catchment (Darren White, North Central CMA, pers. Comm. 13 June 2014).

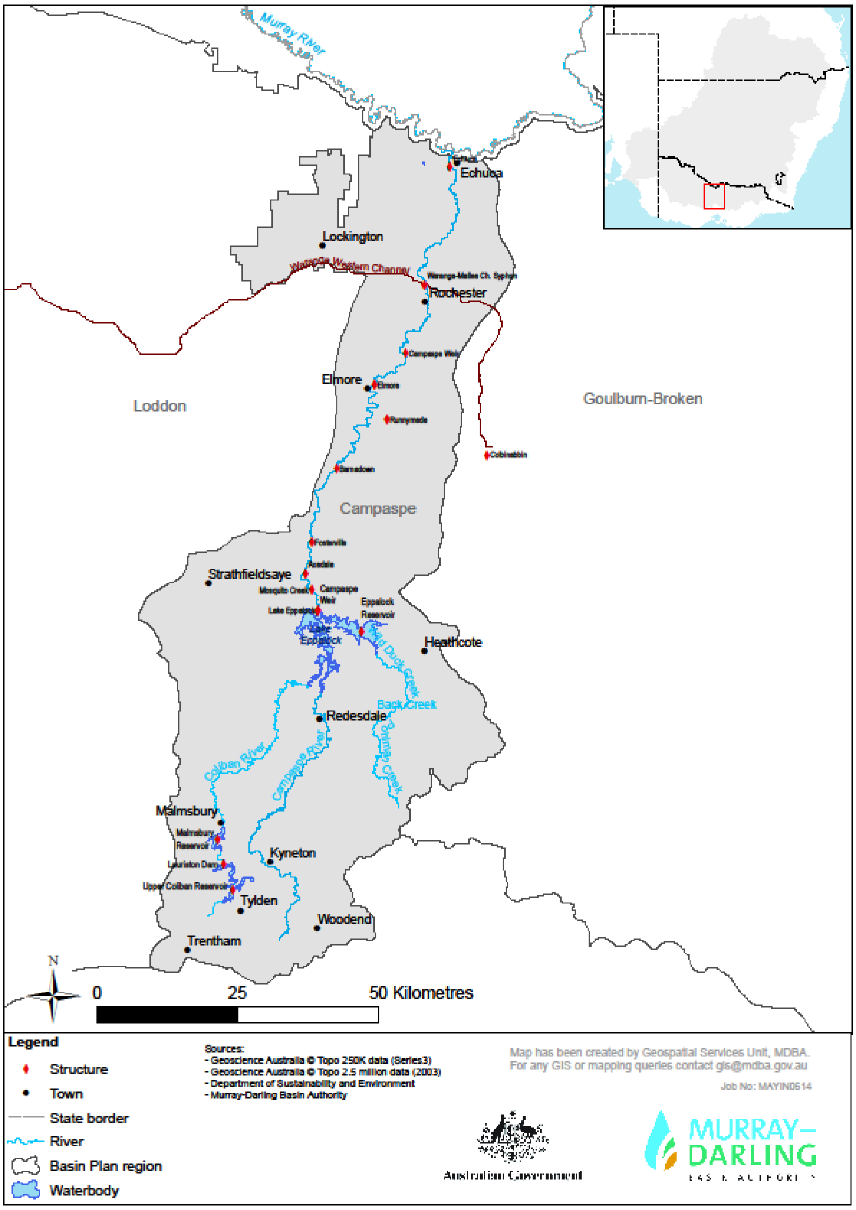

Figure 18 The Campaspe River catchment in Victoria

In the Millennium drought native fish populations were adversely impacted by the significant reduction in flows, reduced persistence of pools, reduced longitudinal connectivity, and in particular, the elimination of winter flows (North Central CMA 2013). At this time during the non-irrigation season (May–August) flow rates in winter varied from 0 to10 megalitres per day (ML/d) (North Central CMA 2014b). In 2011–2012 the first winter base flow for 10 years was reinstated through the entire length of the lower Campaspe (below Lake Eppalock). This was achieved using water held by the Commonwealth Environmental Water Holder to top up base flows to 200 ML/d (North Central CMA 2011).

Further winter flows are required in the Campaspe River to continue to build the resilience and condition of the small native fish populations that remain in the system. Winter flows below Lake Eppalock will assist in mobilising sediments and scouring deep pools for fish habitat (and ensuring pools are at least maintained over the winter period), and will provide important food resources to ensure native fish survival and growth.

