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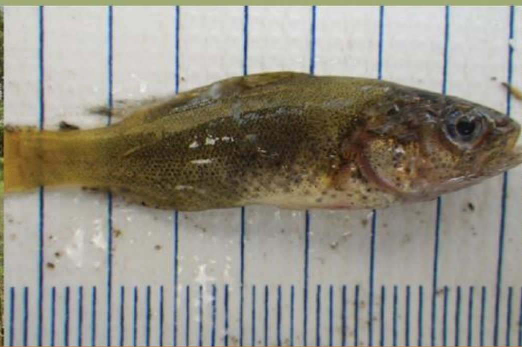


# Murrumbidgee Selected Area Monitoring and Evaluation Plan. Revised 2018

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Piggery Lake - Lowbidgee floodplain

# Contents

# 1 Introduction

The Commonwealth Environmental Water Holder (CEWH) is responsible under the *Water Act 2007* (Cth) for managing Commonwealth environmental water holdings. The holdings must be managed to protect or restore the environmental assets of the Murray-Darling Basin, and other areas where the Commonwealth holds water, so as to give effect to relevant international agreements. The Basin Plan (2012) further requires that the holdings must be managed in a way that is consistent with the Basin Plan's Environmental Watering Plan. The *Water Act 2007* (Cth) and the Basin Plan also impose obligations to report on the contribution of Commonwealth environmental water to the environmental objectives of the Basin Plan.

Monitoring and evaluation are critical for supporting effective and efficient use of Commonwealth environmental water. They provide important information to support the CEWH to meet their reporting obligations in addition to demonstrating overall effectiveness at achieving ecological objectives.

The Long-Term Intervention Monitoring Project (LTIM Project) is the primary means by which the Commonwealth Environmental Water Office (CEWO) will undertake monitoring and evaluation of the ecological outcomes of Commonwealth environmental watering. The LTIM Project will be implemented at seven Selected Areas over a five year period from 2014-15 to 2018-19 to deliver five high-level outcomes (in order of priority):

- Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan
- Evaluate the ecological outcomes of Commonwealth environmental watering at each of the seven Selected Areas
- Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin not monitored
- Support the adaptive management of Commonwealth environmental water
- Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

This Monitoring and Evaluation Plan (M&E Plan) details the monitoring and evaluation activities that will be implemented under the LTIM Project for the **Murrumbidgee Selected Area**. This M&E Plan includes:

- A description of the Selected Area including hydrological zones
- Evaluation questions relevant to the Selected Area
- Monitoring indicator methods and protocols
- A monitoring schedule
- Evaluation methods and protocols
- A communication and engagement plan

The project management plan, risk assessment, quality planning; and health, safety and environmental plans are provided as standalone documents.

## 1.1 About this M&E Plan

The Murrumbidgee catchment in southern NSW is one of the largest river catchments in the Murray-Darling Basin (MDB) (87,348 $km^2$). The Murrumbidgee River is one the most regulated rivers in Australia, controlled by multiple major reservoirs including the Snowy Mountains Hydro-electric Scheme, the Australian Capital Territory (ACT) Water Supply Scheme, and, in NSW, primarily by two large dams: Burrinjuck Dam (1,026,000 ML capacity, operational in 1911) on the Murrumbidgee River and Blowering Dam (part of the Snowy River scheme)(1,628,000 ML capacity, operational since 1968) on the Tumut River (CSIRO 2008b). The Murrumbidgee has an extremely high level of water resource development with an average diversion rate of 53% (2257 GL/year) of all available water (CSIRO 2008b).

Environmental water holdings in the Murrumbidgee Selected Area are significant, with Commonwealth water holdings of 234,067 ML general security and 173,000 ML (long-term allocation of supplementary water in the Nimmie-Caira) and NSW environmental water holdings (including both licensed water and Adaptive Environmental Water) of 238,355 ML, giving a combined environmental water holding of over 497,000 ML (assuming long-term average allocations and up to 705,000ML with full allocation). Infrastructure for the delivery of environmental water through weirs, dams, regulators and re-diversion is well developed, allowing environmental watering actions to continue to some sites in drought conditions (e.g. Wassens, Arnaiz *et al*. 2008).

The Murrumbidgee Selected Area covers the lowland section of the Murrumbidgee catchment and largely encompasses the Murrumbidgee portion of the "aquatic endangered ecological community of the Natural Drainage System of the Lower Murray River Catchment", identified under the (*Fisheries Management Act 1994* (NSW)). The Selected Area contains three significant regions: the Murrumbidgee River main channel, the mid-Murrumbidgee wetlands and the Lowbidgee floodplain. The Murrumbidgee Selected Area provides critical habitats for a number of federally-listed endangered species, including trout cod (*Maccullochella macquariensis*), Murray cod (*Maccullochella peelii*), silver perch (*Bidyanus bidyanus*), Macquarie perch (*Macquaria australasica)*, southern bell frog (*Litoria raniformis*) and vulnerable fishing bat *(Myotis macropus)* (Commonwealth Environment Protection and Biodiversity Conservation Act, 1999 - EPBC). The Lowbidgee floodplain also contains some of the Murray-Darling Basin's largest breeding sites for colonially-nesting waterbirds and waterbird species listed under bilateral migratory bird agreements that Australia has signed with Japan (*Japan-Australia migratory bird agreement (JAMBA), 1974*), China (*China-Australia migratory bird agreement (CAMBA), 1986*) and the Republic of Korea (*Republic of Korea- Australia migratory bird agreement (ROKAMBA), 2007*).

This M&E Plan has been developed to provide a comprehensive, hypothesis driven monitoring program, capable of supporting adaptive management and Basin wide evaluation in the Murrumbidgee Selected Area. The plan takes into account the significant environmental water holdings in the Selected Area, flexible delivery options and high diversity of important aquatic habitats. The focus of the monitoring and evaluation plan is on large-scale cost-effective monitoring activities, rather than intensive small scale monitoring within a single habitat type. The benefit of the large-scale approach is that it provides a more robust framework upon which to base Selected Area evaluation of the contribution of Commonwealth environmental water.

## 1.2 M&E Plan development and rational

The M&E Plan has been developed to follow five guiding principles of the Outcomes Framework which underpins the management of Commonwealth environmental water (Commonwealth Environmental Water 2013):

***The need to provide a robust evaluation of the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan:***

- To protect and restore water-dependent ecosystems of the Basin;
- To protect and restore the ecosystem functions of water-dependent ecosystems;
- To ensure that water-dependent ecosystems are resilient to risks and threats; and
- To ensure that environmental watering is coordinated between managers of planned environmental water, owners and managers of environmental assets, and holders of held environmental water.

***Acquire the capacity to evaluate ecological outcomes of Commonwealth environmental watering in the Murrumbidgee Selected Area.***

The evaluation approach for the M&E Plan is outlined in section 4. We have developed the M&E Plan to evaluate the ecological outcomes of Commonwealth environmental water for each individual indicator. In addition Selected Area evaluation of key ecological responses is based on a series of statistical process models designed to quantify the relative contribution of Commonwealth environmental water along with that of key covariates as described in the Cause-Effect-Diagrams (CEDs) (MDFRC 2013). By focusing monitoring activities and the selection of covariates on the CEDs we are better able to make predictions and evaluate expected outcomes for the wide range of flow objectives expected to occur through the Murrumbidgee Selected Area over the course of the LTIM Project program.

***Develop and inform robust models that can infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin.***

The M&E Plan framework has been established to evaluate relationships and patterns that have generality and transferability at two spatial scales. At the basin scale the M&E Plan will contribute data to Basin evaluations undertaken by The Murray-Darling Freshwater Research Centre (MDFRC), within the Murrumbidgee Selected Area the M&E Plan has been established to enable ecological outcomes to be inferred across to unmonitored wetlands within zones. This is achieved by maintaining sufficient replication within each of the target zones to account for spatial variability, allowing for cross validation and testing of modelled predictions.

***Support the adaptive management of Commonwealth environmental water.***

A key goal of the Murray-Darling Basin Authority's (MDBA) Environmental Watering Plan is to "*ensure that environmental watering is coordinated between managers of planned environmental water, owners and managers of environmental assets, and holders of held environmental water*". This plan has been developed in consultation with NSW environmental water managers, landholders and managers of NSW and Commonwealth estates, including the Murrumbidgee Valley National and Regional Parks, Yanga National Park and Nature Reserve, and the Nimmie-Caira System Enhanced Environmental Water Delivery Project.

In highly regulated systems, such as the Lowbidgee floodplain, water is actively managed in order to achieve the desired ecological objectives, and monitoring is a critical component of this process. Active water management is particularly important in supporting waterbird breeding. For example, the Nimmie-Caira floodplain supports some of Australia's largest breeding colonies of Straw-necked ibis that are particularly sensitive to sudden changes in water level around their nests. Information on the status of nesting birds and water levels is needed during breeding events to support real-time adaptive management of environmental water (Brandis, Ryall *et al*. 2011a). In recent water years, the Redbank system's egret and cormorant colonies in Yanga National Park were initiated and successfully managed using Commonwealth and NSW environmental water, with monitoring actions playing a critical role in informing the need for top-up flows (Childs, Webster *et al*. 2010). Top-up flows are also critical in maintaining successful breeding by the vulnerable southern bell frog across the Lowbidgee floodplain. During return flows, monitoring activities are also critical in providing real time information on risks associated with hypoxic black water, exotic fish movement into the river channel, as well as identifying needs for returns and reconnection flows when significant recruitment of native fish is observed on floodplains. Adaptive management and frequent communication between Monitoring and Evaluation Providers (M&E Providers) and a range of stakeholders are critical for the success of environmental watering actions.

# 2 Murrumbidgee Selected Area

Wetlands make up over 4% (370,000 ha) of the Murrumbidgee Catchment, with over 1000 wetlands identified (Murray 2008). Nationally important wetlands, including the mid-Murrumbidgee and Lowbidgee floodplain, cover over 208,000 ha (2.5% of the catchment area). For the purposes of the assessment of environmental water requirements and identification of monitoring zones, three key areas are identified in the Murrumbidgee Monitoring and Evaluation Plan (Gawne, Brooks *et al*. 2013a). Each area is identified by the MDBA as a "*key environmental asset within the Basin*" and "*important site for the determination of the environmental water requirements of the Basin*". They are:

- The Lower Murrumbidgee River (in-channel flows) (Murray-Darling Basin Authority 2012a),
- The mid-Murrumbidgee River wetlands (Murray-Darling Basin Authority 2012b), and
- The lower Murrumbidgee floodplain (Murray-Darling Basin Authority 2012c).

## 2.1 Zones

Monitoring zones represent areas with common ecological and hydrological attributes. We identified separate zones for riverine and wetland habitats across the Murrumbidgee Selected Area. In most cases, we aimed to align zones with existing classifications by MDBA and NSW Office of Environment and Heritage (NSW OEH). In order to align closely with established management units across the Murrumbidgee Selected Area, we have taken a broad scale approach to the selection of zones, focusing on large scale differences in hydrology, vegetation and faunal communities. It is noted that our zones cover large areas, and, in the case of wetland zones, there remains considerable heterogeneity within as well as between zones. As a result, higher levels of replicate monitoring locations are required in some zones to enable statistical evaluation of ecological outcomes.

### *Riverine zones*

The Murrumbidgee River is over 1600 km long, with the LTIM Project Selected Area covering the lowland section (approximately 786km). In the Murrumbidgee River we have identified three zones that have a degree of hydrological uniformity that can be accurately estimated using the existing gauge network. The zone classification also takes into account key inflows (tributaries) and outflows (distributaries and irrigation canals) (Figure 1).

- **Narrandera reach (187.3 km)** – Includes major irrigation off-takes, also key populations of Murray Cod
- **Carrathool reach (358.0 km)** – Downstream of Tom Bullen storage and major irrigation off-takes, reduced influence of irrigation flows, principle target for in-channel Commonwealth environmental watering actions, partly affected by hypoxic blackwater in 2010-11
- **Balranald reach (241.4 km)** – Aligns with the Lowbidgee floodplain, impacted by hypoxic black water in 2010-11 resulting in reduced abundance of large-bodied native fish

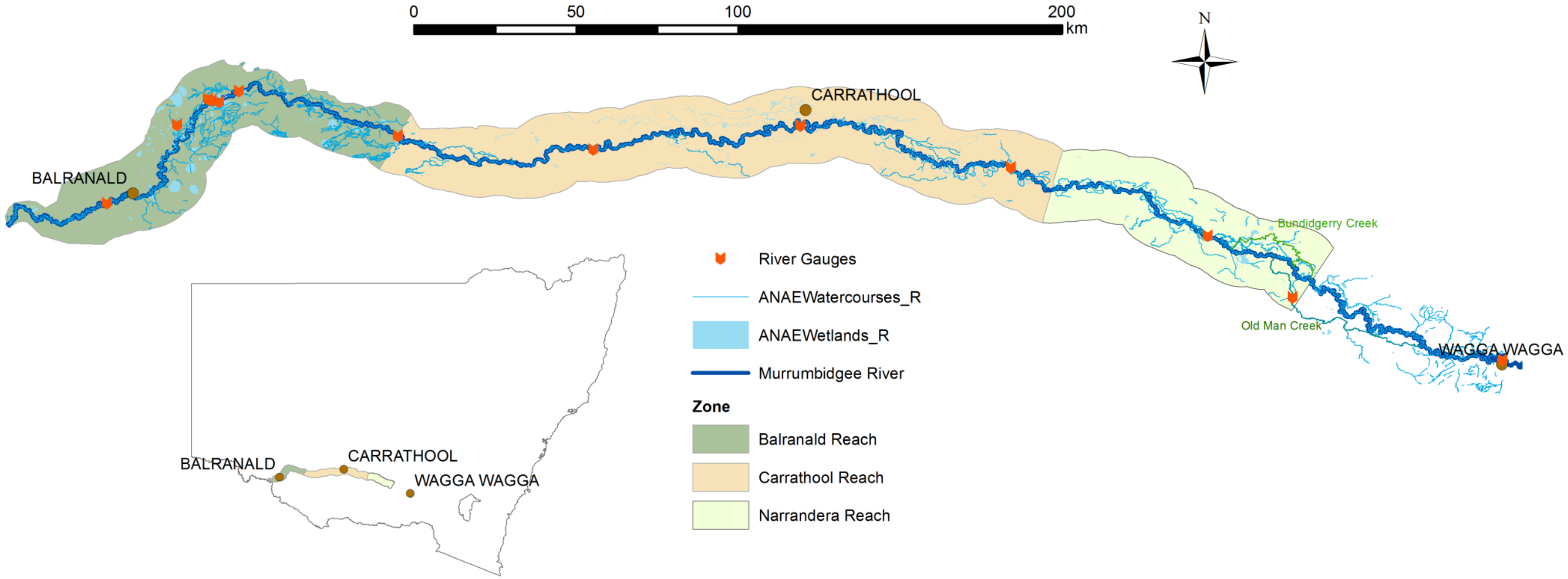


Figure 1 Distribution of riverine zones in the Murrumbidgee Selected Area.

### *Wetland zones*

Identification of zones across floodplain habitat is more complex than in riverine systems, due to the diversity of aquatic habits, complexity of hydrological regimes (spatiotemporal variability of flows), diversity of vegetation types and presence of flow control structures (water management units). Ultimately we opted for very broad zones, dominant vegetation type, faunal communities and expected ecological responses. These align with the management units identified by NSW OEH and are recognised by MDBA and CEWO. Zones were classified for the two key regions: the mid-Murrumbidgee River (Murray 2008) and the lower Murrumbidgee floodplain (Murrumbidgee Catchment Management Authority 2009). See Table 2 for a list of key wetlands in each zone.

These regions are split into six broad zones (Figure 2):

- **mid-Murrumbidgee wetlands (82,800 ha)** – River red gum forest interspersed with paleochannels and oxbow lagoons
- **Pimpara–Wagourah (55,451 ha)** – Mosaic of creek lines, paleochannels and wetlands, with River red gum and black box mostly north of the Murrumbidgee River
- **Redbank (92,504 ha)** – Mosaic of river red gum forest and woodland, spike rush wetlands - divided into two management subzones (north and south Redbank)
- **Nimmie-Caira (98,138 ha)** – Mosaic of creek lines, paleochannels, open wetlands and lakes dominated by lignum and lignum-black box communities
- **Fiddlers-Uara (75,285 ha)** – Paleochannels and creek lines bordered by black box
- **The Western Lakes (3459 ha)** – Open quaternary lakes with inactive lunettes west of the Lowbidgee floodplain

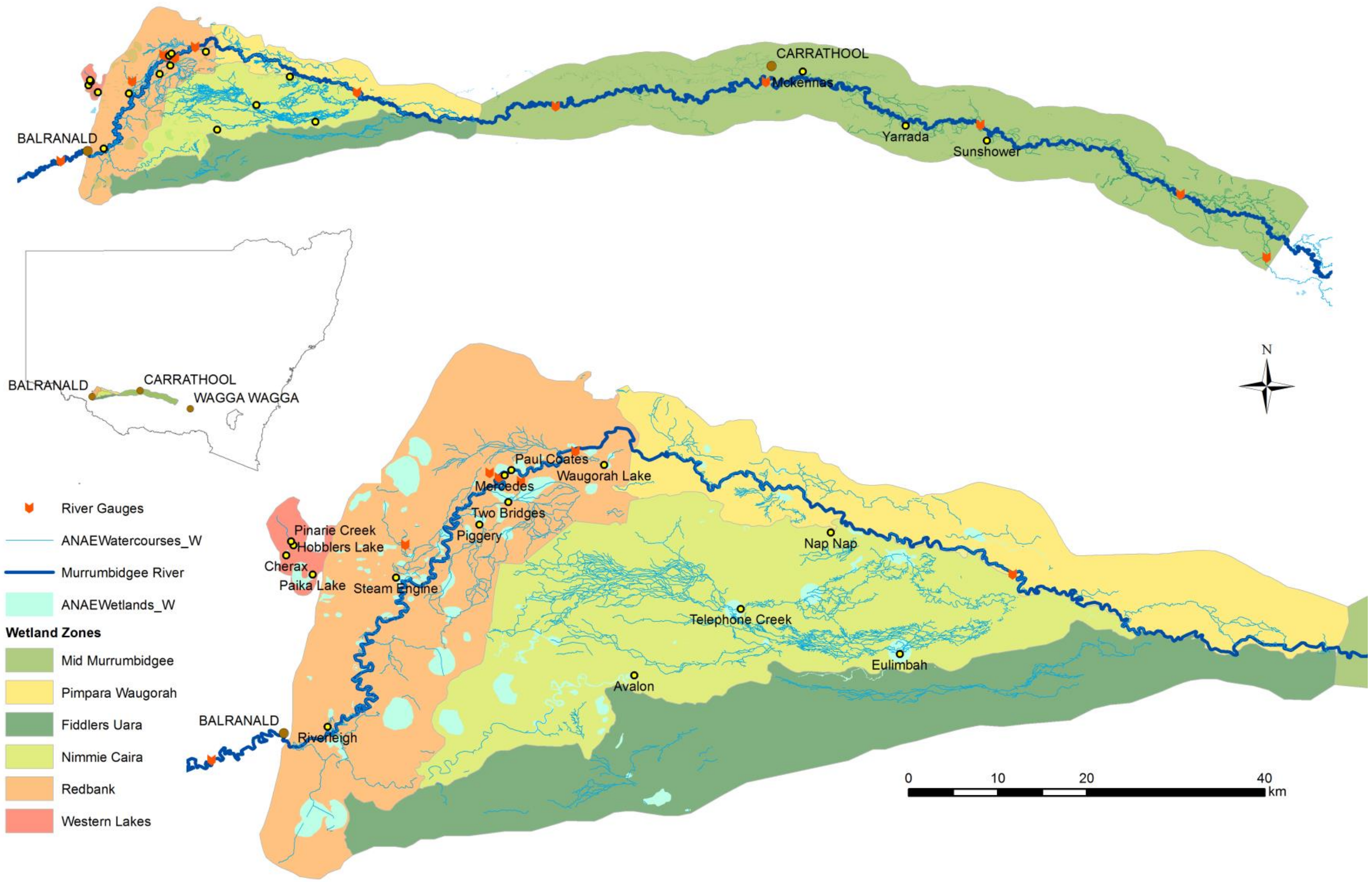


Figure 2 Distribution of wetland zones in the Murrumbidgee Selected Area and locations of key wetlands.