Implementation

The minimum requirement to achieve this Priority is to provide winter base flows. This should be possible under most climate scenarios. Winter base flows use little water and have no conflict with the delivery of water for irrigation. They also prevent water quality decline.

The prevailing conditions throughout the water year will determine the extent to which this Priority can build on winter base flows to achieve a more ideal scenario of winter high flows. At the time of preparing the Priority, the Resource Availability Scenarios outlook predictions for 2014–15 in the southern Basin range from moderate to dry.

For winter flows over the barrages in the Coorong, a small but dedicated water allocation is required. This should be provided for three months over the period and take into account the volume necessary to operate all fishways; provide attractant flows through the barrages (a specific water flow designed to attract fish and direct them towards the entrance of the fishway); and connectivity through barrage gates. Considerable coordination and collaboration with upstream water users would also be required (see Strategy: *Maximise environmental benefits by coordinating and collaborating through effective governance arrangements).*

Depending on inflows, environmental water may be used to contribute to a range of flow components including base flows, freshes, high flows, and bank-full events. Environmental flows could build on natural flows (see Strategy: *Maximise environmental benefits by managing water in harmony with natural cues*) and the delivery of consumptive water when it occurs in winter (see Strategy: *Maximise environmental benefits through the use of all water.*

Winter flows in dry and very dry resource availability scenarios

In a very dry scenario, there may be insufficient flows upon which held environmental water can build to increase winter base flows. In a low inflow scenario, environmental water holders and managers can follow natural cues to deliver a winter/spring fresh (of as great a volume as practicable).

Winter flows in a moderate resource availability scenario

During a moderate resource availability scenario, a more complete flow regime may be provided in winter, with the exception of bank-full and over-bank flows. As more water becomes available, the winter base flow requirement should increase as appropriate to establish winter low flows and occasional (*e.g.* four per season of four days duration) winter high flows. Winter and spring high flows can be achieved through a combination of held environmental water delivered in conjunction with unregulated tributary inflows.

Winter low flows should be implemented for as long as possible during the irrigation shut-down season, to increase longitudinal connectivity. This will provide conditions for fish to optimise their habitat and resource requirements. Winter high flows will mobilise sediment to scour deep pools and prepare substrates for nesting in spring. A further outcome of high flows in the cool months of winter/spring is flushing of organic material from the river channel and higher benches, which should reduce the likelihood of black water events during high flows in summer.

Winter flows in wet and very wet resource availability scenarios

In very wet and wet scenarios, large unregulated natural flows will likely achieve the Priority, ideally though a winter bank-full event. In these scenarios, held environmental water may not be required, except to manage flood recession and extend the duration of high winter flows after the flow peak has passed. Provision of a bank-full event in winter/spring will optimise habitat, food resources, and adult body condition for successful breeding and recruitment in spring.

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Enhance and protect refuge habitat: Native fish in the northern Basin

Basin Annual Environmental Watering Priority

Improve survival of native fish populations by enhancing and protecting dry period refuge habitat in the northern Basin.

Expected benefits

It is anticipated that enhancing and protecting dry period refuge habitat in the northern Basin will contribute to the following benefits in 2014–15:

- increased persistence of refuge habitats during a median to dry resource availability scenario
- improved habitat diversity and water quality and quantity at refuge sites
- provision of longitudinal connectivity for native fish movement
- maximised opportunities for survival and improved body condition of adult native fish in refuges. This could enhance breeding responses and provide higher juvenile recruitment.

Why is this of Basin significance?

This is considered a priority because:

- the northern Basin has many areas of high conservation significance that support nationally and state-listed threatened species and populations. Fish communities in the northern Basin have a distinctly different fish assemblage to the southern Basin, and are important to the overall biodiversity of fish in the Murray–Darling Basin
- refuges are important for the survival of native fish communities during dry periods in the northern Basin. Extraction of water exacerbates dry conditions and increases native fish reliance on refuges
- given the dry forecast and a high probability of El Niño conditions occurring in the second half of 2014 (BoM 2014), early planning is essential to support the northern Basin fish community. Actions that allow native fish to build condition, and actions that improve the quality and extent of refuge habitats prior to dry periods, will increase individual fish survival during drought and will enhance the resilience of native fish populations.

Significance of fish refuges

Dryland rivers naturally have prolonged periods of low or cease-to-flow conditions broken by irregular high flows and floods. Native fish communities in the northern Basin have evolved to these ‘boom and bust’ cycles and their resilience and persistence is due in part to the presence of refuge habitat (Balcombe et al. 2006; Lobegeiger 2011).