# 3 Commonwealth environmental watering

The Commonwealth Environmental Water Office manages environmental water in the Murrumbidgee Catchment in partnership with the MDBA, NSW OEH (including the National Parks and Wildlife Service), NSW State Water Corporation, NSW Office of Water, the Murrumbidgee Local Land Services (formerly the Catchment Management Authority), the Murrumbidgee Environmental Water Allowance Reference Group, and local land managers and water users. Multiple large scale watering actions have been undertaken for the past decade with the use of substantial Commonwealth and NSW environmental water holdings see Table 1. These normally include a combination of flows targeting a range of aquatic habitats, to address unique ecological objectives. For example: in-channel flows in the Murrumbidgee River; wetland watering actions across multiple zones within the Lowbidgee floodplain; in-channel flows managed to allow for connection to the mid-Murrumbidgee wetlands; reconnection flows to the mid-Murrumbidgee River from the wetlands; and in-channel freshes managed as piggy-back flows associated with The Living Murray (TLM) releases or periods of tributary inflows. In any given water year, Commonwealth watering options and related monitoring activities are required to be flexible to accommodate changing flow priorities and climatic conditions, opportunities and risks.

In the Murrumbidgee, there is considerable public scrutiny of Commonwealth watering actions and risk management during environmental flows. In particular management of hypoxic black water, algal blooms and taste and odour issues (real or perceived) is critical. Likewise flows across the Lowbidgee floodplain are highly regulated and managed. While the presence of extensive infrastructure provides significant flexibility in water actions in a given year, it also requires high levels of adaptive management with top-up flows frequently required to sustain waterbird and southern bell frog breeding across the floodplain.

## 3.1 Hydrology of the Murrumbidgee Selected Area

The Murrumbidgee River and connected wetlands receive regular inflows as a result of spring snow melt and rainfall in the upper catchment (Murray 2008) (Figure 3). Prior to the millennium drought, the majority of wetlands through the mid-Murrumbidgee were considered to be permanent, with others exhibiting fluctuating seasonal water levels that rarely resulted in complete drying (Chessman 2003). Likewise, the Lowbidgee floodplain received considerable inundation each year with overbank flows in spring and summer maintaining over 200,000 ha of lignum, black box and river red gum wetland complexes (Kingsford and Thomas 2001).

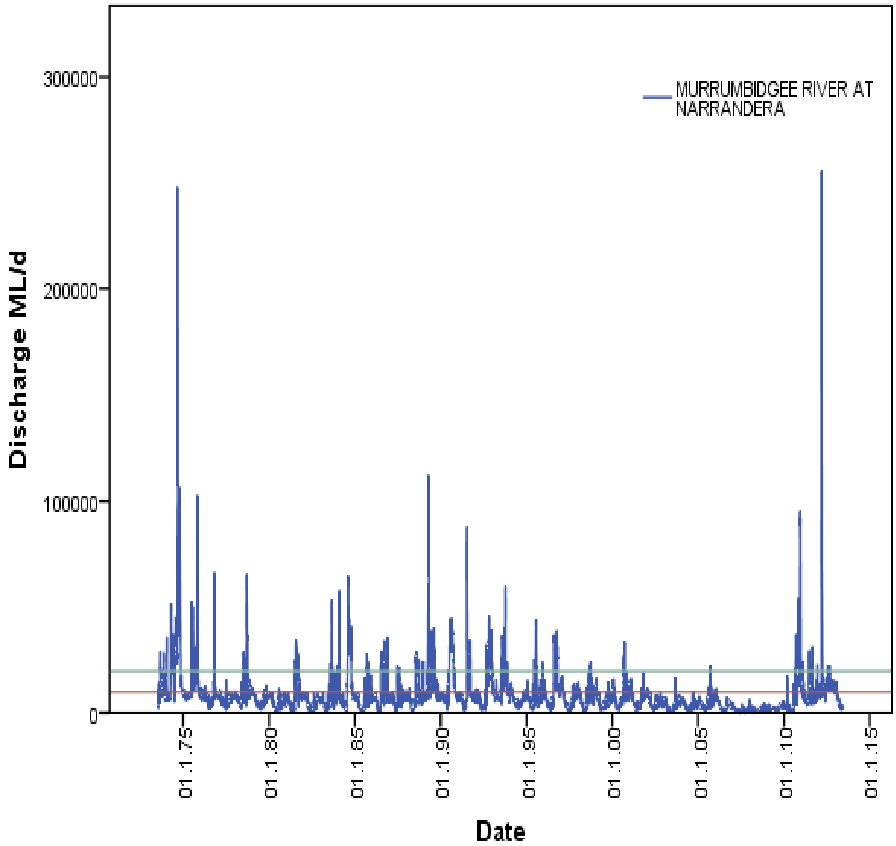


Figure 3 Flows in the Murrumbidgee Selected Area between 1973 and 2013. Green line indicates commence to fill for mid-Murrumbidgee wetlands. Red line indicates natural overbank flows into Lowbidgee. Note that infrastructure facilitated delivery can occur at times of very low flows in the Lowbidgee and is largely independent of discharge.

## 3.2 Water holdings in the Murrumbidgee Selected Area

River regulation and consumptive water use in the Murrumbidgee has reduced water flows into both the mid-Murrumbidgee wetlands and Lowbidgee floodplain and altered the seasonality of riverine flow peaks. However, the combined Commonwealth and NSW environmental water holdings are significant (Table 1) with over **690,000 ML** of combined Commonwealth and NSW water holdings. In combination with the substantial investment in infrastructure to assist in the delivery of environmental water under the NSW Rivers Environmental Restoration Program (RERP) these water holdings are expected to make significant progress toward restoring key beneficial attributes of the hydrograph and reducing the frequency on extreme drying events.

Table 1 Summary of Commonwealth and NSW environmental watering holdings: For modifications see: http://www.environment.gov.au/topics/water/commonwealth-environmental-water-office/southern-catchments/murrumbidgee

| **Account** | **Security** | **Registered entitlements (ML)** |
|---|---|---|
| Environmental Water Allowance (EWA) | EWA[1] | 50,000 |
| NSW Environmental Water Holdings (EWH) | General | 22,676 |
| | Unregulated (event based) | 5,937 |
| | Supplementary access | 5,679 |
| Commonwealth Environmental Water (CEW) | High | 5,125 |
| | General | 205,308 |
| | Unregulated (event based) | 164 |
| | Supplementary access | 20,820 |
| | Conveyance | 8,856 |
| | Nimmie-Caira supplementary water (Lowbidgee) access licence (long-term annual diversions)(pending transfer to CEWO) | 381,000 (173,000long-term average allocation) |
| **Total availability ( full allocation)** | | **705,565ML** |

### 3.2.1 History of Commonwealth environmental water use in the Murrumbidgee Selected Area

In this section we consider the range of watering actions that have been undertaken using Commonwealth environmental water since 2011 as a means of identifying the likely scope of watering actions expected in a given year.

**2011-12**

There were two major watering actions undertaken in 2011-12 in the Murrumbidgee Selected Area, the mid-Murrumbidgee reconnection flow and a series of watering events culminating in a full system watering of the North Redbank system on the Lowbidgee floodplain.

***Mid-Murrumbidgee reconnection flow***

The 2011-12 major watering action targeted the mid-Murrumbidgee wetlands in June 2011, and involved nearly 161 GL comprising of 110 GL of Commonwealth environmental water, 23 GL from The Living Murray, 21 GL from New South Wales Environmental Water Allowance and 8 GL from private donations. The water was released from Burrinjuck and Blowering Dams with the environmental flow reaching a maximum daily discharge of 24,908 ML/day in the Murrumbidgee River downstream of Burrinjuck Dam on 17$^{th}$ June 2011 and 9,492 ML/day in the Tumut River downstream of Blowering Dam on 16$^{th}$ June 2011. In December 2011 further releases were made from the Burrinjuck Dam and Tombullen storage totalling 98,175 ML, which further inundated a sub-set of wetlands in the mid-Murrumbidgee.

***North Redbank watering***

In the latter part of 2011 and into 2012, three Commonwealth environmental watering events were undertaken in the lower Murrumbidgee River channel and Lowbidgee wetlands. The first watering action involved an initial filling of the North Redbank wetlands using 20,200 ML of environmental water including 17,800 ML of Commonwealth and 2,400 ML of NSW environmental water to support wetland habitat and water dependent species. The second action involved a return flow using a controlled release from the lower North Redbank wetlands through an escape into the Murrumbidgee River channel during which time a series of smaller watering actions were undertaken a) 4,700 ML of Commonwealth environmental water was provided into the top of the North Redbank wetlands so water levels in the wetlands were maintained and; b) 33,700 ML of Commonwealth environmental water was provided in the Murrumbidgee River channel to dilute the carbon rich water from the North Redbank wetlands escape (Baupie Escape) and to promote spawning opportunities for small-bodied fish. The environmental watering was suspended from the end of February until mid May 2012, due to a large natural flood event. Environmental water was then delivered in the lower Murrumbidgee River after the peak of the flood had passed to improve water quality and therefore fish habitat. A total of 28,500 ML of environmental water was delivered (26,700 ML of Commonwealth environmental water with the remainder contributed by NSW).

### 2012-13

In 2012-13 six key watering options, targeting the Murrumbidgee River, Mid-Murrumbidgee wetlands, Lowbidgee and Western lakes were considered, and two watering actions were delivered (Options 1 and 5).

#### *Murrumbidgee River*

The watering action in the Murrumbidgee River channel (Option 1) commenced 10 October 2012 and was completed on 14 December 2012. The principle aim of the Commonwealth environmental watering action was to "*support the breeding and growth of native fish communities in the mid and lower Murrumbidgee River*". The total water estimate for this event was 240 GL, which was drawn from Commonwealth environmental water (150,000 ML), The Living Murray (45,000 ML) and NSW environmental water allocation (28,956.8 ML). The flow was delivered to maintain a constant river level at approximately 1/3 of bank full or 6,000 ML/day at Darlington Point to promote spawning, larval dispersal and survival of large bodied native fish and microcrustacea production. It is noted that this level is well below minor flood levels.

#### *Wetlands west of the Lowbidgee (Western Lakes)*

The principle objective of the Western Lakes watering action (Option 5) was to "*re-establish and maintain the health and regeneration of native plant communities, and to provide habitat for native animals including waterbirds, fish and frogs*". Western

Lakes watering commenced on 11 September 2012, the total water usage was 4,979 ML of Commonwealth environmental water and 194 ML from the NSW environmental water allocation for a total usage of 5,173 ML between 11 September and 17 December 2012. Flows were measured at the Glen Dee Gauge.

## 3.3 Practicalities of watering

### 3.3.1 Site selection and potential watering targets

There are over 2000 individual wetlands, creek lines and anabranches within the Murrumbidgee Selected Area (Murray 2008) as well as extensive areas within the Murrumbidgee River that can be targeted with Commonwealth environmental water. A list of key wetlands within each zone that that can feasibly be targeted with Commonwealth environmental water using existing infrastructure is contained in Table 2. On advice from the Commonwealth Environmental Water Office the Murrumbidgee Selected Area specifically excludes wetlands, creek lines and anabranches previously listed in the Murrumbidgee Monitoring and Evaluation requirements documents (Gawne, Brooks *et al*. 2013a) that do not fall within the mid-Murrumbidgee wetland classification zone, “other Murrumbidgee” including Mirrool Creek.

Table 2 List of key water bodies and complexes that have the potential to be targeted with Commonwealth environmental water during the LTIM Project period. Compiled from (Murray 2008, Murrumbidgee Catchment Management Authority 2009, Sinclair Knight Merz 2011, Hardwick and Maquire 2012, Murray-Darling Basin Authority 2012c, Spencer, Wassens *et al.* 2012, Wassens, Jenkins *et al.* 2014).

| zone | name | lat | long |
|---|---|---|---|
| Fiddlers-Uara | Fingerboards | -34.6604 | 143.7512 |
| | Fiddlers Creek | -34.596 | 144.289 |
| | Uara Creek | -34.5948 | 144.0211 |
| Mid-Murrumbidgee (see (Murray 2008) for full list of wetlands | Berry jerry | -35.0181 | 147.3470 |
| | Narrandera State Forest | -34.4417 | 146.3116 |
| | Tombullen Swamp | -34.642 | 146.141 |
| | Turkey Flats Swamp | -34.629 | 146.339 |
| | Yanco High School Lagoon | -34.6276 | 146.3943 |
| | Coonacoocabil Swamp West | -34.62 | 146.262 |
| | Sunshower Lagoon | -34.618 | 146.028 |
| | Coonacoocabil Swamp East | -34.618 | 146.292 |
| | Coonacoocabil Lagoon | -34.604 | 146.269 |
| | Gooragool Lagoon | -34.577 | 146.098 |
| | Yarrada Lagoon | -34.5695 | 145.815 |
| | Maude Weir Lagoon | -34.474 | 144.304 |
| | McKenna's Lagoon | -34.428 | 145.504 |
| Nimmie-Caira (see (Murrumbidgee Catchment Management Authority 2009) | Loorica Lake | -34.6154 | 143.8833 |
| | Avalon Swamp | -34.5827 | 143.9112 |
| | Tala Lake | -34.567 | 143.724 |
| | Woolshed Swamp | -34.5625 | 143.6692 |
| | Woolshed Creek | -34.5625 | 143.6692 |
| | Suicide Swamp | -34.5484 | 144.0685 |
| | Eulimbah Swamp | -34.5445 | 144.2021 |
| | Talpee Creek | -34.5426 | 143.7218 |
| | Tiger Swamp | -34.541 | 143.749 |
| | Nimmie Caira wetlands | -34.5389 | 144.0527 |
| | Telephone Bank Swamp | -34.5178 | 144.0127 |
| | Torry Plains | -34.51 | 144.062 |
| | Egret Swamp | -34.4859 | 143.6911 |
| | Nap Nap Swamp | -34.446 | 144.1691 |
| | Athen | -34.4419 | 143.7059 |
| | Narkungerie Swamp | -34.435 | 143.7525 |
| | Pelican Swamp | -34.427 | 143.931 |
| | Waugorah Creek | -34.3897 | 143.893 |

Table 2 (cont) List of key water bodies and complexes that have the potential to be targeted with Commonwealth environmental water during the LTIM Project period. Compiled from (Murray 2008, Murrumbidgee Catchment Management Authority 2009, Sinclair Knight Merz 2011, Hardwick and Maquire 2012, Murray-Darling Basin Authority 2012c, Spencer, Wassens *et al.* 2012, Wassens, Jenkins *et al.* 2014)

| zone | name | lat | long |
|---|---|---|---|
| Red bank (See (Murrumbidgee Catchment Management Authority 2009) for full list of wetlands | Yanga Lake | -34.7178 | 143.6003 |
| | Devils Creek | -34.6542 | 143.6201 |
| | Yanga Lake | -34.7178 | 143.6003 |
| | South Yanga | -34.672 | 143.659 |
| | Balranald Shire Common | -34.6368 | 143.581 |
| | Riverleigh | -34.6314 | 143.6112 |
| | Baupie | -34.6076 | 143.6201 |
| | Moola | -34.6006 | 143.6211 |
| | South Yanga National Park | -34.5891 | 143.6442 |
| | Glen Avon | -34.5702 | 143.6324 |
| | Springbank | -34.5466 | 143.6392 |
| | Breer Creek Swamp | -34.5331 | 143.7356 |
| | Murrundi | -34.5323 | 143.6516 |
| | Wynburn | -34.4881 | 143.6789 |
| | Breer Swamp | -34.4852 | 143.7237 |
| | River Smyths | -34.4822 | 143.7154 |
| | Narwie West | -34.4702 | 143.6613 |
| | Narwie | -34.4555 | 143.7212 |
| | Yanga National Park | -34.4409 | 143.7767 |
| | Tarwillie Swamp | -34.436 | 143.7874 |
| | Piggery Lake | -34.4212 | 143.7651 |
| | Twin Bridges | -34.4025 | 143.7917 |
| | Top Creek Swamp | -34.3919 | 143.8631 |
| | Top Narockwell | -34.3884 | 143.8184 |
| | Lake Meremley | -34.3855 | 143.6519 |
| | North Stallion Swamp | -34.3847 | 143.8998 |
| | Pococks Swamp | -34.3802 | 143.7833 |
| | Little Piggery | -34.379 | 143.7561 |
| | Waugorah Lake | -34.3668 | 143.8916 |
| | Shaws Swamp | -34.3557 | 143.8673 |
| | Juanbung Springdale | -34.355 | 143.841 |
| | Redbank System | -34.352 | 143.783 |
| | River Paddock Swamp | -34.3416 | 143.8929 |
| | Tala Lake | -34.567 | 143.724 |
| | Tala Swamp | -34.617 | 143.6735 |
| | Woolshed Swamp | -34.5625 | 143.6692 |
| | Woolshed Creek | -34.5625 | 143.6692 |
| Western Lakes | Paika Lake | -34.4809 | 143.5769 |
| | Paika East | -34.4808 | 143.5902 |
| | Paika Creek | -34.4715 | 143.601 |
| | Cherax Swamp | -34.455 | 143.567 |
| | Dundomallee Reserve Wetlands | -34.4279 | 143.6028 |
| | Hobblers Lake | -34.3333 | 143.8981 |
| | Penarie Creek | -34.2652 | 143.3413 |
| Other Murrumbidgee (Excluded from Murrumbidgee Selected Area) | Sandy Creek wetlands | -34.993 | 146.762 |
| | Molley's Lagoon | -34.721 | 146.3485 |
| | Gum Hole Lagoon | -34.7165 | 146.3589 |
| | Fivebough and Tuckerbil Swamps Ramsar site | -34.5302 | -34.4871 |
| | Thirty Mile Gums | -34.2182 | 145.1567 |
| | Campbells and Nericon Swamp | -34.217 | 146.033 |
| | Lower Mirrool Creek | -34.176 | 145.483 |
| | Barrenbox Swamp | -34.141 | 145.838 |

## 3.4 Flow management

Compared to other catchments in the Murray-Darling Basin, ecological characteristics and water requirements of aquatic communities in the Murrumbidgee Selected Area are well documented (CSIRO 2008a, Murray 2008, Sinclair Knight Merz 2011, Hardwick and Maquire 2012, Murray-Darling Basin Authority 2012b, Murray-Darling Basin Authority 2012a, Murray-Darling Basin Authority 2012c, Spencer, Wassens *et al*. 2012, Gawne, Brooks *et al*. 2013a, Gawne, Brooks *et al*. 2013b, Murray-Darling Basin Authority 2014). There is also a well established framework for environmental watering throughout the Murrumbidgee Selected Area with considerable investment in infrastructure-improved water management though the Lowbidgee floodplain under the RERP. In 2011 Sinclair Knight Mertz undertook a comprehensive assessment of water delivery options through the Murrumbidgee Selected Area, including detailing major infrastructure, and flow volumes required to fill key environmental assets (Sinclair Knight Merz 2011).

The MDBA's Basin Plan currently lists four major flow types that have been used to develop the sustainable diversion limit: Base flow, Freshes, Bank full, and Overbank (Gawne, Brooks *et al*. 2013b). In the Murrumbidgee Selected Area a range of capacity constraints limit the extent to which water levels in the Murrumbidgee River can be increased above 23,000 ML at Narrandera (Fresh) and Commonwealth and NSW watering options targeting the mid-Murrumbidgee wetlands typically focus on achieving 23,000 ML (1/3 bank full) to allow reconnections to important oxbow lagoons between Wagga Wagga and Carrathool. Across the Lowbidgee floodplain, there are also considerable opportunities to create infrastructure facilitated overbank flows through the Lowbidgee floodplain during both base flow conditions and even in dry years (e.g less than 20% of the Commonwealth's allocation as of 2011).

Due to the disconnect between flow types outlined in the Basin Plan and watering opportunities in the Murrumbidgee Selected Area the identification of Commonwealth and NSW environmental watering options are typically based on the Water allocations set by NSW Office of Water under the Murrumbidgee water sharing plan, a summary of the watering options with a given environmental watering allocation is provided in Table 3.

Table 3 Expected watering targets with given allocations set by NSW Office of Water each year (assumes infrastructure facilitated overbank flows in redneck, Nimmie-Caira, Fiddlers-Uara and Western Lakes)

| | | **Allocations** | | | |
|---|---|---|---|---|---|
| **Wetland zone** | **Example wetlands** | **<30% extreme drought)** | **20-50% (dry)** | **50-70% (average)** | **70-100% (Wet)** |
| Nimmie-Caira | Eulimbah Swamp | ■ | ■ | ■ | ■ |
| | Telephone Bank | ■ | ■ | ■ | ■ |
| | Suicide Bank | ■ | ■ | ■ | ■ |
| | Nap Nap Swamp | ■ | ■ | ■ | ■ |
| | Loorica Lake | | | ■ | ■ |
| | Avalon Swamp | ■ | ■ | ■ | ■ |
| Redbank | Two Bridges Swamp | ■ | ■ | ■ | ■ |
| | Tarwillie Swamp | | ■ | ■ | ■ |
| | Top Narockwell Swamp | | ■ | ■ | ■ |
| | Mercedes Swamp | ■ | ■ | ■ | ■ |
| | Breer Swamp | | ■ | ■ | ■ |
| | Egret Swamp/River Smyths | | | ■ | ■ |
| | Tala Swamp | | | ■ | ■ |
| | Shaws Swamp | ■ | ■ | ■ | ■ |
| | Piggery Lake | ■ | ■ | ■ | ■ |
| | Wagourah Lagoon | ■ | ■ | ■ | ■ |
| | Wagourah Lake | | ■ | ■ | ■ |
| | North Stallion Swamp | | | | ■ |
| | Steam Engine Swamp | | ■ | ■ | ■ |
| | Paul Coates | ■ | ■ | ■ | ■ |
| | Riverleigh | | ■ | ■ | ■ |
| | Murrundi | | ■ | ■ | ■ |
| Mid-Murrumbidgee wetlands | Yarradda Lagoon | | | ■ | ■ |
| | McKennas Lagoon | | | ■ | ■ |
| | Sunshower | | | ■ | ■ |
| | Dry Lake | | | ■ | ■ |
| | Gooragool Lagoon | | | ■ | ■ |
| | Narrandera State Forest | | | ■ | ■ |
| | Euroley | | | | ■ |
| | Yanco Ag. | | | ■ | ■ |
| | Berry Jerry | | ■ | ■ | ■ |
| Fiddlers Western Lakes | Paika Lake | | | ■ | ■ |
| | Hobblers | | | ■ | ■ |
| | Cherax | | | ■ | ■ |
| | Penarie Creek | | | ■ | ■ |
| | Fiddlers Creek | | | ■ | ■ |

### 3.4.1 Capacity Constraints

Water delivery through the Lowbidgee floodplain is highly complex as water can be moved via a well-developed network of canals, regulators and other structures. Water infrastructure available to deliver Commonwealth environmental watering across the floodplain is detailed in the NSW Adaptive Environmental Water Use Plan for the Murrumbidgee Water Management Area (NSW Commissioner for Water 2013) and summarised in Table 4.

Water levels at Maude and Redbank Weir can be raised to allow for diversions into the Nimmie-Caira and Redbank systems respectively even when river levels are low. There are a number of constraints that limit daily delivery volumes via canal and regulator structures across the Lowbidgee floodplain, including the presence of private structures, and channel capacity constraints (see Table 4). During very dry years carriage losses along canals can be significant and as a result watering actions may be restricted to areas closer to the off takes to limit losses. The mid-Murrumbidgee wetlands have limited infrastructure (the exceptions being Yanco Agricultural High School Lagoon, Turkey Flats and Gooragool Lagoon which can be filled via Murrumbidgee Irrigation Area (MIA) infrastructure and inflows into these wetlands are dependent on river heights exceeding their commence to fill (around 23,000 ML/Day at Narrandera) see (Murray 2008, Sinclair Knight Merz 2011) for commence to fill values for individual wetlands).

Table 4 Summary of key infrastructure (including Asset numbers) and flow constraints in the Murrumbidgee (CSIRO 2008a, Murray 2008, Sinclair Knight Merz 2011, Hardwick and Maquire 2012, Murray-Darling Basin Authority 2012b, Murray-Darling Basin Authority 2012a, Murray-Darling Basin Authority 2012c, Spencer, Wassens *et al.* 2012, Gawne, Brooks *et al.* 2013a, Murray-Darling Basin Authority 2014).

| **Zone** | **Important infrastructure and gauges to support water delivery and monitoring** | **Constraints** |
|---|---|---|
| Nimmie Caira<br><br>Fiddlers-Uara | Nimmie Creek Off-take Regulator (87019)<br>North Caira Bridge Regulator (87021)<br>South Caira Bridge Regulator (87035)<br>Uara Creek<br>Fiddlers | Above 650 ML/day the South Caira channel spills in various directions through recently constructed cuttings |
| | | The offtake channel to Uara Creek currently has a private structure which limits diversions to 300 ML/day<br>Fidders has two 500 ML/day offtakes (Suez and Warwaegae offtakes) however this is not utilised fully as have to raise weir pool to reach 1000 ML/day target and no target waterings occur at this level |
| South Redbank | Yanga Regulator (Asset 87084)<br>Waugorah Regulator (87059),<br>Mercedes Pipe Regulator<br>IAS regulator<br>IES regulator | 1AS – Aquatic vegetation growth limits average daily flows to 450 ML/day at 5.64 M or up to 600 ML/day @ 5.75 M Redbank weir pool<br>1ES – 70 ML/day @ 5.64 or 150 at 5.75 M Redbank weir pool |
| North Redbank and Western Lakes | Glenn Dee Regulator (87000)<br>Juanbung Regulator (87005)<br>Athen Gauging Station (41000256)<br>Patto's Pipe<br>Bill's Pipe | The new flume gated Glen Dee regulator will only run about 700 ML/day down the North Redbank channel at 5.75 M.<br>If Lake Marimley have irrigation orders channel share reducing capacity of e-water diversion to as low as 200-300 ML/day. |
| Murrumbidgee River | Murrumbidgee River downstream Burrinjuck at Gundagai | Private land access and inundation (Mundarlo Bridge) limits flow to max 32,000 ML/D |
| | Mid-Murrumbidgee wetlands aligned with Narrandera zone at Darlington Point | Minor flood level 23,000 ML/D |
| | Murrumbidgee River at Balranald | Channel capacity and delivery of flows to downstream locations on River Murray -9,000 ML/D |
| Tumut River Downstream Blowering | Tumut River Downstream Blowering at Tumut<br>Tumut River Downstream Blowering at Oddy's Bridge | Channel constraint and erosion control limit flow to 9,000 Ml/D at Tumut and 9,300 ML/D at Oddy's Bridge |

## 3.5 Flow objectives

In identifying flow objectives we found it informative to consider the objectives, ecological values and expected outcomes presented in key published documents, e.g. (Murray-Darling Basin Authority 2012b, Murray-Darling Basin Authority 2012a, Murray-Darling Basin Authority 2012c, Gawne, Brooks *et al*. 2013a, NSW Commissioner for Water 2013) and CEWO annual watering plans 2011-2014, along with critical values identified by the Murrumbidgee Selected Area working group, which are summarised in Table 5. Analysis of these documents reveal three key themes related to ecosystem function, the maintenance and improvement in vegetation communities (Flora) and supporting habitat requirements, and providing recruitment opportunities for native fauna (Fauna). We designed the M&E Plan to cover the three broad objectives identified in the key published documents, while allowing enough flexibility to evaluate specific annual flow objectives- such as in-channel flows to promote silver perch spawning, wetland flows to support southern bell frog breeding, return flows to promote fish movement, in-channel flows to stimulate primary and secondary productivity and hypoxic black water risk management.

Table 5 Summary of flow objectives outlined in Commonwealth and State plans for the Murrumbidgee

| Document | Ecosystem function | Flora | Fauna |
|---|---|---|---|
| MDBA Site-specific ecological targets **Murrumbidgee River** | Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon | | Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) |
| MDBA Site-specific ecological targets **Mid-Murrumbidgee River Wetlands** | Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain | Provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition. | Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates) |
| MDBA Site-specific ecological targets **Lower Murrumbidgee River Floodplain** | Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain. | Provide a flow regime which ensures the current extent of native vegetation of floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition. | Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds.<br>Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates). |
| Adaptive Environmental Water Use Plan for the Murrumbidgee Water Management Area (NSW) relevant to the LTIM Project area | Contribute to maintaining the ecological character of wetlands and floodplains on the Lowbidgee floodplain | Contribute to maintaining the ecological character of mid-Murrumbidgee lagoons such as enhance river and wetland habitat for water dependent biota in the Murrumbidgee Regulated River Water Source. | Contribute to the successful completion of colonial waterbird breeding in wetlands on the Lowbidgee floodplain and enhance opportunities for threatened and other native fish and waterbird recruitment in the Murrumbidgee Regulated River Water Source.<br>Provide recruitment opportunities and maintain viable populations of southern bell-frog *Litoria raniformis* in the Lowbidgee floodplain and mid-Murrumbidgee Wetlands |
| 2011-12 Mid-Murrumbidgee reconnection Annual CEWO plan | Decrease dissolved organic carbon, total organic carbon and particulate organic carbon levels and reduce black water risk. | Promote Aquatic and semi-aquatic vegetation cover and species diversity | Promote frog breeding and recruitment.<br>Promote recruitment of native fish (as measured by the abundance of juveniles). |

| | | | |
|---|---|---|---|
| | To promote early successional algal taxa (e.g. diatoms) and higher biofilm diversity. A high diversity of biofilms usually indicates good ecosystem health.<br>To contribute nutrients and food into the water column, thus providing an important food resource for downstream communities | | Increase waterbird diversity. |
| 2012-13 Action Murrumbidgee River watering action (option 1) Annual CEWO plan | Support ecosystem functions that relates to mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter).<br>Support ecosystem functions that relate to longitudinal connectivity (i.e. connectivity along a watercourse) and lateral connectivity (i.e. connectivity between the river channel, wetlands and floodplain) to maintain populations.<br>Support ecosystem functions that relate to creation and maintenance of bed, bank and riparian habitat. | Maintain health of existing extent of riparian, floodplain and wetland native vegetation communities.<br>Provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities. | Support breeding and recruitment of native fish.<br>Support habitat requirements of native fish (i.e. maximise opportunities for Murray cod and trout cod to locate nest sites and maintain inundation of nest sites long enough to complete spawning cycle). |
| 2012-13 Action Western Lakes watering (Option 5) Annual CEWO plan | | Maintain health of existing extent of riparian, floodplain and wetland native vegetation communities.<br>Provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities. | Support breeding and recruitment of native fish.<br>Support the habitat requirements of waterbirds.<br>Support breeding of colonial nesting waterbirds.<br>Support breeding and recruitment of other native aquatic species, including frogs, turtles and invertebrates.<br>Support habitat requirements of other native aquatic species, including frogs, turtles and invertebrates. |
| 2013-14 Multiple watering actions throughout the Lowbidgee floodplain and water lakes<br><br>Return flows to the Murrumbidgee River | Support wetland productivity, nutrients and carbon fluxes, primary productivity (Chl-a) and secondary productivity (Microinvertebrates).<br>Support riverine productivity, nutrients and carbon fluxes, primary productivity (Chl-a) and secondary productivity (Microinvertebrates). | Maintain health of existing extent of riparian, floodplain and wetland native vegetation communities.<br>Provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities. | Support breeding and recruitment of native fish.<br>Support the habitat requirements of waterbirds.<br>Support breeding and recruitment of other native aquatic species, including frogs, turtles, and invertebrates.<br>Support habitat requirements of other native aquatic species, |

| | | | |
|---|---|---|---|
| Annual CEWO plan | | | including frogs, turtles, and invertebrates.<br>Support habitat requirements of native fish |

# 4 Contents of the M&E Plan

***Commonwealth environmental watering objectives***

As noted previously in section 3.2, there are five major groups of documents relating to water requirements and environmental flow objectives in the Murrumbidgee Selected Area: the MDBA site specific ecological targets documents, the Monitoring and Evaluation Requirements (MER) document for the Murrumbidgee (Gawne, Brooks *et al*. 2013a), the NSW Adaptive Environmental Water Use Plan for the Murrumbidgee Water Management Area , and annual Commonwealth and NSW OEH environmental watering plans (see Table 5). Analysis of these documents reveals three broad watering goals:

- Maintenance of ecological functions, including connectivity, primary and secondary productivity and water quality that support recruitment and populations of aquatic species
- Providing opportunities for recruitment, dispersal and persistence of aquatic fauna, such as microinvertebrates, fish, frogs, turtles and waterbirds, including species listed under the Commonwealth EPBC Act 2007.
- Providing opportunities for flora recruitment, maintaining and enhancing, vegetation diversity and tree condition

This M&E Plan therefore includes a range of monitoring activities under these three broad objectives designed to contribute data to allow for the evaluation of Category 1 indicators at the Basin scale and evaluate ecological outcomes of Commonwealth environmental watering within the Selected Area (Figure 4). Wherever practical, monitoring activities have been bundled, thus allowing data on multiple indicators to be collected simultaneously while minimising travel and staffing costs and allowing for data on key covariates to be collected simultaneously to allow for Selected Area evaluation. The wetland bundle includes wetland fish, frogs, tadpoles, turtles, microcrustacea, waterbird diversity, vegetation diversity, water quality (spot measurements), water quality metrics associated with black water and algal bloom risks (nutrients, carbon and Chlorophyll-a) and hydrology. The riverine bundle includes larval fish, microcrustacea, stream metabolism, water quality (spot measurements), water quality metrics associated with black water and algal bloom risks (nutrients, carbon and Chlorophyll-a) and hydrology.

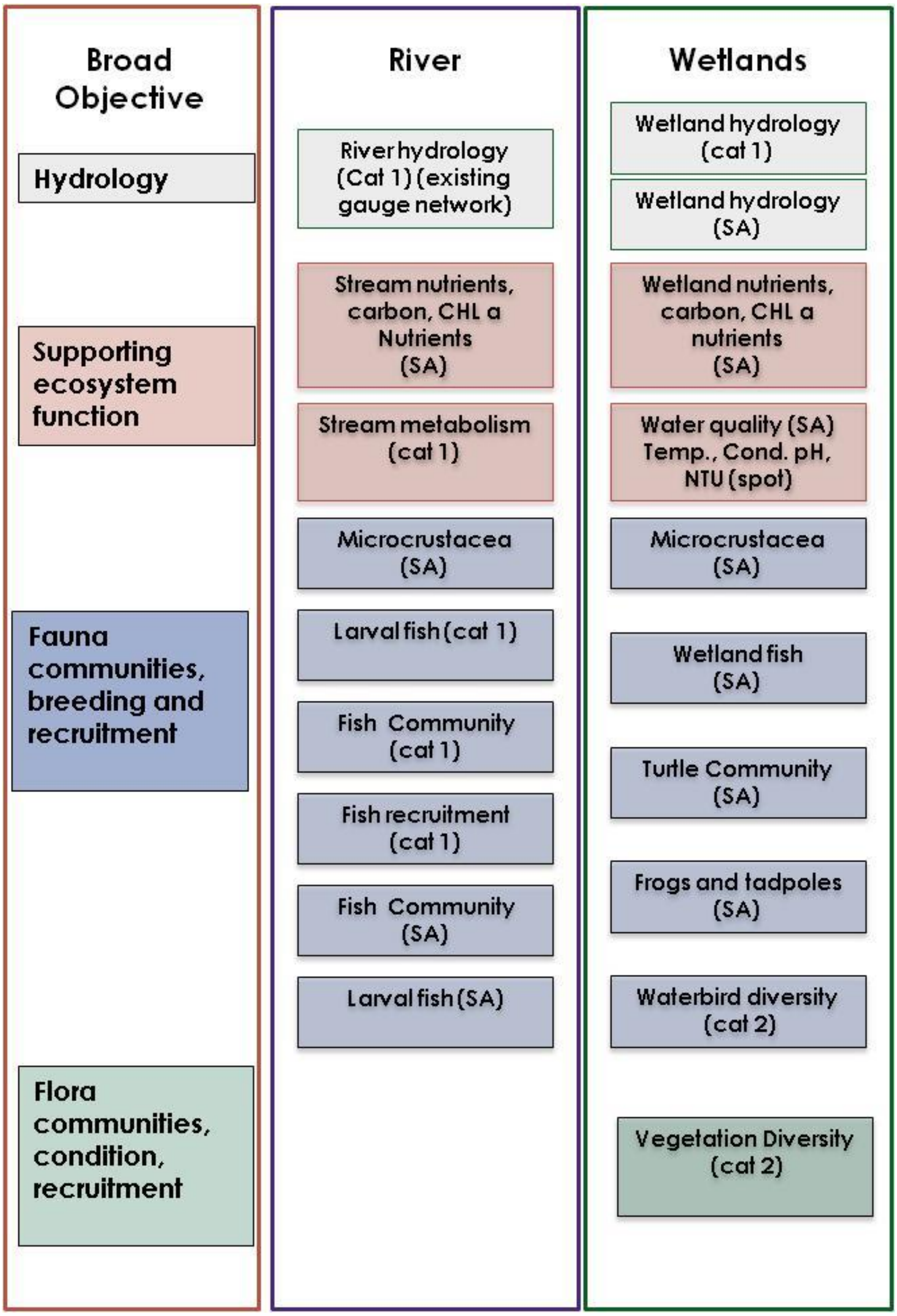


Figure 4 Generalised M&E Plan framework and indicators proposed for the Murrumbidgee Selected Area (SA) and Category 1 and Category 2 (Cat 1 and Cat 2) Basin scale.