Dry period refuges usually take the form of deep and permanent sections of main river channels, wetlands, waterholes and billabongs where freshwater animals retreat to survive the time between high flow events (Arthington and Balcombe 2011; Leigh et al. 2010; Lobegeiger 2011).

The persistence and quality of refuges are controlled by the frequency, magnitude and duration of flow, water depth, degree of channel incision, and the amount of surrounding vegetation (Leigh et al. 2010; Webb et al. 2012; Rayner et al. 2009). Ideally, refuges form a connected network across the landscape and are able to maintain good water quality and periodic hydrological connection during dry phases.

It is essential that native fish have access to a network of high quality refuge habitats when needed. Native fish in high quality refuge sites have higher survival rates and, depending on the duration of the dry phase, can retain better body condition. When wet conditions are restored, these survivors have increased capacity to breed and recolonise the landscape (Arthington and Balcombe 2011). By reducing population losses during dry periods and acting as sources of recolonisation after disturbance, refuges can increase native fish population resilience (Magoulick and Kobza 2003).

Condition of the northern Basin fish community

The northern Basin supports populations of nationally vulnerable Murray cod and silver perch (EPBC Act 1999). It is a stronghold for endangered and threatened species that have severely declined in the southern Basin — including the endangered freshwater catfish, olive perchlet, southern pygmy perch and southern purple-spotted gudgeon. The northern Basin also supports a native fish Endangered Ecological Community in the lower Darling River and the lower Lachlan River (NSW *Fisheries Management Act* 1994a, b). Upland regions of the Condamine River encompass important populations of the northern river blackfish that are listed as 'no-take' under Queensland legislation. Four native fish species occur in the northern Basin, that are not present in the south: spangled perch, desert rainbowfish, Hyrtl's tandan and Rendahl's tandan.

Some fish communities in the northern Basin are rated as having the highest condition in the Murray–Darling Basin overall (SRA2 2012). The Paroo River, for example, has good native fish health; and the Condamine and Border rivers have moderate fish health. The remaining rivers are rated as having poor or very poor fish health (SRA2 2012). Generally northern Basin fish populations have a higher proportion of native compared to alien fish. For example the Border, Condamine, Darling, Paroo and Warrego rivers all have native species contributing more than 75% of their total fish numbers (SRA2 2012). This illustrates the importance of these northern Basin systems to overall native fish assemblage in the Murray–Darling Basin.

Effect of river regulation and water extraction on the northern Basin fish community

River regulation and the extraction of water resources have altered native fish communities in the northern Basin. Changes to flow regimes have resulted in smaller and fewer populations of native fish, lower native species diversity, localised extinctions of susceptible native species and increases in alien species. Water extraction also amplifies the negative effects of dry and drought conditions on native fish populations, and compromises fish refuge habitats by reducing their quality, persistence and connectivity (Rayner et al. 2009; Rolls et al. 2013).

Water extraction in unregulated systems, particularly of summer low-flows, also has negative consequences for native fish populations. Summer low-flows are critical for maintaining water levels and water quality in refuge habitats and for allowing fish passage among refuges. In some rivers a very high proportion of small-to-moderate flow events are extracted. This not only reduces the extent of filling and connection of refuges, but can also influence the extent that water travels downstream.

The effect of river regulation and water extraction on native fish communities is highest in systems where impacts have been endured for many decades. Some unregulated rivers in the northern Basin have not experienced a long history of significant extraction — such as the Paroo, Warrego and Barwon–Darling. These rivers often have a more natural flow regime and are particularly valuable for native fish. Unregulated rivers are often characterised by diverse native fish communities and can be more successful at recruiting native fish than regulated systems (Rolls et al. 2013). Further, unregulated rivers and creeks in the northern Basin are particularly important for remnant populations of threatened species such as freshwater catfish and southern pygmy perch. Given the above, dry period fish refuges in unregulated systems are critically important for ensuring the survival of native fish source populations for the broader northern Basin (McNeil et al. 2013a).

Significant places

A variety of permanent and semi-permanent freshwater habitats can act as dry period fish refuges. In-stream sites include deep pools and holes; and during extended drought conditions, can also include permanent weir pools in regulated rivers (McNeil et al. 2013b; Rolls and Wilson 2010). Large and deep in-channel waterholes can contain water for several years after a flow event, and provide important refuge for large-bodied fish species such as adult golden perch and freshwater catfish (Balcombe et al. 2006). Weir pools can also provide suitable drought refuges for native fish, although their value is improved significantly when supported by fish passage infrastructure.