## 4.1 Approach to evaluation & synthesis

In order to account for known variability in the Murrumbidgee Selected Area, we have focused on developing a monitoring and evaluation program that provides a robust framework to evaluate the ecological outcomes of Commonwealth environmental water at a range of spatial and temporal scales. Thus, we have developed a monitoring and evaluation strategy that identifies broad scale pattern and process, targeting multiple taxonomic groups and trophic levels over the range of ecosystem types present within the Murrumbidgee Selected Area (Figure 5). By building in appropriate levels of spatial and temporal replication, the approach enables us to evaluate the short and long-term contributions of Commonwealth environmental water to achieving the goals of the Basin Plan.

The evaluation framework includes fixed monitoring locations within key river and wetland zones. Fixed sites are monitored continuously across the five year period, to provide data allowing the evaluation of long-term (5 year) outcomes of Commonwealth environmental watering at the Basin (Category 1and 2) and Selected Area (SA) level. The Monitoring and evaluation plan includes capacity for 12 fixed sites across three of the six wetland zones (Nimmie-Caira, Redbank, and mid-Murrumbidgee) and six fixed sites in across two zones in the Murrumbidgee River. Establishing fixed sites allows for the deployment of data loggers, for example Dissolved Oxygen loggers for Category 1 Stream metabolism assessment and water depth loggers in wetlands support calculation of the Category 1 wetland hydrology metrics.

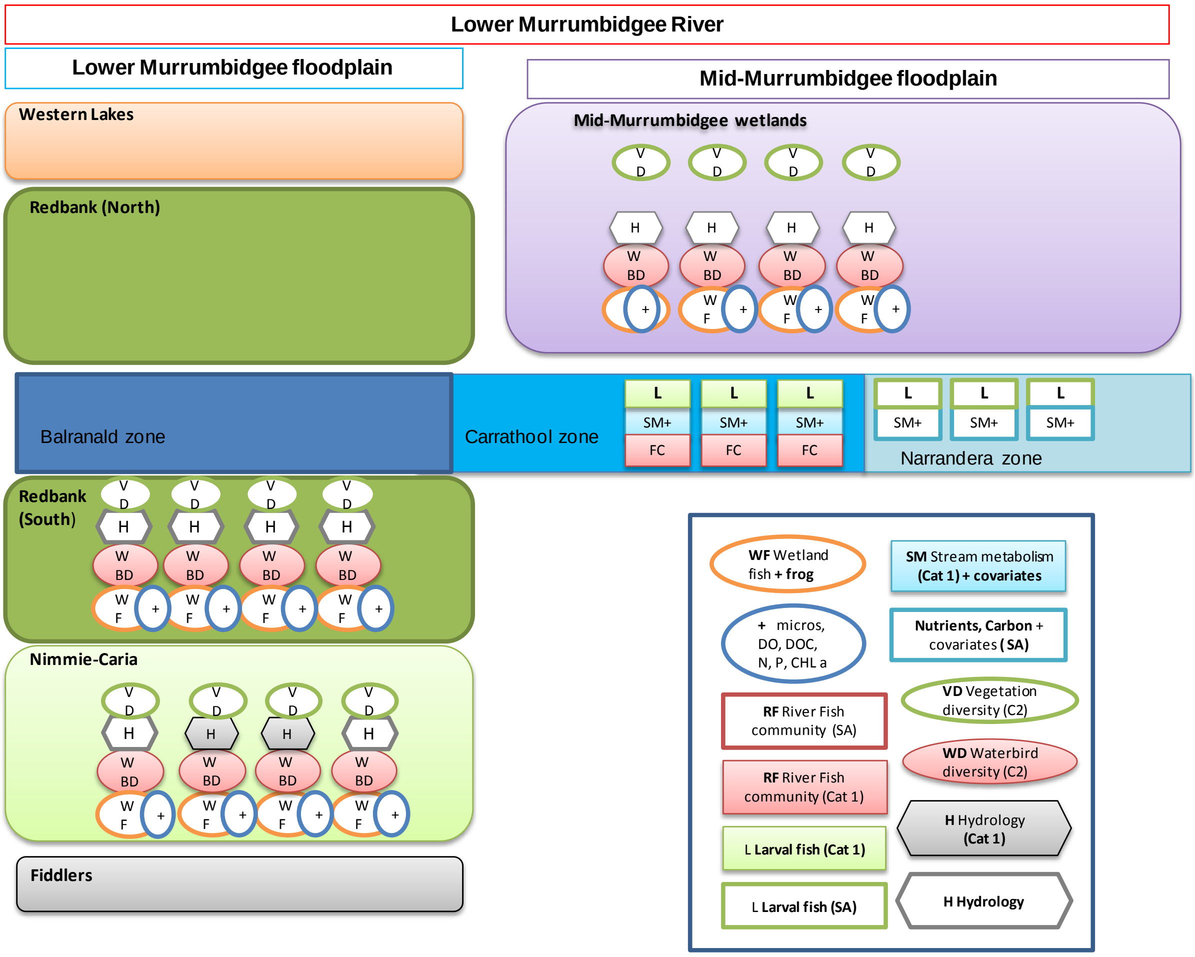


Figure 5 Conceptual representation (not to scale) of key monitoring activities within the Murrumbidgee Selected Area that will be incorporated into the Selected Area evaluation to test relationships described in the CEDs (note that not all zones, sites and key monitoring activities are represented).

### 4.1.1 Evaluation

Selected Area monitoring activities have undergone a process of robust statistical optimisation to identify the minimum sampling units required to detect an ecological response with a desired level of certainty. This process allows the Selected Area monitoring activities to collect data across multiple zones with lower costs than for Category 1 activities and with a high degree of statistical certainty. In very large areas, such as the Murrumbidgee Selected Area, the proposed Category 1 and Selected Area (SA) design allows us to maintain a sufficient level of spatial and temporal replication to capture ecological responses, across multiple zones that would not be logistically possible if Category 1 methods were applied across multiple zones. Given the large volumes of Commonwealth environmental water available for use in the Murrumbidgee each year, this approach enables us to fully support both Basin and Selected Area evaluation as well as ongoing adaptive management.

Wetland ecosystems are complex, and the response of individual indicators to Commonwealth environmental watering actions can be facilitated or in some cases hindered by a range of parameters present in the aquatic system. These complex relationships are outlined within the Cause-Effect-Diagrams (CEDs) for each indictor (Murray Darling Freshwater Research Center 2013). For example, while water is the overriding influence on wetland ecosystems, complex biotic interactions such as food availability, predation, competition and dispersal can exert a strong influence on ecological outcomes. The Selected Area evaluation aims to quantify the relative contribution of each component of the CEDs, through the development of a series of process models (based on Structural equation modelling, see next section) generated using data collected on key response outcomes and covariates, including components of the hydrological regime, ecosystem type, and the associated response of critical covariates such as water temperature, microcrustaceans, DOC and nutrients.

Based on previously collected data in the Murrumbidgee Selected Area, we determined that wetland and riverine systems respond differently to water availability and timing (Wassens, Jenkins *et al*. 2014). Consequently, we will develop separate sets of process models linking monitored ecosystem components within river and wetland zones to relevant hydrological metrics and covariates. The process models will provide a summary of current understanding of system dynamics and the anticipated response of the system to alternative water management scenarios (Bino, Steinfeld *et al*. 2013, Murray Darling Freshwater Research Center 2013, Wassens, Jenkins *et al*. 2013a). The models will allow us to quantify the relative contribution of key variables within the CEDs that drive anticipated responses, the variables for assessing those responses, and explicitly identify uncertainties in current knowledge. Developing process models for each CED will also enable us to evaluate different ecological states arising during Commonwealth environmental watering actions. As well as providing a sound framework for the evaluation of ecological outcomes of Commonwealth environmental watering actions, process models can be easily integrated into an adaptive management framework (Kingsford and Briggs 2012). As more information is gathered, we will continuously evolve and update our models so in time, these will provide more robust predictions of ecosystem responses to watering strategies (Bino et al. 2013).

### 4.1.2 Methodology for developing whole ecosystem response models

The Murrumbidgee Selected Area covers an extensive area and receives relatively large volumes of Commonwealth environmental water each year. Consequently, it is not possible to directly monitor and evaluate ecological outcomes in all wetlands and riverine zones receiving Commonwealth environmental water. Instead, monitoring activities are focused on representative areas within key zones, with the analytical approach designed to allow the development of robust models that are able to infer the observed ecological outcomes with regard to Commonwealth environmental watering actions to unmonitored areas within the Selected Area. In order to develop such models, a monitoring framework must accommodate for both trend and intervention monitoring at appropriate temporal and spatial scales. For this, ecological response monitoring activities will follow an experimental design that takes place before, during, and after any intervention by watering actions (BACI) (Downes, Barmuta *et al*. 2002). For the riverine zones, a Before-After-Intervention design will be established due to the inability to establish any control locations. Under this design, we will examine changes before and after watering action have taken place and test for significant ecological responses. Where possible, control sites (areas that did not receive Commonwealth environmental Water) will be utilised to create a more robust Multiple Before-After-Control-Impact (Multiple BACI) experimental design. As we collect more information on the ecosystem, we will be able to develop more robust ecosystem response models for the various Murrumbidgee wetlands and ultimately provide support for evidence-based decision making. Stratifying our monitoring activities according to floodplain habitat (zones) will enable us to account for the inherent variability in responses of monitored indicators and provide a more complete measure of condition and response to watering actions. Generalised linear mixed models will be used to test the effects of watering actions between control and effect sites.

In addition, we will employ a structural equation modelling (SEM) approach to test our relationships described in the CEDs, including the directional and non-directional relationships among observed (measured) and unobserved (latent) variables, including relationships with hydrological conditions (Hoyle, 1995; MacCallum & Austin, 2000). We will use SEMs as a method to represent, estimate, and test the CEDs (mostly) linear relations between variables (Rigdon, 1998). The ultimate objective of a SEM approach is to understand the patterns of correlation/covariance among measured variables and to explain as much of their variance as possible with the model specified (Kline, 1998). SEMs are particularly useful as they allow for imperfect measures by explicitly specifying measurement error. This approach relies on the construction of detailed conceptual models (which will be prepared at the start of each water year for each key ecological response to be evaluated) and quantifying the relative contribution of each component of the model. The models will be refined over successive water years as more data becomes available.

# 5 Monitoring and evaluation plan key indicators, evaluation questions and methods

This section provides details on each of the proposed monitoring activities, including evaluation questions, Predictions, cause and effect diagrams and an outline of field and laboratory methodology.

The Lowbidgee floodplain supports one of Australia's most significant populations of Southern bell frog (Vulnerable EPBC A). Pictured from Avalon swamp in the Nimmie-Caira zone (February 2014)

## 5.1 Ecosystem type

The Australian National Aquatic Ecosystem (ANAE) Classification Framework has been developed using the best available mapping and attribute data. Wetland polygons, riverine polygons, and river centre lines were attributed with the majority coverage of each attribute without dividing them further. In the Murrumbidgee Selected Area, the ANAE database currently has good coverage of riverine habitats and some coverage of the wetlands through the mid-Murrumbidgee but very limited coverage of wetland habitats through the Lowbidgee (see Figure 1 and Figure 2). Validation of wetlands already classified in the ANAE database is proposed as in-kind with no additional cost to the M&E Plan. However, as per the standard method, "*If the ecosystem is not mapped then record coordinates (GDA94) of the centre of the ecosystem and either locate compatible GIS mapping or delineate the boundary of the ecosystem using remote sensed data*". As the majority of wetlands across the Lowbidgee floodplain are currently unmapped, we proposed to classify boundaries for key wetlands as part of the M&E Plan.

***Short-term (one year) and long-term (five year) questions:***

What did Commonwealth environmental water contribute to sustainable ecosystem diversity?

Were ecosystems to which Commonwealth environmental water was allocated sustained?

Was Commonwealth environmental water delivered to a representative suite of ecosystem types?

***Relevant protocols for the Murrumbidgee Selected Area***

LTIM Project Standard Protocol: Fish (River)

LTIM Project Standard Protocol: Fish (Wetland)

LTIM Project Standard Protocol: Fish (Larvae)

LTIM Project Standard Protocol: Hydrology (River)

LTIM Project Standard Protocol: Hydrology (Wetland)

LTIM Project Standard Protocol: Macroinvertebrates

LTIM Project Standard Protocol: Stream metabolism

LTIM Project Standard Protocol: Vegetation diversity

LTIM Project Standard Protocol: Waterbirds breeding

LTIM Project Standard Protocol: Waterbirds diversity

### 5.1.1 Methods

The wetlands across the Lowbidgee floodplain are complex with poorly defined boundaries, and as such the ANAE and other databases have very limited spatial data on wetland boundaries, with many not included and some only included as simple estimates of wetland areas using circles. NSW Office of Environment and Heritage is in the process of delineating boundaries for some key wetlands, but it is not clear whether these will align with these boundaries would be available in a suitable timeframe. Consequently, we will be required to undertake a classification of wetland boundaries at the 12 fixed monitoring sites within the Lowbidgee floodplain. The vegetation structure, relatively flat nature of the landscape and significant annual variability in flow makes current remote sensing based methods for the delineation of wetlands impractical. Instead, metrics describing inundation patterns will be derived in a GIS using modelled inundation spatiotemporal data already produced by NSW OEH, combined with digital terrain models. The modelling will incorporate a fuzzy element that will reflect the uncertainty inherent in such modelling. Probabilities of membership of wetland areas will be assigned to individual map pixels (Figure 6) with the end-result being a most-likely extent and associated likely range of extents, which could, for example, include a 95% confidence range. This process will be undertaken in year one of the project with outputs also informing wetland hydrology assessments (next section).

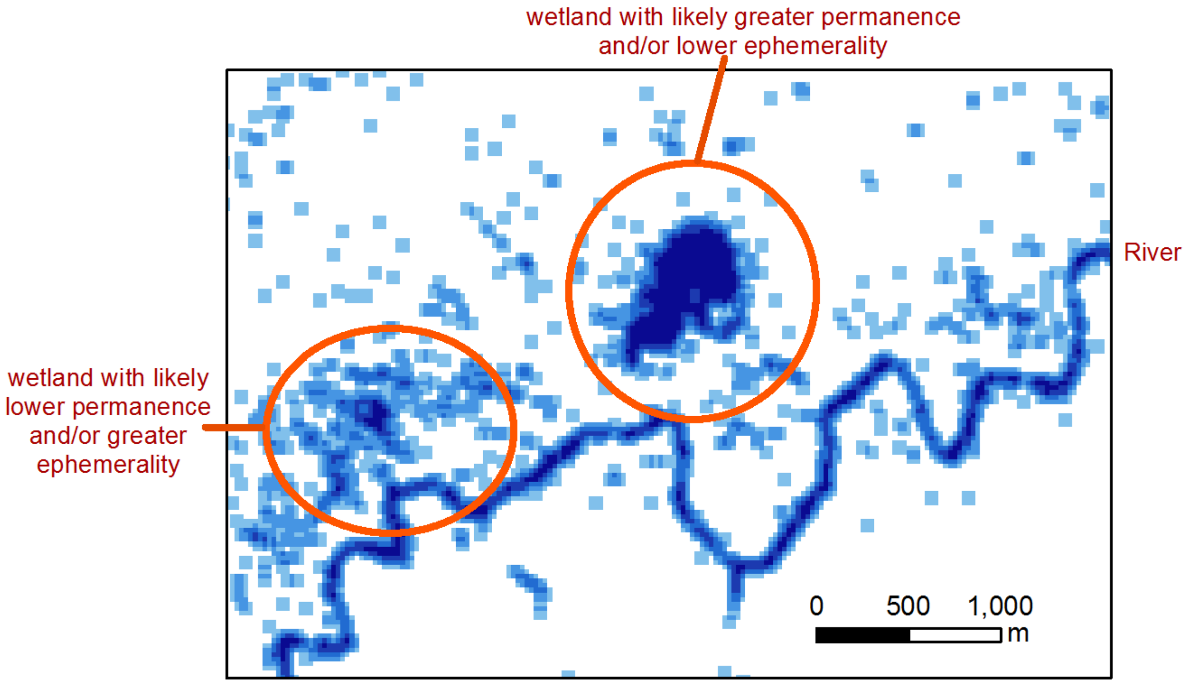


Figure 6 Mapping wetland extent with modelled inundation data incorporating uncertainty. Darker blues indicate higher likelihoods of inundation.

### 5.1.2 Data analysis framework against evaluation questions

Evaluation of wetland extent will be considered in association with wetland hydrology (12 sites) described in the following section. Spatial boundary layers created during these activities will be provided to CEWO for inclusion in the ANAE database.

## 5.2 Wetland hydrology (Category 1 and Selected Area)

***Background***

In the Murrumbidgee catchment, wetland types vary from large open water lakes and small oxbow lagoons with relatively well defined sills and boundaries, to shallow vegetated swamps and marshes with complex bathymetry and poorly defined boundaries. As noted previously, due to the complex hydrology of wetlands in the Lowbidgee floodplains, wetland boundaries have not yet been spatially defined and the ANAE database does not contain any information for wetlands across the Lowbidgee floodplain (with the exception of large lake systems). Within the oxbow lagoons of the mid-Murrumbidgee zone it is possible to identify the perimeter of a lake or lagoon from a single date moderate resolution satellite image such as SPOT-5 and Landsat 7 ETM+ (Figure 7a). In floodplain wetlands, however, the perimeter of an individual wetland is ambiguous and not easily distinguishable from a single image date, because at any one point in time there is a mosaic of wetland vegetation types and a gradient of flooding (Figure 7b). The presence of levee banks and regulatory structures also influence flooding patterns. To counter the problems of undefined boundaries and complex bathometry in the Lowbidgee floodplain, the required metrics for wetland hydrology will be collected using a combination of wetland extent estimation (derived from historical data and current Landsat images) and a LiDAR derived digital terrain model (DTM). Note that while the field methods are the same, the full set of Category 1 metrics will only be modelled at Category 1 waterbird breeding sites during waterbird breeding events. Selected Area metrics will be calculated at the 12 core monitoring sites and will provide data on the duration of connection - river inflows and outflows (start and end points in days), The extent of inundation (modelled) during each survey period (September, November, January and March) and the wetland volume (modelled) during each survey period.

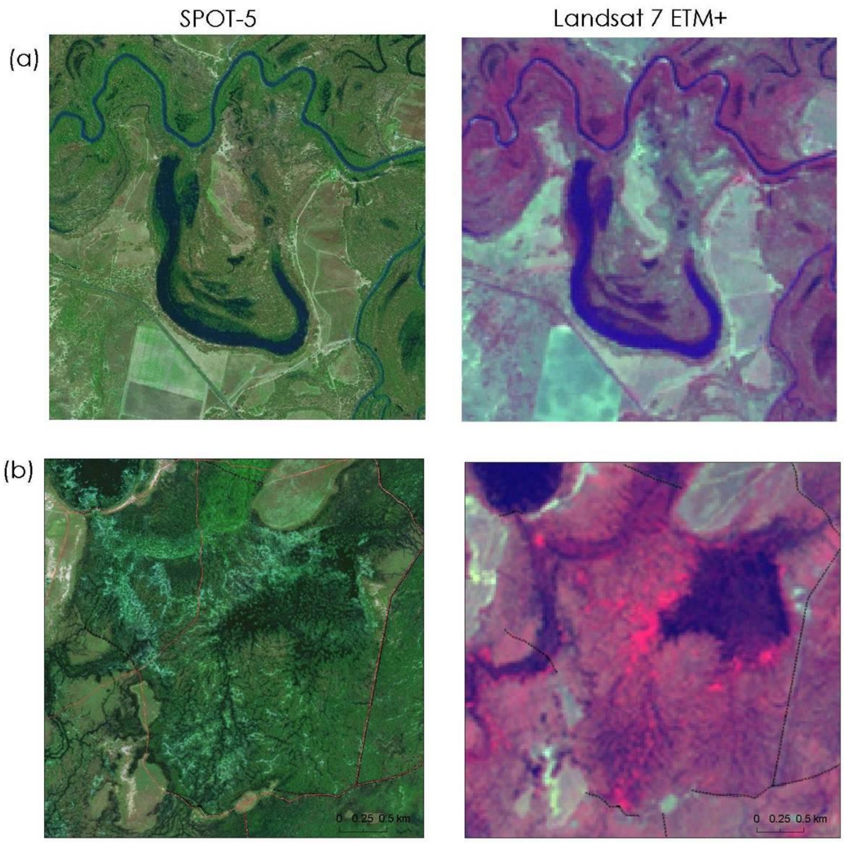


Figure 7 SPOT-5 (10m) (December 2010) and Landsat-5 TM (25m) (January 2012) showing (a) perimeter of Yarrada Lagoon wetland site in the Mid-Murrumbidgee wetland zone and (b) Tarwillie Swamp wetland site in the Redbank wetland zone of the Lowbidgee floodplain (black lines are levee banks).

***Basin scale evaluation questions:***

Wetland hydrology indirectly addresses the following Basin scale evaluation questions:

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to hydrological connectivity?

What did Commonwealth environmental water contribute to waterbird populations?

What did Commonwealth environmental water contribute to native fish species diversity?

What did Commonwealth environmental water contribute to fish community resilience?

*Short-term (one year) and long-term (five year) questions:*

What did Commonwealth environmental water contribute to waterbird breeding?
What did Commonwealth environmental water contribute to waterbird chick fledging?
What did Commonwealth environmental water contribute to waterbird survival?
What did Commonwealth environmental water contribute to native fish reproduction?
What did Commonwealth environmental water contribute to native larval fish growth and survival?

| LTIM Project indicator | Evaluation questions | Metrics | Critical covariates/ Other data sources | Sampling regime |
|---|---|---|---|---|
| Hydrology Cat 1 and SA | Cat 1 metrics<br>What did Commonwealth environmental water contribute to hydrological connectivity?<br>What did Commonwealth environmental water contribute to:<br>- waterbird populations?<br>-waterbird breeding?<br>- chick fledging?<br>-waterbird survival?<br>SA metrics<br>What did Commonwealth environmental water contribute to:<br>-native fish species diversity?<br>-fish community resilience?<br>- native fish reproduction?<br>-native larval fish growth and survival?<br>Microinvertebrate production and diversity<br>-Frog reproduction and diversity | Duration of connection - river inflows and outflows (start and end points in days)<br><br>Extent of inundation (modelled)<br><br>Wetland volume (modelled) | Barometric pressure<br><br>Wetland extent<br>Wetland bathymetry (DEM) | Permanent sites: 3 zones: mid-Murrumbidgee n=4), Redbank (n=4), Nimmie-Caira (n=4)<br><br>Install depth loggers<br>1 per wetland<br>Four survey periods (September November, January and March) |

### 5.2.1 Methodology

***Site monitoring of water level***

Water level loggers will be deployed across the 12 core wetland monitoring sites. At all sites a single depth logger placed will be established at the deepest point. Note that loggers cannot be installed until the wetlands are dry, and, in some cases, it may not be possible to install loggers in 2014.

*Determining event inundation extent*

A light detection and ranging (LiDAR) derived 1m digital terrain model (DTM) representing a bare earth surface (without buildings or vegetation) will be used as the basis of wetland bathymetry measurements in the Murrumbidgee Selected Area. Good quality LiDAR was captured between February and September 2008 during a very dry period and is available to the project team through NSW OEH. The spatial accuracy of the DTM is ±0.60 m horizontal and ±0.15 m vertical, which will provide sufficient accuracy to derive rates of rise and fall to within 0.2 m.

Water level data collected from the water level loggers will be applied to DTM data within a GIS. Those areas of the DTM with elevations below the recorded water level will be classified as inundated. Maps and associated area metrics will be derived to describe the level and character of inundation.

This DTM based approach will be supplemented and validated using detailed remote-sensing based monitoring of inundation extents from environmental flows that is continuously being carried out in the Lowbidgee floodplain by NSW OEH (Spencer, Thomas et al. 2011b, Thomas, Lu et al. 2012). This LTIM Project will rely on the continuation of the NSW OEH monitoring to provide systematic mapping of inundation extents, particularly over the large area of the Lowbidgee floodplain (Wetland zones: Nimmie Caira and Redbank). The main data source will be the freely available Landsat 8 imagery downloaded from the USSG website (http://glovis.usgs.gov/) in the World Reference System (WRS-2) (NASA 2010) path/rows 94/84 (Lowbidgee) and 93/84 (Mid-Murrumbidgee). Available image dates will be plotted on the hydrograph of flows measured at the relevant gauging stations along the Murrumbidgee River. Individual image scenes will be normalised to top of atmosphere reflectance, subsetted and resampled to 25 m pixels to align with previous inundation mapping (Spencer, Thomas et al. 2011b, Thomas, Cox et al. 2013). A combination of water and vegetation spectral indices are used to derive three inundation classes that represent open water, a mixed zone of water and wetland vegetation, and emergent wetland vegetation. Inundation classes are merged to delineate inundated area from not inundated areas (Thomas, Kingsford *et al*. 2011) (Figure 8).

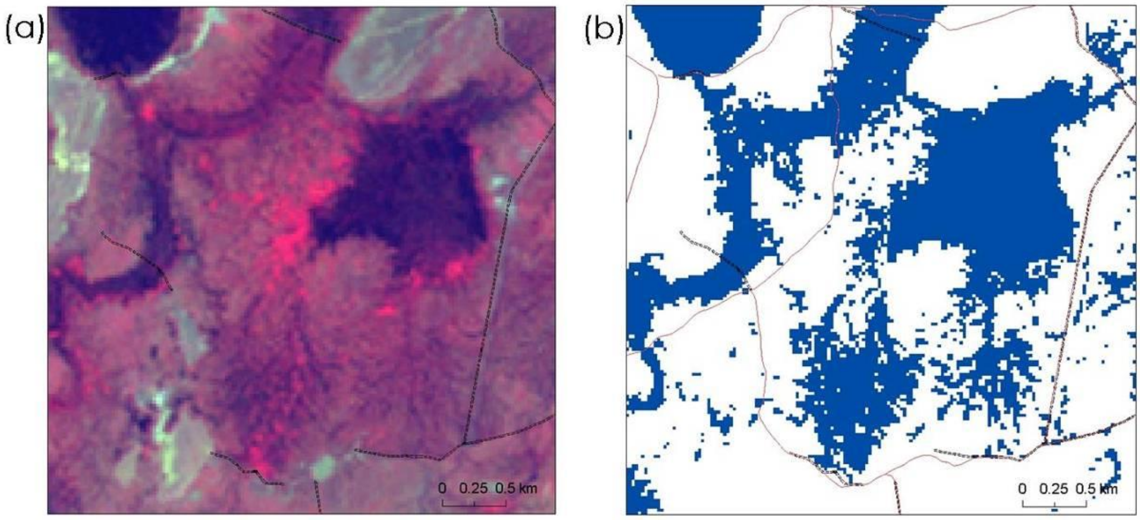


Figure 8 (a) Landsat 7 image (January 2012) data source for detecting (RGB:472) (b) inundated area within Tarwillie Swamp wetland site in the Redbank zone of the Lowbidgee floodplain (roads solid line; levee banks dotted line).

*Determining volume*

For the inundation extents, maps of water depth will be derived by subtracting water-surface elevations from the water-bottom elevations derived from the DTM. Using these maps of water depth, calculation of total volume of water for discrete wetlands is a simple calculation within a GIS using depth at each included pixel ($d_p$) and pixel area ($A$), i.e.

$$volume = \sum_p A d_p$$

***Temporal metrics***

*Changes in volume*

Calculations of volume within discrete wetland areas will be calculated daily to provide a time series of hydrological inputs and outputs.

*Duration of connection*

In the mid-Murrumbidgee the single depth logger in combination with the existing Murrumbidgee River gauge network will be adequate to determine the number of days of connection to the river channel. In the Lowbidgee floodplain, environmental flows are typically infrastructure-facilitated and with water delivery managed by State Water. In systems with infrastructure facilitated water delivery the duration of connection (number of days that the regulator structure is open) will be provided by state water.

*Total wetland extent (perimeter delineation)*

The distribution of flooding patterns based on a time series of inundation maps highlight the most likely flow paths that occur at varying return intervals through floodplain wetlands (Figure 9a and b). Wetland boundaries will be classified according to the DTM, which provides detailed drainage patterns and the location of earth-work structures such as levee banks. These data will be combined within a GIS to delineate wetland boundaries within the floodplain.

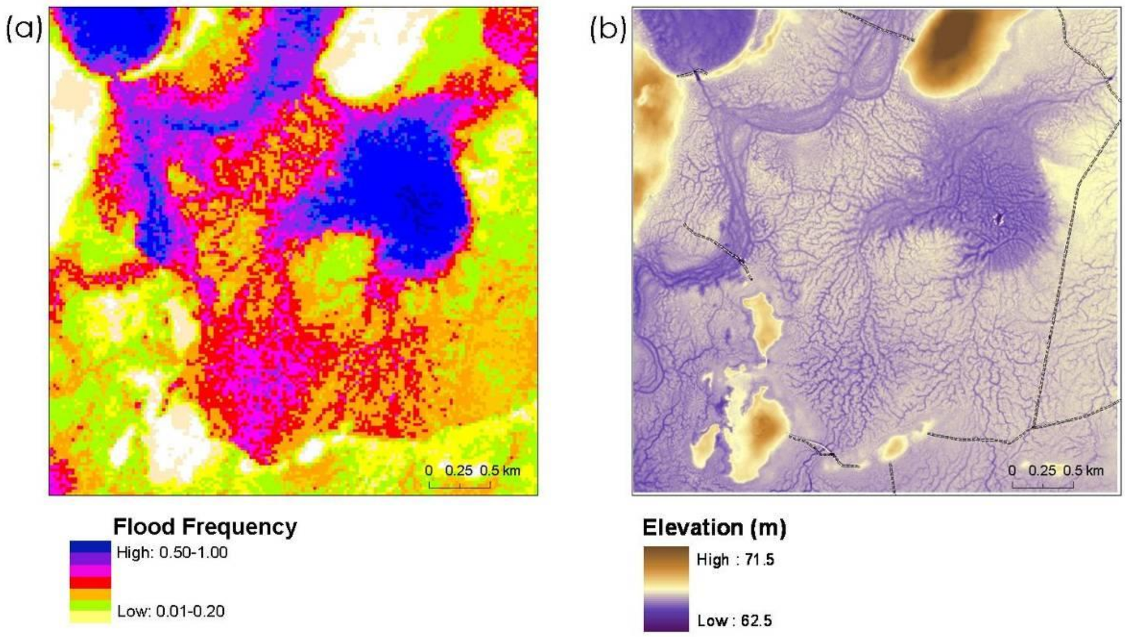


Figure 9 (a) Distribution of flooding frequency patterns (probability of occurrence, 1988-2006) highlighting most likely flow paths and (b) 1m Digital Terrain Model (DTM) drainage patterns and existing levee banks (black dotted line) in Tarwillie Swamp wetland site (currently unmapped) in the Redbank wetland zone of the Lowbidgee floodplain.

*Error and confidence*

While an accurate DTM and reliable depth measures will be available, along with a detailed validation process, a significant level of error cannot be discounted. The level of likely error will be estimated to accompany wetland hydrology metrics. An estimate of the level of error in the DEM is already available and will enable a fuzzy dataset to be used within any GIS based analysis of bathymetry related metrics. For example, a probability of inundation at each pixel (particularly at inundation area boundaries) can be produced rather than a simple Boolean style map. A range of inundation areas can then be produced within a set confidence limit. Best estimates will be produced along with confidence intervals for each derived wetland hydrology metric.

The relatively large area subject to monitoring in the Murrumbidgee Selected Area is subject to change; patterns of inundation can be affected by subtle changes in geomorphology due to flow deposition and erosion, vegetation growth and infrastructure change.

## 5.3 River Hydrology

The Murrumbidgee River is heavily regulated and has a very well developed network of gauges maintained by the NSW Office of Water within the main river channel and key off-takes (Figure 10) (Sinclair Knight Merz 2011). River zones in the Murrumbidgee Selected Area were specifically defined with a view to reducing hydrological heterogeneity and aligning key monitoring activities with the existing gauge network. As a result, we are of the view that the current gauging network will be sufficient to provide hydrological information to support Category 1 monitoring activities and this activity is not costed as part of the M&E Plan (Table 6).

Table 6 Summary of Gauges in the Selected Area (from NSW Office of Water).

| Zone | Number | Name | Lat | Long | Zero Elevation (m) |
|---|---|---|---|---|---|
| Wagga Wagga | 410001 | Murrumbidgee River At Wagga Wagga | -35.1006 | 147.3674 | 170.05 |
| Narrandera | 410005 | Murrumbidgee River At Narrandera | -34.7554 | 146.5489 | 137.39 |
| | 410007 | Yanco Creek At Offtake | -34.7061 | 146.4094 | 134.80 |
| | 410013 | Main Canal At Berembed | -34.8779 | 146.836 | 149.07 |
| | 410023 | Murrumbidgee River At D/S Berembed Weir | -34.8797 | 146.836 | 147.88 |
| | 410036 | Murrumbidgee River At D/S Yanco Weir | -34.6953 | 146.4007 | 132.48 |
| | 410093 | Old Man Creek At Kywong (Topreeds) | -34.9274 | 146.7844 | 152.37 |
| Carrathool | 410002 | Murrumbidgee River At Hay | -34.5169 | 144.8418 | - |
| | 410021 | Murrumbidgee River At Darlington Point | -34.5664 | 146.0027 | 117.86 |
| | 410040 | Murrumbidgee River At D/S Maude Weir | -34.4790 | 144.2996 | - |
| | 410078 | Murrumbidgee River At Carrathool | -34.4493 | 145.4174 | 97.231 |
| Balranald | 410041 | Murrumbidgee River At D/S Redbank Weir | -34.3813 | 143.7804 | - |
| | 410130 | Murrumbidgee River At D/S Balranald Weir | -34.6665 | 143.4904 | 54.253 |
| | 41000236 | Talpee Creek D/S Pee Vee Creek Junction | -34.5284 | 143.7305 | 60.35 |
| | 41000240 | Waugorah Creek U/S Regulator | -34.3549 | 143.8580 | 65.33 |
| | 41000241 | Weather Station At North Of Woolshed Creek Regulator | -34.5619 | 143.6645 | - |
| | 41000244 | Woolshed Creek D/S Of Regulator | -34.5627 | 143.6697 | 61.79 |
| | 41000246 | Yanga Creek At D/S Offtake | -34.3854 | 143.8029 | 65.26 |
| | 41000255 | North Redbank Channel At Glendee | -34.3766 | 143.7712 | 65.126 |
| | 41000256 | North Redbank Channel At Athen | -34.4491 | 143.6861 | 63.775 |

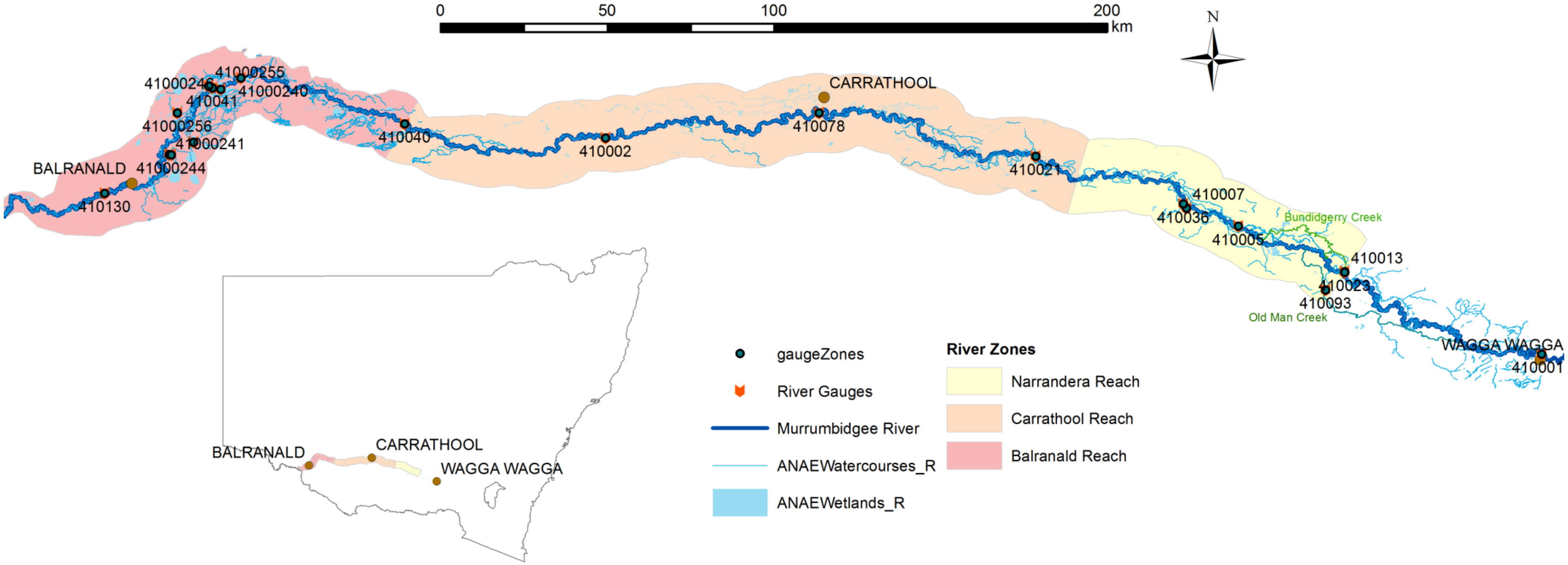


Figure 10 Spatial distribution of gauges across the Murrumbidgee Selected Area (see Table 6 for details of individual gauges).