Examples of some in-stream sites in the northern Basin that could be relevant to this Priority include: deep pools in the Namoi River, Dumaresq River and Macintyre River; distributary channels of the Lower Balonne, Severn River and Myall Creek; permanent and semi-permanent waterholes on the Gwydir River, Gingham watercourse, Mehi River, Carole Creek, Barwon–Darling River, Warrego River and Paroo River; weir pools at Chinchilla weir and Reilly's weir on the Condamine River and Cunnamulla weir on the Warrego River.

Off channel sites, such as wetlands, occur in the lower reaches of many rivers and can also provide important dry period refuges for native fish. Examples of wetland refuge locations in the northern Basin that could be relevant to this Priority include: Great Cumbung Swamp and Burrawang West lagoon on the lower Lachlan River; the Macquarie Marshes on the lower Macquarie River; the Gwydir wetlands on the Gingham Channel and lower Gwydir River; Mallowa wetlands on the Gwydir River; the Macintyre and Weir River wetlands on the Border Rivers; semi-permanent lagoons on the Condamine–Balonne River; and wetlands in the Cuttaburra Creek system and Yantabulla Swamp on the Warrego River.

Identification of key refuge sites and their watering requirements is incomplete in many areas of the northern Basin. Work is needed to identify key native fish refuges and in absence of detailed surveys, information on refuge habitats will rely on local knowledge and experiences gained during the Millennium drought.

Implementation

The unregulated areas of the northern Basin limit the ability to actively manage environmental water in some reaches. However, positive outcomes for native fish refuges can be achieved under all Resource Availability Scenarios (RAS) and in both regulated and unregulated systems.

In a moderate to wet RAS there is likely to be a series of pulse events entering the system; contributing to longitudinal and lateral connectivity and enhancing refuge habitats and fish condition. In this scenario, natural inflows may be sufficient to prepare refuge habitat. In a dry scenario there are opportunities to use environmental water to prepare and support refuges. In regulated systems, all water has the potential to contribute towards this Priority regardless of whether releases are intended for environmental, consumptive or operational purposes (see Strategy *Maximise environmental benefits through the use of all water*).

This 2014–15 Priority can be achieved through:

- watering actions that enhance native fish condition and refuges prior to a drying phase
- protecting and coordinating with natural inflows when they occur
- delivering and protecting low flows (base flows and freshes) to maintain refuges in dry conditions.

Enhancing native fish condition and refuges prior to a drying phase

To prepare refuges for prolonged drying phases, flows should aim to extend the persistence and quality of refuges. Timing of flow delivery will be critical to ensure refuges are filled before conditions are too dry. Environmental water can be provided to fill in-stream refuges, scour pools, and to create habitat diversity. Base flows, freshes and bank-full events may be possible under dry to moderate RAS.

Seasonally appropriate flows that inundate benches and support in-stream vegetation will contribute to improved productivity and food resources that will in turn improve fish condition. Depending on the RAS, flows aligned with natural cues to promote spawning and recruitment (see Strategy: *Maximise environmental benefits by managing water in harmony with natural cues*) may also help to build resilience of some native fish populations to withstand drying phases.

Fish stranding is of particular concern heading into drying phases. Receding water levels are a cue for fish to move from off-stream habitats to the main channel and into refuge habitats. Therefore, managed flow events should include a gradual rate-of-fall to allow native fish to return to main channels as water levels drop; and to move between in-channel refuge habitats.

Protecting and coordinating with natural inflows

The MDBA notes that there are increasing efforts by water managers to make the best use of natural inflows to achieve environmental outcomes. Natural inflows (or unregulated flows) trigger a greater biological response from native fish compared to water from storages (Wallace et al. 2011; Hutchison et al. 2008). Natural inflows have higher carbon and nutrient concentrations and have chemical cues that elicit increased native fish spawning, recruitment and movement. Fish condition can be improved by protecting seasonal inflows and by protecting flows that coincide with naturally high periods of in-stream productivity.

Coordination of regulated and unregulated flows in the northern Basin could contribute to the protection of natural inflows in the Barwon–Darling and consequently enhance fish refuge habitat. For example, delivery of held environmental water in regulated tributaries such as the Macquarie, Namoi or Gwydir could contribute to a flow in the Barwon–Darling River system. If these managed deliveries occurred in conjunction with a natural cue such as an unregulated event, the flow can build on the natural inflow to the Barwon–Darling River and could enhance refuge habitat. It is recognised that coordinating the delivery of held or managed environmental water with unregulated events is challenging as it requires detailed planning, regular communications and cooperation across agencies. Coordination of flows to the Barwon–Darling should also consider balancing the needs of individual catchments within the wider system. Finally, the protection of held environmental water as it moves into unregulated stretches may be required, such as the development of water shepherding arrangements.

Delivering and protecting low flows to maintain refuges

In the event of significant drying, actions should focus on the maintenance and protection of drought refuges for native fish. Water availability will limit the scope of actions, and they may include provision of low-flows to create short-term connections among refuges and to allow fish redistribution. Low-flows can maintain depth in refuge habitats and can sustain permanent waterholes. Low-flows can also maintain in-stream habitat and may be used to mitigate negative impacts associated with poor water quality. The MDBA notes that a number of regions are prioritising flows for drought refuge support in the northern Basin in 2014–15 in anticipation of further drying.

Extraction from refuges during dry phases is a threat to refuge persistence and quality. The MDBA notes that under present legislative frameworks there are different capacities to limit extraction from drought refuges across the northern Basin. Development of rules that protect low-flows and refuge habitat from over extraction will be essential in the long term; as well as continued use and acquisition of permanent and temporary environmental water. In the interim, if the dry phase does reach critical points (dependent on intensity and duration), strategic pumping into refuges may need to be considered to sustain key sites where flow delivery is not possible.

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Enhance and protect refuge habitat: Waterbird refuge

Basin Annual Environmental Watering Priority

Maintain waterbird habitat, including refuge sites, and food sources, to support waterbird populations across the Murray–Darling Basin. Support waterbird breeding where feasible.

Expected benefits

It is anticipated that maintaining waterbird habitat across the Murray–Darling Basin will contribute to the following benefits in 2014–15:

- maintain suitable habitat for colonially-nesting waterbirds, wading birds and migratory shorebirds (herein collectively referred to as waterbirds)
- assist waterbird populations to build resilience to endure future extended dry periods and capitalise on flooding periods
- identify and maintain a viable mosaic of wetlands for waterbirds
- maintain refuge sites for waterbirds
- respond to opportunistic waterbird breeding events and provide suitable management support subject to resource availability.

Why is this of Basin significance?

This is important at a Basin-scale because:

- river regulation and drying conditions have resulted in a long-term decline in waterbird habitat extent and condition
- the loss of waterbird habitat has caused a widespread decline in waterbird numbers
- enhancing and protecting refuge habitat for waterbirds provides opportunities to build resilience in waterbird populations (so they can endure future extended dry periods); while supporting flooding events where appropriate will assist with breeding events.

Significance of waterbird habitat

Waterbirds depend on the availability of wetlands to provide suitable habitat for roosting and nesting, with abundant food resources and protection from predators. The Murray–Darling Basin has 19 major catchments and tens of thousands of wetlands that provide food, shelter and breeding opportunities that support colonial nesting waterbirds, rare wading birds and many other waterbirds. The Coorong in South Australia is the only coastal wetland in the Murray–Darling Basin and provides important non-breeding habitats for migratory shorebirds (Rogers and Paton 2009) as well as breeding habitat for some species (e.g. Australian pelicans).

River regulation and the associated reduction in variability and drying conditions have resulted in loss and degradation of viable waterbird habitat (Finlayson et al. 2005; Junk et al. 2013; Baker et al. 2004). This has caused a decline in the condition of viable habitats for waterbirds and reduced their capacity to endure dry conditions and breed during floods.

Remnant wetlands have become smaller and more isolated; and the total area of habitat available in the Basin has been reduced. During dry periods the availability of wetlands that provide food resources and good quality habitat has become restricted to a handful of refuge sites. Further decline in habitat quality and availability are possible as another dry phase is forecast for the

Murray–Darling Basin. The continuing loss of wetland habitat is of conservation concern for the future condition of waterbird populations (Hagemeijer 2006).

Refuge sites are vital for waterbirds to survive dry times. The availability, size and spatial distribution of refuge sites during dry periods have a strong influence not just on individual survival, but on the nature and rate of subsequent population recovery after the dry period breaks (Magoulick and Kobza 2003).

Condition of waterbird populations

Colonial nesting waterbirds and rare wading birds

Aerial waterbird surveys of eastern Australia have been conducted since 1983. Results indicate a long-term decline in the abundance of waterbirds along with a reduction in wetland area (Kingsford and Porter 2009; Porter and Kingsford 2013). Following high rainfall events in 2010, there was an increase in waterbird numbers and wetland area in 2011 and 2012 (Figures 19 and 20). Wetland area, and subsequently total number of waterbirds, declined considerably in 2013, compared to the previous year.