## 5.4 Stream Metabolism

Note that some components of this monitoring program are currently under review. The structure and function of river and floodplain ecosystems is driven by the supply of carbon-based energy and nutrients derived from organic matter. Organic matter enters aquatic ecosystems through in-situ aquatic primary production (algae and macrophytes) and terrestrial inputs (fallen leaves and branches). Organic matter derived from these two pathways contrasts in quality and quantity, with different consequences for the supply of basal resources to aquatic food webs (Marcarelli, Baxter *et al*. 2011). Perturbations that affect this supply have the potential to alter the structure and function of aquatic ecosystems, with flow-on effects to biota at higher trophic levels such as microinvertebrates and fish.

Stream metabolism is an integrated measure of both primary production and respiration, providing a functional measure of ecosystem health (Young, Matthaei *et al*. 2008) and a means to evaluate changes to the supply of energy to aquatic food webs (Figure 11). Metabolism is affected by: the availability of nutrients, particularly carbon, nitrogen and phosphorous, geomorphic features that enable organic matter to accumulate, water temperature, which affects the rates of biochemical reactions, and the availability of light, which affects rates of photosynthesis (Young and Huryn 1996).

Flow affects metabolism by disturbing microbial and algal communities that carry out carbon transformations by changing the availability of nutrients and by changing physicochemical conditions. In undisturbed streams, metabolism is in a constant state of flux but is typically dominated by heterotrophy in upland, lowland and floodplain ecosystems with increasing dominance of primary production in medium-sized streams (Vannote, Minshall *et al*. 1980). Where regulation has reduced the frequency of bankfull and overbank flows, connections between rivers and heterotrophic energy sources are severed, increasing system reliance on in-stream production (Robertson, Bunn *et al*. 1999a). Environmental flows have the potential to re-establish natural energy pathways, boosting overall rates of metabolism in river channels through the supply of nutrients and energy, while increasing heterotrophy relative to primary production.

Returning environmental water from floodplain wetlands back into river channels provides an alternative tool for water managers to emulate the benefits of large-scale flooding, at small scales without the need for overbank river flows. Water flowing across floodplains accrues dissolved organic matter, enabling nutrients to flow back into the river as they would during larger flood events. These reconnecting flows have the potential to return large amounts of energy and nutrients to the river, stimulating primary production and respiration and thus increasing the supply of basal resources to riverine food webs.

The reduced frequency of floodplain inundation, typical of regulated systems, enables large amounts of organic matter to accumulate on floodplains as litter and coarse woody debris, with floods releasing substantial amounts of dissolved organic carbon (Robertson, Bunn *et al*. 1999b). Under certain conditions, very high organic matter inputs coupled with high water temperatures can lead to a rapid increase in microbial metabolism leading to decreases in dissolved oxygen concentration; these are often referred to as hypoxic blackwater events (Howitt, Baldwin *et al*. 2007, Hladyz, Watkins *et al*. 2011) (Figure 12). Where large amounts of this carbon-rich water enters river channels, dissolved oxygen can become severely low for a substantial distance downstream, killing sensitive biota including large-bodied fish. Monitoring productivity (Chlorophyll-a and metabolism), nutrient and carbon levels, dissolved oxygen and stream metabolism in both river and wetland habitats can enable assessment of the risks of a low dissolved oxygen event. It can provide information to better understand the responses of aquatic flora and fauna, including fish, to nutrient fluxes and physicochemical conditions during a managed return flow event.

Chlorophyll-a is the most dominant photosynthetic pigment and is used as an indicator of phytoplankton primary productivity and algal biomass (Wetzel and Likens 2000). Monitoring Chlorophyll-a within wetland and river sites will give an indication of the level of primary productivity before, during and after the delivery of flows and will be measured in conjunction with microcrustaceans and fish reproduction to determine whether changes in primary productivity within wetland and river sites have flow on affects for higher trophic levels (Kobayashi, Ryder *et al*. 2009).

There are three overarching uses of Commonwealth environmental water that have the potential to affect stream metabolism in the Murrumbidgee Catchment. These include pulsed flows targeted at the Narrandera zone to inundate the mid-

Murrumbidgee wetlands, pulsed flows targeted at Carrathool zone to support spawning by large and medium bodied fish, as well as return flows where water from flooded wetlands is allowed to flow into the river (largely in the Balranald zone). For in-channel flows, the lack of shepherding of environmental water coupled with the State Water Corporation's obligation to deliver water in the most efficient way possible means that flows may not uniformly influence the Narrandera and Carrathool zones.

In Australia, metabolism has not previously been measured at the broad spatial scales proposed by the LTIM Project program. Unlike many other variables studied in aquatic ecosystems, open-system metabolism is sampled across entire river lengths of up to five kilometres, integrating information across entire reaches. Factors that contribute to spatial heterogeneity include geomorphic features (banks, snags, bars), water depth, vegetation (shading, litter inputs) and nutrient inputs (return flows from wetlands or irrigation drainage). As metabolism is measured at broad scales, it is expected to be relatively consistent among reaches with similar geomorphology and hydrology.

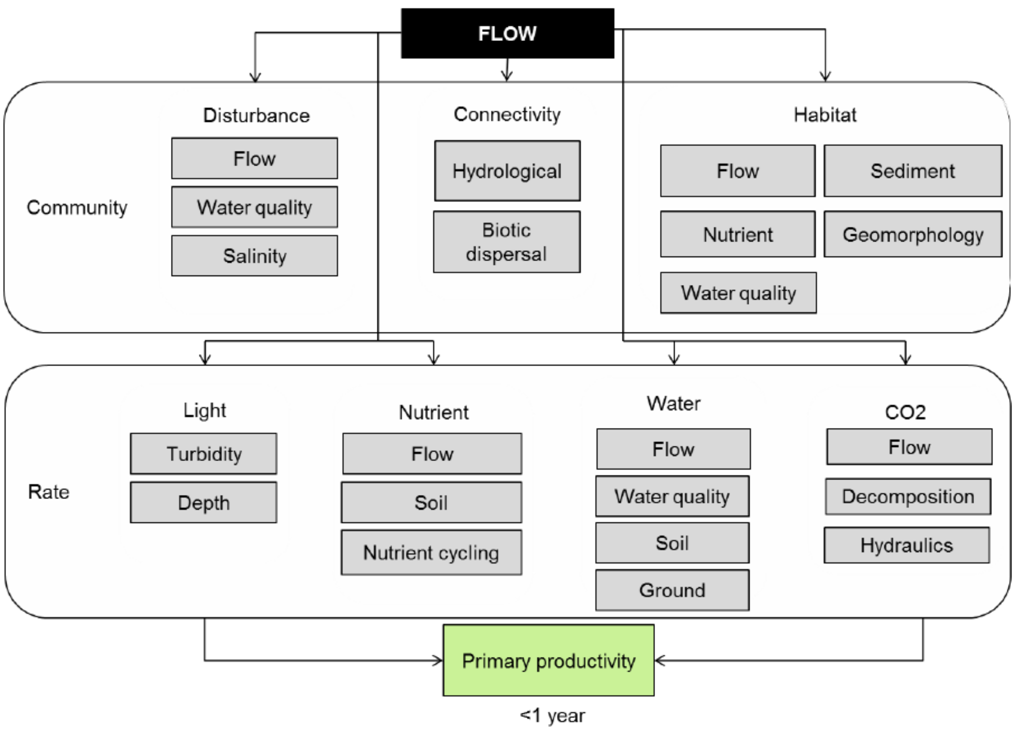


Figure 11 Revised primary productivity CED.

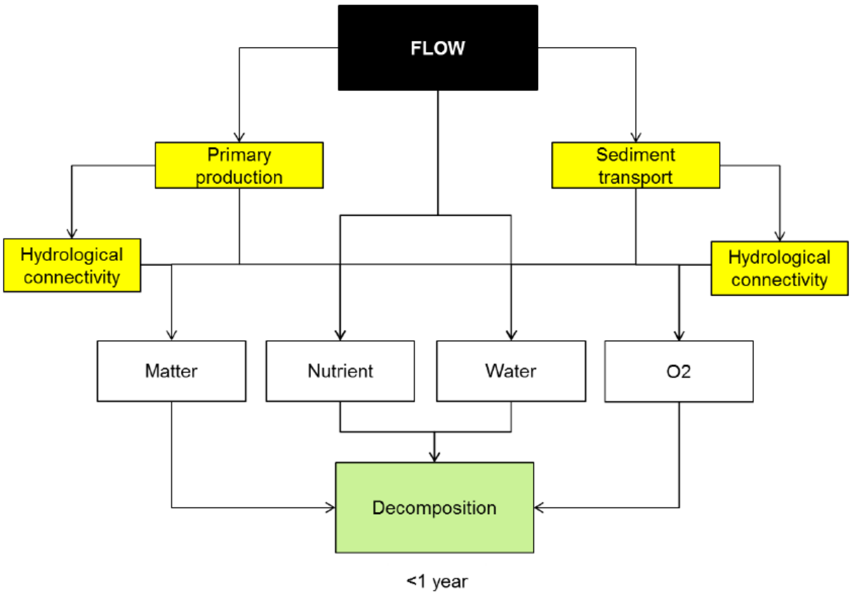


Figure 12 Revised decomposition CED. Yellow boxes indicate other CEDs.

### 5.4.1 Evaluation Questions

***Basin scale evaluation questions:***

*Short-term (one year) and long-term (five year) questions:*

What did Commonwealth environmental water contribute to patterns and rates of decomposition?

What did Commonwealth environmental contribute to patterns and rates of primary productivity?

***Selected Area evaluation questions:***

*Category 3 metabolism monitoring:*

What did Commonwealth environmental water contribute to patterns and rates of decomposition?

What did Commonwealth environmental contribute to patterns and rates of primary productivity?

***Flow types:*** All flow types

***Predictions:***

- Primary production and respiration increase in response to pulsed delivery of Commonwealth environmental water
- By inundating adjacent riparian habitat, pulsed environmental flows will increase carbon availability in-stream, shifting metabolism towards net heterotrophy
- Nutrient availability increases in response to pulsed delivery of Commonwealth environmental water.

***Category 3 Hypoxic blackwater risk and return flows metabolism monitoring (Optional monitoring as required):***

What did Commonwealth environmental water contribute to patterns and rates of decomposition in riverine habitats adjacent to return flows?

What did Commonwealth environmental water contribute to patterns and rates of primary productivity in riverine habitats adjacent to return flows?

What did Commonwealth environmental water contribute to hypoxic blackwater risk in wetlands and riverine habitats?

***Flow type:*** Overbank (both river flows and infrastructure assisted)

***Predictions:***

- During return flows increased rates of primary production and respiration in reaches downstream from wetlands receiving Commonwealth environmental water
- During return flows increased use and fixing of carbon and nutrients in reaches downstream from wetlands receiving Commonwealth environmental water
- Longer- term reduction in carbon accumulation and subsequent reduction in the risk of hypoxic black water events across the floodplain following Commonwealth environmental watering actions in wetlands and floodplains.

| LTIM Project indicators | Evaluation questions | Metrics | Critical covariates / Other data sources | Sampling regime |
|---|---|---|---|---|
| Stream metabolism (Cat 1) | What did Commonwealth environmental water contribute to patterns and rates of decomposition?<br>What did Commonwealth environmental water contribute to patterns and rates of primary productivity? | Continuous logging (10 minute intervals) of: photosynthetically active radiation (PAR), barometric pressure, dissolved oxygen (DO), temperature.<br>Monthly water samples assayed for: dissolved organic carbon (DOC), Chlorophyll-a, *Nutrients (TN, TP, NOx, NH4, FRP)**<br>Monthly spot measures of conductivity, turbidity and pH.<br>Daily metabolism (gross primary production, community respiration, net daily metabolism*)* | River discharge. | Carrathool zone Murrumbidgee River (1 site)<br>As per Cat 1 standard method |
| River nutrients, carbon and Chlorophyll a | Short term: What did Commonwealth environmental water contribute to native fish reproduction?<br><br>What did Commonwealth environmental water contribute to native larval fish growth?<br><br>What did Commonwealth environmental water contribute to native fish survival? | dissolved organic carbon (DOC), Chlorophyll-a, *Nutrients (TN, TP, NOx, NH4, FRP)**<br>Monthly spot measures of conductivity, turbidity and pH. | River discharge. | Paired with larval fish sites Murrumbidgee River Carrathool zone (2 sites), Narrandera Zone (3 sites)<br>Fortnightly sampling water for 3 months in line with larval fish monitoring.<br>Methods for nutrients and carbon as per Cat1 standard methods.<br>Chlorophyll-a assayed via a more accurate method. |

| LTIM Project indicators | Evaluation questions | Metrics | Critical covariates / Other data sources | Sampling regime |
|---|---|---|---|---|
| Hypoxic Blackwater risk and return flows (**Optional component**) | What did Commonwealth environmental water contribute to patterns and rates of decomposition in riverine habitats adjacent to return flows?<br><br>What did Commonwealth environmental water contribute to patterns and rates of primary productivity in riverine habitats adjacent to return flows?<br><br>What did Commonwealth environmental water contribute to hypoxic blackwater risk in wetlands and riverine habitats? | Continuous logging (10 minute intervals) of: photosynthetically active radiation (PAR), barometric pressure, dissolved oxygen (DO), temperature over the release period.<br>Daily water samples assayed for: dissolved organic carbon (DOC), Chlorophyll-a, Nutrients (TN, TP, NOx, NH4, PO4)*<br>, Daily spot measures of conductivity, turbidity and pH.<br>Daily metabolism (gross primary production, community respiration, net daily metabolism). | Wetland hydrology, aquatic veg cover,<br>fish and tadpole abundance | Return flows:<br><br>Mobile series of seven sites, locations changed to wherever return flows are planned.<br><br>Methods for metabolism and nutrients as per Category 1 standard methods. Chlorophyll-a assayed via a more accurate method. Wetland oxygen assayed using 12 hour deployments of dissolved oxygen loggers.<br><br>**Additional wetland monitoring:** Continuous logging (10 minute intervals) of dissolved oxygen and temperature spanning a minimum of 12 hours (late afternoon to following morning) to capture the full range of oxygen conditions at each flooded wetland. |
| Wetland nutrients, carbon and Chlorophyll a | Short term: What did Commonwealth environmental water contribute to native fish reproduction?<br><br>What did Commonwealth environmental water contribute to native larval fish growth?<br><br>What did Commonwealth environmental water contribute to native fish survival? | Dissolved organic carbon (DOC), Chlorophyll-a, *Nutrients (TN, TP)**<br><br>Spot measures of conductivity, turbidity, DO and pH. | Wetland hydrology aquatic veg cover, | Aligned with core wetland monitoring sites<br>12 sites across 3 zones: Mid-Murrumbidgee, Redbank, Nimmie-Caira,<br>5 in 5 years, 4 surveys per year<br>Analysed in the laboratory. |

### 5.4.2 Methods

***Category 1 in-stream metabolism monitoring***

The Category 1 stream metabolism point will be established in the Carrathool zone (358 km) aligned with Category 1 larval fish and riverine fish sites. Sites will use discharge data from the established gauge network at Darlington Point, Carrathool and Hay gauging stations. Metabolism will be monitored continuously for six months between September and February

***River Nutrients, Carbon and Chlorophyll a***

Fortnightly duplicate water samples to be analysed for nutrients (TN, TP, FRP, NOx, $NH_4$, $PO_4$), dissolved organic carbon (DOC) and Chlorophyll-a over a three month period in line with Category 1 and Selected Area larval fish monitoring. Each site will be approximately 150 m long, with samples collected randomly along this length from mid-stream. Nutrient samples as well as spot measures of temperature, conductivity, turbidity and pH will be made at three separate locations using a calibrated multiparameter handheld meter. Nutrients including (TN, TP, FRP, NOx, $PO_4$ as per standard method) and DOC will be analysed at a NATA accredited laboratory. Chlorophyll a will be analysed at the CSU laboratory to achieve the lower detection limits. In the laboratory, Chlorophyll-a is extracted from filter papers using an ethanol buffer technique. Chlorophyll-a concentration is measured using a spectrophotometer (Eaton, Clesceri *et al*. 2005).

***Hypoxic blackwater risk evaluation and return flows monitoring (Optional indicator) Note that monitoring of return flows will be funded under separate contracts as required.***

Return flows are a key feature of Commonwealth environmental watering actions in the Lowbidgee. Return flows will be studied using a before/after control impact design, monitoring river sites downstream of the escape regulator and control sites upstream (a total of seven sites). Control sites include one immediately upstream of the escape regulator, but far enough upstream to be away from any effects of the release, and one additional site upstream of this. Four impact sites will be located downstream of the escape regulator. One further site will be sampled within the wetland immediately behind the escape.

The spatial spread of river sites will vary depending on river discharge and the relative magnitude of return flows, but are nominally 1 km apart. Sample frequency will depend on how long the return flow lasts, but is nominally two samples before the release, one sample each day for seven days during the release, and two samples after the release (i.e. 11 sampling occasions). The spacing of sites and frequency of sampling will be adjusted to match the scale of any planned event.

Changes in stream metabolism related to return flows will be event based and involve intensive monitoring before, during and after (daily sampling) in and around the point of discharge from the floodplain. Field data collection will be consistent with the category 1 standard methods including collection of continuous dissolved oxygen, temperature, discharge, PAR and barometric pressure, and duplicate water samples to be analysed for nutrients (TN, TP, FRP, NOx, $NH_4$), dissolved organic carbon (DOC). Chlorophyll-a will be analysed at CSU using a spectrophotometer . Each site will be approximately 100 m long, with samples collected randomly along this length from mid-stream. For each sampling event, spot measures of temperature, conductivity, turbidity and pH will be made at three separate locations using a calibrated multiparameter handheld meter. During each sampling event, return flow discharge will be estimated using an acoustic doppler velocimeter following the Category 1 standard methods for estimating discharge.

***Wetland nutrients, carbon, Chlorophyll a and blackwater risk monitoring***

Nutrients, Carbon, dissolved oxygen and chlorophyll a are critical covariates explaining microinvertebrate, aquatic vegetation, fish and tadpole responses to Commonwealth environmental watering in floodplain wetlands. Environmental watering actions can be used to reduce the long-term risks of hypoxic blackwater by allowing for the transformation and uptake of carbon. Monitoring of nutrients, carbon, Chlorophyll a will be undertaken at each fish wetland site (n=12) four times per year in conjunction with wetland fish monitoring and therefore represents a minor additional cost to the project. In addition, dissolved oxygen loggers will be deployed overnight (for twelve hours), capturing the peak dissolved oxygen in the previous afternoon as well as the night time trough, as the peak risk of fish mortalities occurs at night when DO levels are at their lowest. Wetland nutrient samples (total nitrogen, total phosphorus and dissolved organic carbon) will be analysed in the laboratory.