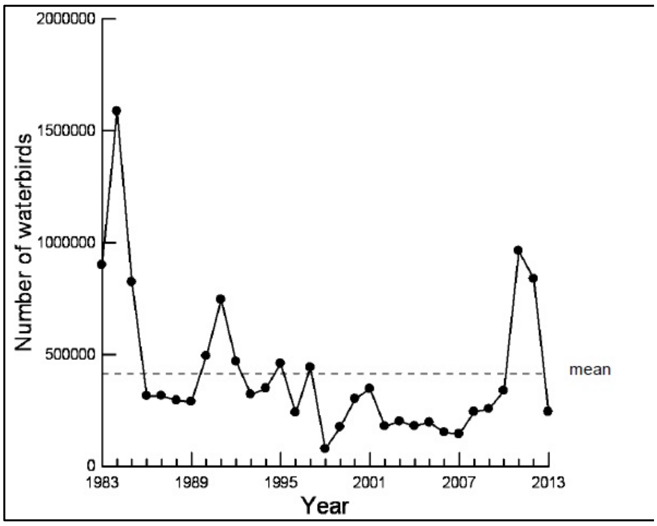

Figure 19 Wetland area in eastern Australia over time (Porter and Kingsford 2013)

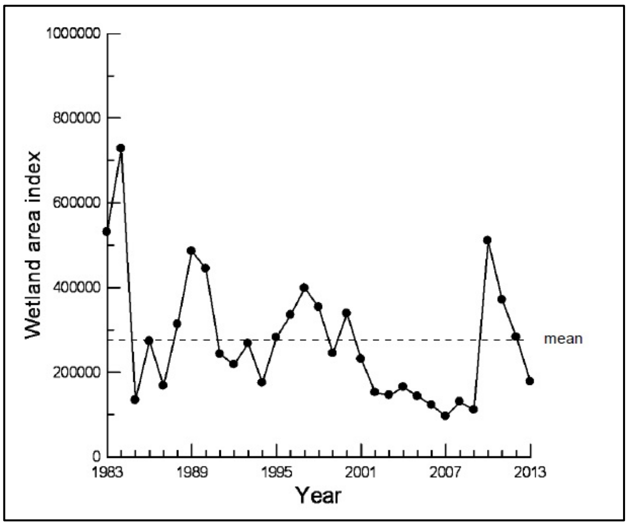

Figure 20 Waterbird abundance in eastern Australia over time (Porter and Kingsford 2013)

Migratory shorebirds

The sharp-tailed sandpiper, red-necked stint and curlew sandpiper are three common migratory shorebirds found in the Coorong. Comparison of annual counts conducted between 2000–2007 with counts in 1985, showed an overall decline in abundance (Figure 21) (Rogers and Paton 2009).

Rates of decline in abundance of red-necked stint and curlew sandpiper have intensified in recent years — some species are rarely recorded in parts of the Coorong where they were considered common in the 1980s (Rogers and Paton 2009). There have also been long-term declines in shorebirds across eastern Australia (Nebel et al. 2008).