### 5.4.3 Data analysis framework against evaluation questions

***Category 3 in-stream metabolism***

Simple linear regression will be used to test the dependence of metabolism on flow, temperature, and other dependent variables (Marcarelli et al. 2010). Using these established relationships, the effect of environmental watering on metabolism will be inferred by the difference between observed environmental flows and the predicted hydrology and nutrient status in the absence of environmental water.

Where applicable, the impacts of environmental flows will be estimated by analysing changes in metabolism and associated covariates before, during, and after discrete releases.

***Return flows monitoring***

The above research questions will be tested using a two-way permutational analysis of variance (PERMANOVA) with time (before, during, after) and location (wetland, river above, river below) as fixed factors. Downstream sites will be treated as replicates for most analysis, though it is expected that the response will vary with distance downstream and that these replicate sites are not truly independent.

***Wetland nutrients, carbon and Chlorophyll a and Blackwater risk monitoring***

Key variables will be included in wetland process models quantifying the ecosystem response to Commonwealth environmental watering. Dissolved oxygen, temperature, discharge, leaf litter and DOC data will be used as inputs into the Blackwater Risk Assessment tool (draft prepared by the MDFRC – see also Whitworth, Baldwin et al. (2013). Outputs from this modelling will be used along with other observations and expert advice to assist decision making regarding watering sites, return flows and river dilution flows.

## Flora – condition, recruitment and diversity

Recovery and maintenance of water dependant vegetation communities throughout the Murrumbidgee Selected Area is a key environmental watering objective in the Murrumbidgee (Murray-Darling Basin Authority 2012b, Murray-Darling Basin Authority 2012a, Murray-Darling Basin Authority 2012c, Gawne, Brooks *et al.* 2013a). Water dependent communities in the Murrumbidgee Selected Area are diverse including river red gum (Riverine forest), black box and lignum (Figure 13). Within these communities there is significant variation in understory communities reflecting the complex bathymetry of wetlands across the Lowbidgee floodplain (Plate 1), including:

- River red gum forest
- River red gum woodlands
- River red gum forest- spike rush
- Black box woodland
- Black-box-river cooba
- Black-box -Lignum
- Lignum
- Seasonally inundated oxbow lagoons
- Permanent oxbow lagoons and creek lines with submerged and floating aquatic forbs.

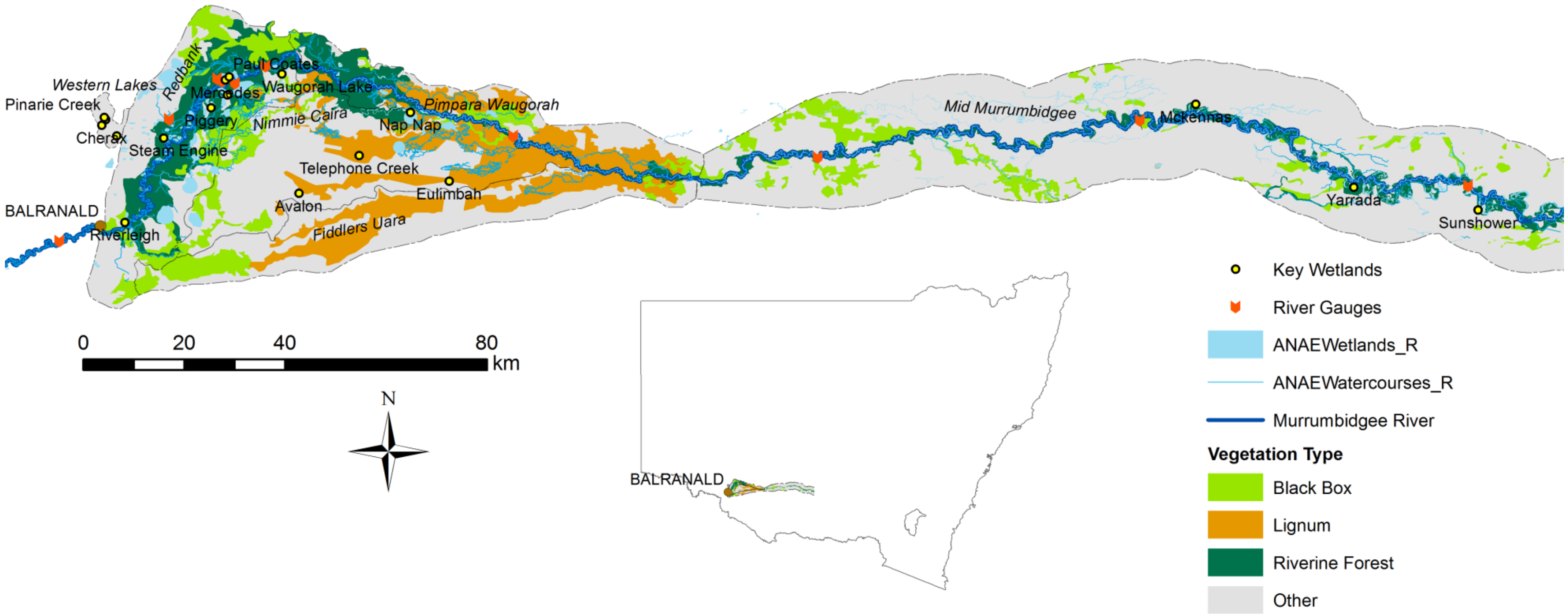


Figure 13 Distribution of water dependent vegetation communities through the Murrumbidgee Selected Area

(a) River red gum- spike rush/aquatic forb community (Redbank)

(b) Lignum-black box –aquatic forb (Nimmie-Caira)

(c) Seasonally inundated oxbow lagoon river red gum- aquatic forb (mid-Murrumbidgee)

(d) Permanent oxbow lagoon river red gum- fringing aquatic (mid-Murrumbidgee)

Plate 1 Subset of water dependent vegetation communities in the Murrumbidgee Selected Area

## 5.5 Vegetation diversity

The percent cover and composition of aquatic vegetation can determine the availability of oviposition sites for macroinvertebrates (Humphries 1996) and calling and spawning locations for frogs (Wassens, Hall *et al*. 2010) and support wetland food webs and zooplankton communities (Warfe and Barmuta 2006). The response of aquatic and semi-aquatic vegetation following a flow event is important in its own right and as a critical covariate explaining the breeding and recruitment outcomes by frogs and waterbirds, as well as nutrient transfer, and composition of microinvertebrate communities.

Prolonged drought can reduce the diversity and cover of wetland vegetation and the resilience of established seed banks (Brock, Nielsen *et al*. 2003, Tuckett, Merritt *et al*. 2010). The recovery of aquatic vegetation communities in the mid-Murrumbidgee wetlands has been intensively monitored by CSU since November 2010. Environmental releases targeting wetlands in the mid-Murrumbidgee region in 2011 were successful in promoting some recovery of aquatic and semi-aquatic vegetation within the wetlands. However, the wetland vegetation communities remained relatively degraded in 2012 (Wassens, Watts *et al*. 2012a).

### 5.5.1 Evaluation questions

***Basin scale and Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to vegetation species diversity?

What did Commonwealth environmental water contribute to vegetation community diversity?

***Predictions:***

- Commonwealth environmental watering actions that increase water levels within wetlands and inundate fringing habitats will promote the germination, growth and flowering of aquatic and semi-aquatic vegetation.

- Commonwealth environmental watering actions will contribute to the reestablishment and maintenance of diverse native aquatic and semi-aquatic vegetation communities, with the rate of reestablishment also influenced by historical management of flows ( historical wetting and drying patterns)
- The response of aquatic and semi-aquatic vegetation communities following Commonwealth environmental watering actions will play a key role in providing habitat to support breeding and recruitment of wetland species, including frogs, small-bodied native fish, and waterbirds

| **LTIM Project indicator** | **Evaluation questions** | **Metrics** | **Critical covariates/ Other data sources** | **Sampling regime** |
|---|---|---|---|---|
| Vegetation diversity (Cat 2) | What did Commonwealth environmental water contribute to Vegetation species diversity?<br><br>What did Commonwealth environmental water contribute to Vegetation community diversity? | Understory species richness<br>Percent cover of each understory species<br>Tree recruitment<br>Photo point | Wetland hydrology<br>Depth, duration, rise and fall, flooding regime | As per standard method<br>Aligned with core wetland monitoring sites<br>12 sites across 3 zones: Mid-Murrumbidgee, Redbank, Nimmie-Caira,<br>5 in 5 years<br>Four surveys per year ( Before, during and after flows)<br>3 x 150 transects or 2 x 250 m transects |

### 5.5.2 Methods

***Understory vegetation diversity (Category 2)***

Vegetation community composition, percent cover and tree recruitment will be assessed as per the standard method and will be undertaken at 12 wetlands (aligned with fish wetland monitoring sites). These sites are representative of dominant vegetation communities across the mid-Murrumbidgee (n=4) (river red gum- oxbows) and Lowbidgee floodplain (n=4) (lignum/black-box, river red gum-spike rush depressions (n=4). Surveys will be undertaken on four occasions in conjunction with wetland fish surveys (September, November, January, and March) to capture annual changes in vegetation growth and establishment and wetland draw down.

Wetland geomorphology differs considerably between the mid-Murrumbidgee region and the Lowbidgee floodplain, and, as a result, different placements and lengths of transects are required to adequately capture the response of vegetation communities. Oxbow lagoons in the mid-Murrumbidgee, while variable in terms of their commence-to–fill and depth, have uniform bathymetry with strong vertical variation in vegetation species composition (e.g. terrestrial-semi-aquatic-aquatic and tree recruitment) with the boundary between these three dominant communities changing over time in response to wetlands' filling and drying patterns (Plate 3).


Plate 2 McKenna's Lagoon in the mid-Murrumbidgee two months after inundation (August 2012) (left) and in dry phase (December 2013) (right) showing strong vertical lines of river red gum recruitment.

Three permanent 90m or150m transects or two 250m transects containing either 30 or 50 1m$^2$ quadrats will be established >100 m apart at each wetland. Transects will align with those established in 2010 and IMEF transects that were established in 1998 (Chessman 2003) where appropriate. Each transect starts at the high water line and runs towards the centre of the wetland. Each 1 m$^2$ quadrat is assessed for Crown Cover, leaf litter, log cover, bare ground, open water, water depth, soil moisture and tree size class percent cover of each species, as per standard method (Category 2). Permanent photo points were established at the start of each transect in 2012 to provide a graphic representation of vegetation recovery over time.

### 5.5.3 Data Analysis framework against evaluation questions

The change in vegetation community composition before, during and after Commonwealth environmental watering actions within the Selected Area, will be analysed using PERMANOVAs for multivariate community data. Vegetation diversity change will be assessed at two temporal scales –within year change in vegetation cover and diversity following environmental watering actions is evaluated within and between water years, and between zones using PERMANOVA (Anderson, Gorley *et al*. 2008) in Primer (Clarke and Gorley 2006). Post-hoc testing will be used to examine where significant differences were observed among times and zones. This will allow us to evaluate whether environmental water changed the relative contribution of key functional groups.

## 5.6 Microcrustaceans

Microinvertebrates play a key role in floodplain river food webs, as prey to a wide range of fauna including fish (King 2004) and as important consumers of algae, bacteria and biofilms. Microinvertebrates are the critical link between stream metabolism and larval fish survival and recruitment (King 2004). As fish are gape limited, the availability of microinvertebrate prey in each size class at different times in the larval fish development is a critical factor influencing growth and survival. Density of microinvertebrates is also considered important for larval success, with densities between 100 and 1000/L reported for marine fish and densities within this range noted in hatching experiments and aquaculture for freshwater species (King 2004). Different taxa of microinvertebrate move at different speeds and this will also influence their availability to larval fish. Microcrustaceans also contribute to biodiversity and their reproduction, growth, and recruitment is heavily influenced by flow regimes (Jenkins and Boulton 2007).

Landscape fish diversity and fish recruitment are strongly influenced by the availability of suitable food resources and limited food supply is a key factor causing failed recruitment and high initial mortality of larval fish (Balcombe and Humphries). The CED for landscape fish diversity ties the area, heterogeneity and connectivity of food and habitat resources to fish diversity, mediated by river flow. In developing a CED for microcrustaceans (Figure 14) we refine the hydrological indicators that influence this critical food supply for fish. Blooms of microinvertebrates are associated with better condition in some fish species (Koehn and Harrington), particularly those utilising wetlands (Beesley, Price *et al*. 2011), where densities of microinvertebrates are higher than in nearby river channel (Jenkins, Iles *et al*. 2013). Microinvertebrates pulse after floods (Jenkins and Boulton 2003) and this higher food availability is associated with improved body condition after floods compared to periods of low flow (Balcombe, Lobegeiger *et al*. 2012). We have designed a monitoring protocol to examine the relationship between microcrustaceans and larval fish as well as fish and other vertebrates in wetlands. The design draws on analysis of existing data from the Murrumbidgee and inland river systems to determine numbers of wetlands, sub-sampling protocols and numbers of individuals to measure.

Differences in microinvertebrate communities, densities and size classes may further drive differences in recruitment success between native fish populations in microhabitats within the main channel and wetland habitats. Connection of wetlands and the river channel can contribute to the exchange of individuals and open up feeding habitats to recruiting fish (Balcombe et al. 2005). In addition, examining the response of benthic microinvertebrate communities during reconnections in association with metabolism, primary productivity (Chlorophyll a), water quality, higher trophic groups, fish and other vertebrates provides direct information on improvements to ecosystem function (connectivity) and resilience during environmental releases as well as informing outcomes for fish, and other aquatic fauna that feed on microinvertebrates. We use existing data from the Murrumbidgee and other inland river systems to design a sampling protocol to examine connectivity during return flows.

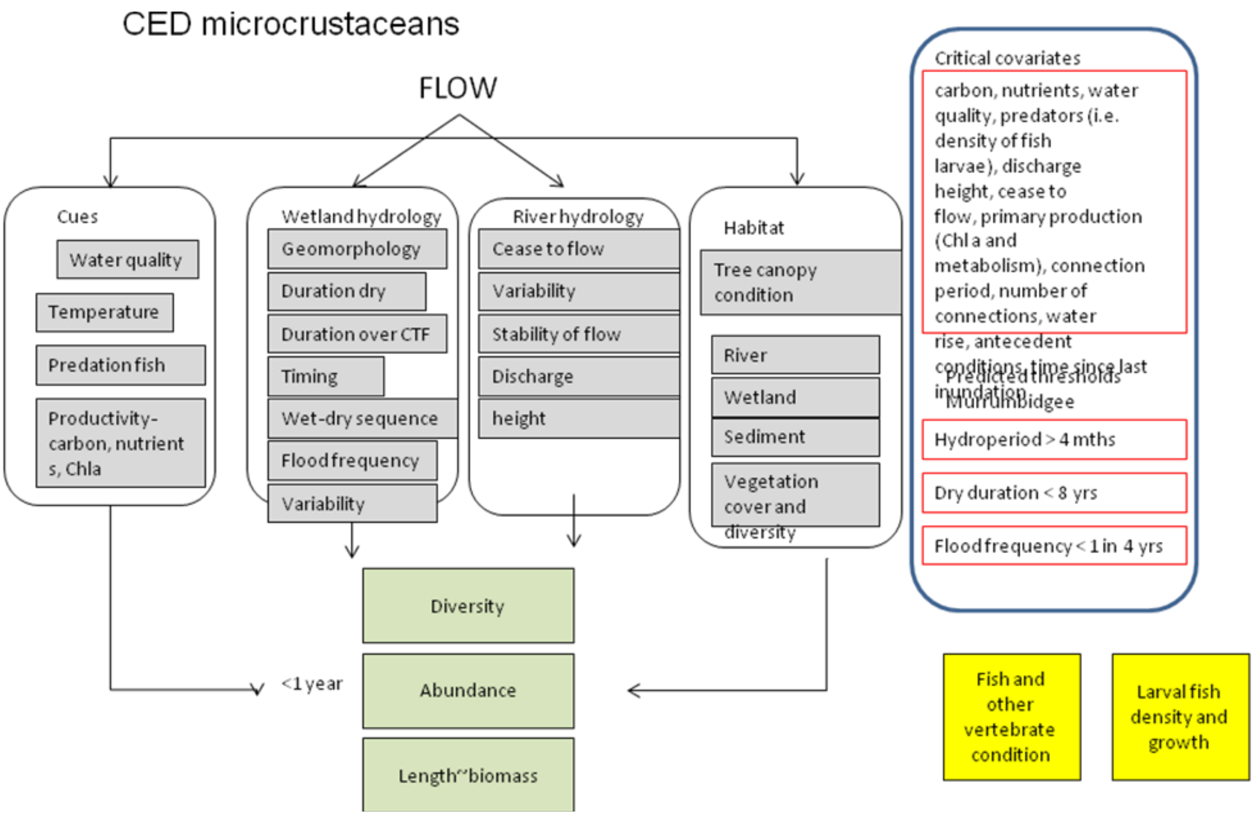


Figure 14 Microinvertebrate CED. Yellow boxes indicate other CEDs.

Microinvertebrate abundance is a Category 3 indicator for the Murrumbidgee system and is a critical covariate linking primary productivity (e.g. stream metabolism) with higher order trophic groups such as fish. It is listed as an indicator for landscape fish diversity under the Basin level 1 objective Biodiversity. Recent empirical evaluation of larval fish and wetland fish responses to environmental flows identified microinvertebrates as a key driver of patterns in larval fish CPUE (Wassens et al. 2013).

The link between microinvertebrate abundance and landscape fish diversity is expressed in two CEDs: fish condition, and fish larval growth and survival. Microinvertebrates are food for some species of freshwater fish as well as providing critical prey for larval fish of all species. It can be included if higher priority indicators are monitored within budget. We recommend including a base level of monitoring in our suite of core sites, times and indicators to provide information on food availability for fish in wetland and channel habitats of the Murrumbidgee. We expand this monitoring to match larval fish sampling in years when recruitment is monitored more intensively.

- In addition to providing a measurable outcome against landscape fish diversity, microinvertebrates also inform two other level 1 objectives: ecosystem function (connectivity) and resilience (ecosystem resilience).
- Wetlands are an important source of microinvertebrates with higher densities and different taxa supported within wetlands making them more food rich than the main river channel.
- Reconnections between the river and its wetland can result in short-term increases in food availability. The density of microinvertebrates will be highest in slow moving riverine and wetland habitats, increasing supply of prey for larval fish and other aquatic fauna.
- The utilisation of microinvertebrates by aquatic predators is influenced by community composition (speed and size), gape (size) and density. As a result size, structure, composition and density of microinvertebrate communities are important

### 5.6.1 Evaluation questions

***Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to breeding and recruitment of native fish?

What did Commonwealth environmental water contribute to wetland productivity nutrients and carbon fluxes, primary productivity (CHL a) and secondary productivity (Microinvertebrates)?