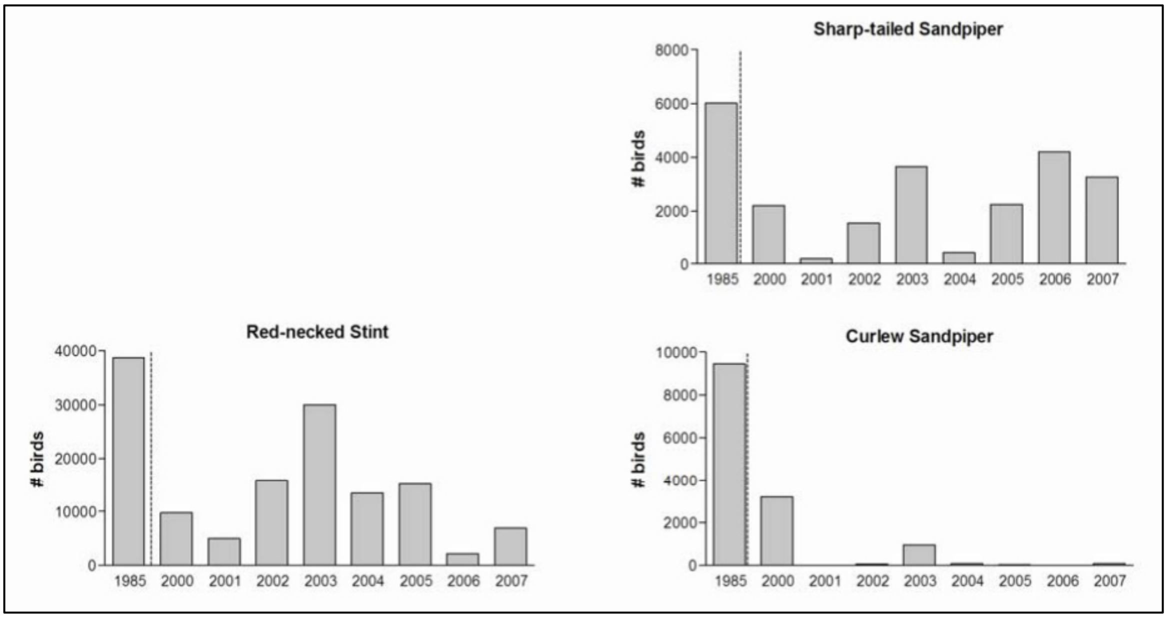

Figure 21 The abundance of sharp-tailed sandpipers, red-necked stints and curlew sandpipers in the Coorong South Lagoon in January 1985 and the period of 2000–2007 (Rogers and Paton 2009)

There are three possible drivers that determine waterbird abundance within moderate–dry resource availability scenarios. These drivers include:

- local changes in habitat and food resources (Halse et al. 1993; Kingsford 1993; Kingsford and Porter 1994; Timms 1997)
- presence of persistent and temporary wetlands (Maher 1991; Maher and Braithwaite, 1992)
- response to an increase or decrease in habitat availability in the Lake Eyre catchment (Kingsford and Porter 1993; Kingsford et al. 2009).

Matters of interest

Habitat for waterbirds

Colonial nesting waterbirds and rare wading birds are highly mobile and use a wide variety of habitats, ranging from: swamps, lagoons, freshwater lakes, estuaries, rivers, dams and on-farm storages; to irrigated fields, sewage treatment works and floodplains (Kingsford and Norman 2002). Vegetation such as lignum, trees, dense reed beds and wet grassland play an important role in providing refuge habitat, nest sites and nesting material. Breeding has been observed primarily during widespread flooding on the large wetland complexes that occur at the lower reaches of major rivers (Kingsford et al. 2013).

Migratory shorebirds are commonly found on coastal mudflats, estuaries, shorelines and inland wetlands (Watkins 1993); where there is available food and some areas of low vegetation to afford protection from predators (Straw and Saintilan 2005). Coastal wetlands such as the Coorong provide important refuge habitat for shorebirds (Rogers and Paton 2009).

Overall, areas with good habitat condition and food resources are most likely to host the majority of waterbirds during adverse conditions (R Kingsford 2014, pers. comm. 5th May). Given the broad range of habitat requirements for waterbirds a mosaic of good quality habitat is important to sustain the presence of diverse and abundant waterbird communities in the Murray–Darling Basin.

Mosaic of persistent and temporary wetlands

A mosaic of wetland habitats is an important determinant of waterbird distribution and abundance at a Basin-scale (Brandis et al. 2009) and may aid the resilience of waterbird populations (Maher and Braithwaite 1992; Kingsford and Porter 1993; Kingsford 1995). Many waterbird species use different habitats for feeding, resting, roosting and breeding and must move between them to survive, reproduce and recruit (Maher and Braithwaite 1992; Haig et al. 1998; Halse et al. 1998).

The ability of individuals to move between resource patches is determined by how ecologically linked that habitat is to its current location (Taylor et al. 1993; Green 1994; Cantwell and Forman 1993; Keitt et al. 1997). Ecologically linked wetlands provide roosting habitats and foraging habitats (see 2013–14 Priority: '*Improve the resilience of colonial waterbird populations by supporting breeding events and improving breeding habitat in the Northern Basin wetlands*'). This reduces the energy expended travelling between wetlands (Rogers et al. 2006). For example, shorebird abundance on inland wetlands has been positively correlated to distance from the Murray Mouth (Paton et al. 2009).

Descriptions of key areas for waterbirds

The sites selected are not an exclusive nor exhaustive list of all important sites in the regulated rivers of the Murray–Darling Basin.

Key wetlands are:

- the Macquarie Marshes, Gwydir Wetlands, the Narran Lakes, Barmah–Millewa Forest
- the Lowbidgee wetlands
- the mid–Murrumbidgee wetlands
- Kerang wetlands
- Menindee Lakes
- Darling Anabranch
- Talyawalka Anabranch
- the lower Lachlan wetlands and the Coorong (these are considered to be key wetlands; they provide large expanses of wetland that function for feeding, roosting and breeding for waterbirds).

Smaller wetlands or lakes which are ecologically linked to the key wetlands and have the highest potential to form a network of refuge habitat could include:

- Murrumbigil Swamp/Lake Merrimajeel, Booligal Swamp and Merrowie Creek in the Lachlan Catchment
- North Redbank wetland system and Fivebough swamp in the Murrumbidgee
- Reedy Swamp and Broken wetlands in the Goulburn Broken
- Thegoa Lagoon in the Murray/Lower Darling
- Lake Murphy, Hird Swamp, Boort wetlands and Round Lake in the Loddon

These wetlands act as sites for feeding and refuge for non-breeding waterbirds. Further, the wetter periods between 2010 and 2012 stimulated early-stage vegetation recovery; which now requires follow-up flows to continue.

Implementation

Implementation of this Priority will improve the resilience of wetland vegetation and expand the network of good condition refuge habitat for waterbirds to withstand future dry periods. It will also support the opportunity for breeding events. Environmental water is required to build on the ongoing recovery of vegetation and prevent further decline in stressed wetland vegetation communities. This becomes particularly important if the system enters a drier period and environmental deliveries are required to prevent refuge sites from drying out completely.

The Resource Availability Scenario may change over the course of 2014–15 and the level of hydrological connectivity and inundation will vary with different inflow scenarios. In wet to very wet scenarios, unregulated flow will achieve the Priority. In moderate to dry scenarios a combination of unregulated flow and held environmental water can be delivered to prepare a series of refuge and breeding habitats, and support breeding events. In very dry scenarios, held environmental water will be required to maintain the condition of refuge habitat.

Coordination of flows

Coordinated watering of ecologically-linked wetlands will provide opportunities to prepare a mosaic of habitat options for waterbirds. This builds on the 2013–14 Priority: '*Improve the resilience of colonial waterbird populations by supporting breeding events and improving breeding habitat in the Northern Basin wetlands*'. In this Priority, the Macquarie Marshes, Gwydir wetlands and the Narran Lakes were listed for their geographical proximity and potential to support major waterbird breeding events. Increasing seasonally-appropriate flow variability will trigger waterbird movement between these wetlands for feeding and roosting or breeding (see Strategy: *Maximise environmental benefits by managing water in harmony with natural cues*).

In the case where a bird breeding event commences, environmental managers should consider the feasibility of delivering environmental water to see this event to completion. Where it is not feasible to deliver environmental water, it may be pertinent to take management steps to ensure breeding is not initiated; or if it does occur, to encourage early abandonment.

Through collaboration it is possible to deliver water to multiple sites that are hydrologically linked and provide support to a mosaic of habitats for waterbirds. This will maintain or extend inundation to a group of key sites and facilitate the dispersal of nutrients within the system to maintain food chains.

Other activities

This Priority builds upon and complements the implementation of the following Priorities for 2014–15 which focus on supporting ecosystem functions and the continued maintenance of a mosaic of refuge habitats. These Priorities are to:

- improve the condition and maintain the extent of wetland vegetation communities in the Gwydir Wetlands (including Ramsar sites) by restoring hydrological connectivity and a flow regime that meets ecological requirements
- improve the condition of wetland vegetation communities in the mid-Murrumbidgee wetlands through a winter or spring fresh
- improve native fish habitat within the Macquarie River below Burrendong Dam by restoring a more natural flow regime and managing cold water pollution

- improve riparian, littoral and aquatic vegetation (e.g. Ruppia tuberosa) and native fish populations by increasing ecosystem connectivity through coordinating water delivery in the River Murray system.

Other proposed waterings in 2014–15 to meet varying ecological objectives, subject to water availability, have the capacity to also maintain waterbird habitat and support any breeding which may occur across the Murray–Darling Basin. Examples include:

- a spring pulse flow in the Lachlan River to stimulate an ecological response for native fish and increase end of system flows to improve the condition of wetland habitat
- an autumn–spring flow in the Macquarie Marshes to maintain the resilience of permanent and semi-permanent wetland vegetation
- a flow into Barmah Forest to support native fish populations and enhance vegetation health, particularly targeting moira grass recruitment
- spring–summer flows to Hird Swamp to promote a natural drying phase over summer and reinstate more natural variable flows
- in-channel flows in the River Murray for ecological functions and enhance habitat in the Coorong, Lower Lakes and Murray Mouth.

Coordination and collaboration between water managers across the Basin is important to achieve multiple outcomes and achieve whole-of-system benefits (see Strategy: *Maximise environmental benefits by coordinating and collaborating through effective governance arrangements*).

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