What did Commonwealth environmental water contribute to connectivity between rivers and wetlands?

***Flow types:*** Fresh, Overbank

***Predictions:***

- Increase in availability of suitable microinvertebrate prey in the channels and wetlands increase due to Commonwealth environmental watering
- Peak in microinvertebrate density and length to match a rise in numbers and condition of fish larvae
- Increase in microinvertebrate densities following Commonwealth environmental watering actions
- Change in microcrustacea community composition following Commonwealth environmental watering actions
- An exchange of microinvertebrate species and biomass (density and length) between channels and wetlands during reconnection events
- Peak in microinvertebrate density and length coinciding with rise in abundance and condition of fish larvae following reconnection events.

| Evaluation questions | metrics | Covariates | Sampling regime |
|---|---|---|---|
| What did Commonwealth environmental water contribute to breeding and recruitment of riverine native fish? | Relative proportion of microcrustacean (taxonomic groups)<br>Density of microcrustaceans<br>Size fraction of key taxonomic groups | Carbon<br>Nutrients<br>Water quality<br>Predators<br>Discharge<br>Height<br>Cease to flow | Aligned with larval fish monitoring sites<br>Murrumbidgee River 2 zones, - 3 river sites per zone aligned with larval fish monitoring (fortnightly sampling for 3 months, 5 in 5 years) |
| *What did Commonwealth environmental water contribute to wetland productivity nutrients and carbon fluxes, primary productivity (CHL a) and secondary productivity (Microinvertebrates)* | Composition of benthic and pelagic microcrustacean communities | | Aligned with core wetland monitoring sites<br>12 sites across 3 zones: Mid- Murrumbidgee, Redbank, Nimmie-Caira Plus an additional 4 river sites as control ( n=16) - 5 in 5 years, 4 surveys per year, benthic and pelagic composite |
| **Option component costed with return flows** | | | |
| *What did Commonwealth environmental water contribute to connectivity between rivers and wetlands?* | Relative proportion of benthic microcrustaceans (taxonomic groups)<br>Density of microcrustaceans<br>Size fraction of key taxonomic groups | Connection period<br>Number of connections<br>Water rise<br>Antecedent conditions (wet or dry before filling)<br>Time since last inundation<br>Water temperature<br>Water quality<br>Nutrients, carbon<br>Primary productivity (Chlorophyll a) | Murrumbidgee River zone 4 aligned with return flow monitoring intensive sampling (3 in 5 years) |

### 5.6.2 Methods

The methods below are designed to address each of the three evaluation questions above.

(1) Responses of larval fish supported by microcrustacean productivity, (2) Wetland productivity and, (3) Connectivity

Sampling methods for microcrustaceans are covered in the Standard Operating Procedure (SOP) contained in Appendix 3. In general a benthic core and pelagic sample will be collected at each sample time, with a single composite sample taken from each site. Microcrustacean samples will be collected in association with monitoring of fish larvae, wetland productivity and reconnection events. Below we outline the experimental designs that will be used for each evaluation question.

***Responses of riverine larval fish supported by microcrustacean productivity***

Microcrustaceans will be sampled along with Category 1 and Selected Area larval fish at six channel sites within the Carrathool ( Category 1 sites) (n=3) and Narrandera (Selected Area)(n=3) . In addition, microcrustaceans will be sampled with Selected Area larval fish in three channel sites in the Narrandera zone. One composite benthic sample and one composite pelagic sample will be collected at each site on each larval fish survey occasion (fortnightly for 3 months)

***Wetlands***

Microcrustaceans will be sampled along with wetland nutrient, carbon, fish and vegetation monitoring (12 sites) and four channel sites (total 16 sites). One composite benthic sample and one composite pelagic sample will be collected at each site on each wetland.

***Return flows (optional component)***

Microcrustaceans will be sampled in six channel sites and 1 wetland site (7 sites) before, during and after return flows from a wetland to the river. Microcrustaceans will be sampled in conjunction with other measurements of metabolism, nutrients and water quality. One composite benthic sample will be collected at each site on each return flow survey occasion (11 times at 7 sites = 77 samples). Monitoring return flows will be contracted separately.

### 5.6.3 Data analysis framework against evaluation questions

The response of microcrustaceans to environmental water will be analysed using ANOVAs for univariate data and PERMANOVAs for multivariate community data. The change in microcrustacean densities, lengths and taxon richness will be tested within and between water years, and between zones with a two (season, zone) or three way (season, year, zone) fixed factor ANOVA using R (R Development Core Team 2008). Similarly the change in microcrustacean communities within and between water years, and between zones will be assessed using PERMANOVA (Anderson, Gorley *et al*. 2008) in Primer (Clarke and Gorley 2006). Post-hoc testing will be used to examine where significant differences were observed among times and zones. This will allow us to evaluate whether environmental water increased productivity and diversity of microcrustaceans. It will also allow us to assess where differences occur between wetlands and the river that relate to connectivity. We will analyse relationships between microcrustaceans and larval fish, fish, frogs and the multiple covariates (see CED) including flow (see Section 3.5). Where possible, the responses of microinvertebrates to environmental flows will be testing before, during and after discrete releases.

Responses in microinvertebrates to return flows will be tested using a two-way permutational analysis of variance (PERMANOVA) with time (before, during, after) and location (wetland, river above, river below) as fixed factors. Downstream sites will be treated as replicates for most analysis, though it is expected that the response will vary with distance downstream and that these replicate sites are not truly independent.

## 5.7 Fish Communities (River)

Fish communities in the Murrumbidgee Catchment are severely degraded, with only eight of the 21 native species historically recorded in the region recorded since 1975 (Gilligan 2005). Alien species (specifically common carp, *Cyprinus carpio*) can occupy up to 80% of the total biomass in some areas. In addition, small-bodied floodplain species such as the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis agassizii*) were historically abundant from Murrumbidgee River wetland habitats (Anderson 1915), but are now considered locally extinct (Gilligan 2005).

The alteration of natural flow regimes has significantly contributed to these declines. The use of Commonwealth environmental water to restore more natural flow characteristics can benefit native fish by increasing reproduction, stimulating in-stream migration associated with triggering a spawning response (Humphries, King *et al*. 1999, Humphries, Serafinia *et al*. 2002, King, Humphries *et al*. 2003) or improving food availability which can translate to improved condition. Many native fish species use wetlands and floodplains for nursery habitat and feeding, thus allowing movement into and out of connected wetlands can increase recruitment and population persistence of some species (Lyon, Stuart *et al*. 2010).

Environmental water delivery is known to provide detectable changes in fish communities. For example, (Wassens, Spencer *et al*. 2014) examined changes to the fish community before and after a large in-channel release in the Murrumbidgee and identified significant changes in community composition, biomass and spawning of native fish species.

Many fish species are highly mobile, and fish community changes can often occur as a result of redistribution at a site scale during environmental water delivery, due to localised changes in hydraulic and structural habitat availability and food resources (Wassens, Spencer *et al*. 2014). However, changes in fish community composition at the reach and valley scale are also likely to occur in response to environmental water delivery (Figure 15 and Figure 16). For example, over longer time scales (>10 years) landscape fish diversity is influenced by available habitat, connectivity and disturbance, which in turn are influenced by the interactions between flow and geomorphology (Jackson, Peres-Neto *et al*. 2001). Providing greater access to habitat through connectivity is achievable using environmental water and will lead to a detectable change over the medium-long term. Over shorter time scales flow can influence fish condition and biotic dispersal and also sustain populations which are currently under threat. Flow can also influence reproduction directly through cues that stimulate reproductive behaviour or by providing suitable available habitat, likewise, fish recruitment is also influenced indirectly by:

1. Increasing riverine productivity and stimulating food (microcrustacea) production
2. Increasing available habitat such as backwaters and nest sites
3. Promoting suitable water quality
4. Facilitating longitudinal and lateral connectivity and dispersal.

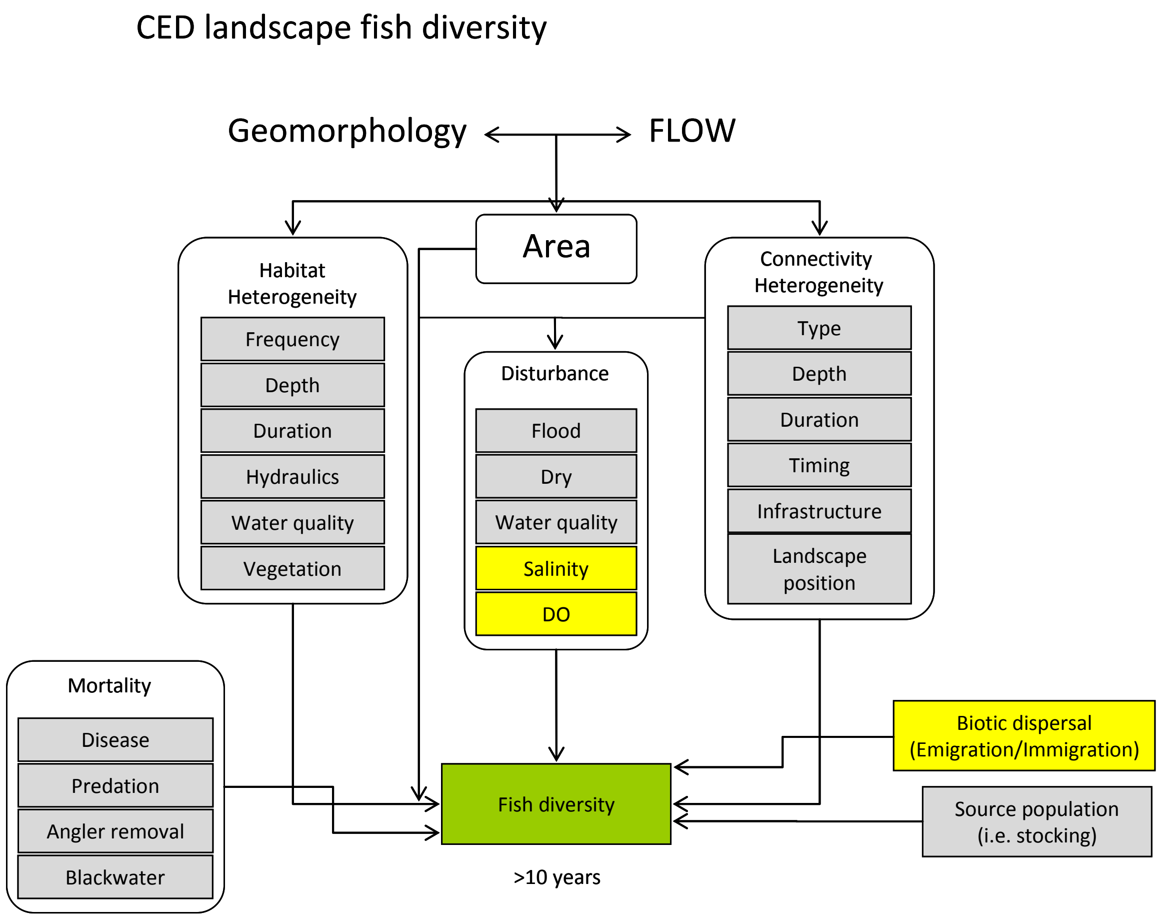


Figure 15 Revised landscape fish diversity CED. Yellow boxes indicate other CEDs.

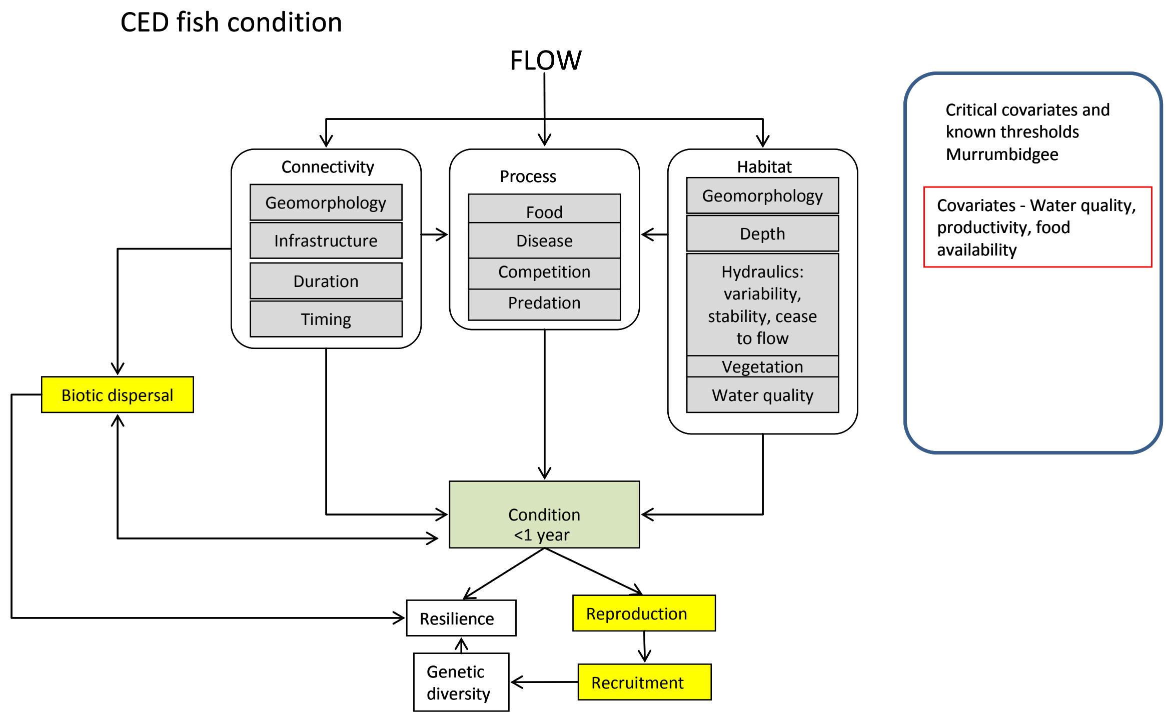


Figure 16 Revised fish condition CED. Yellow boxes indicate other CEDs.

### 5.7.1 Evaluation Questions

***Basin scale evaluation questions:***

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to native fish populations?

What did Commonwealth environmental water contribute to native fish diversity?

*Short-term (one year) questions:*

What did Commonwealth environmental water contribute to native fish community resilience?

What did Commonwealth environmental water contribute to native fish populations?

What did Commonwealth environmental water contribute to native fish diversity?

***Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to native fish populations?

What did Commonwealth environmental water contribute to native fish diversity?

***Flow types:*** Freshes, bank full, Overbank

***Predictions:***

Native fish survival:

- Commonwealth environmental watering increases fish body condition in the Murrumbidgee River

Native fish populations:

- Commonwealth environmental watering maintains or increases native fish recruitment in the Murrumbidgee River
- Commonwealth environmental watering maintains or increases native fish biomass in the Murrumbidgee River

Native fish diversity:

- Commonwealth environmental watering facilitates recovery of rare native species in the Murrumbidgee River through recruitment
- Commonwealth environmental watering facilitates recovery of the fish community through recolonisation

| LTIM Project indicators | Evaluation questions | Metrics | Critical covariates/ Other data sources | Sampling regime |
|---|---|---|---|---|
| Fish (river) Cat 1 | Long term: What did Commonwealth environmental water contribute to native fish populations?<br><br>What did Commonwealth environmental water contribute to native fish diversity?<br><br>Short term: What did Commonwealth environmental water contribute to native fish survival?<br><br>What did Commonwealth environmental water contribute to native fish populations?<br><br>What did Commonwealth environmental water contribute to native fish diversity? | CPUE<br>Length and mass of target species<br>Length-age of target species | Hydrology (River)<br>Water quality,<br>Water temperature, nutrients, chlorophyll a,<br>fish (larvae),<br>fish (movement), fish (wetland) | Murrumbidgee River (Carrathool reach)<br>10 sites<br>Annual sampling (Mar-May)consisting of:<br>Electro fishing (n=16 × 2 x 90 sec shots)<br><br>Small mesh fyke nets (n=10/site)<br><br>Additional sampling in yrs 1&5 for equilibrium and periodic otolith – multiple active and passive methods |
| Fish (river) SA | | CPUE, abundance, diversity, species richness, condition, native species biomass, size structure, SRA indices (nativeness, expectedness, recruitment index) | Hydrology (River)<br>Water quality,<br>Water temperature | Murrumbidgee River. 3 zones (Narrandera, Carrathool and Balranald reach)<br>21 sites spread across 3 zones (n=7 sites per zone), SRA sampling protocol. Note: Data from some Cat 1 sites in the Carrathool zone will be used for Selected Area analysis and reporting Year 1 and 5 sampling (Mar-May) consisting of SRA protocol:<br><br>Electrofishing (n=12 × 90 sec shots)<br><br>Unbaited bait traps (n = 10 × min 1.5 hr soak) |

### 5.7.2 Methods

***Category 1***

Standard methods will be used in zone 2 (Darlington point to Carrathool) for Basin-scale reporting. These methods will provide information on native fish responses to environmental water across multiple time scales. Note that we have provided a budget for the destructive sampling of periodic and equilibrium species in years one and five based on the expected level of effort required to obtain the required sample sizes and size range of species required to generate age-growth curves. This sampling will occur in addition to annual community sampling and at other locations within zone 2 (Darlington point to Carrathool) to avoid influencing annual survey results. Further, in order to improve comparability with historical data (SRA, NSW DPI) and for use in Selected Area analysis and reporting, the following additional protocols and augmentations at each site have been proposed;

1. The amount of sampling effort per 90 second electrofishing 'shot' is to be partitioned between littoral/structural and open water habitats at a ratio of 5:1 in order to maintain comparability with CPUE data generated using the standard Sustainable River Audit (SRA) protocol. This means that within any single electrofishing operation, 75 seconds should be used to sample littoral/structural habitats and 15 seconds of sampling should be undertaken in open-water habitats < 4 m deep.
2. Length data from all species is recorded for all operations of every gear type (with sub-sampling of 20 individuals per shot/net/trap) to allow generation of SRA metrics. This includes alien and both large and small bodied species.
3. The individual weight of the first 50 individuals measured for length of each non-target species will also be recorded.

***Selected Area***

In addition to the standard methods, fish communities within the Murrumbidgee River Selected Area will be assessed in year 1 and year 5 at 19 sites using a modified SRA protocol which reflects longer term monitoring activities (*see* Wassens et al. 2013).

These sites will be located between Narrandera and Balranald and comprises 21 sites total; seven nested within each of three zones (zones Narrandera, Carrathool and Balranald). Sampling will be conducted from March-May, and the timing of this sampling will enable us to determine the presence of young–of–year fish as well as contribute to long-term data on changes in fish community structure, including indices of diversity, abundance, size structure, biomass and condition.

Long term sites will be retained, where possible, within the Selected Area to facilitate long-term comparisons with existing datasets. A subset of sites from the Carrathool zone, with data collected using Category 1 standard methods will be used in Selected Area analysis, resulting in fish community data from all three in-channel zones within the Selected Area. The proposed approach enables reporting on valley-scale changes in fish community structure following environmental watering and can be used to inform longer term trajectories of change. The distribution of sites will also enable us to evaluate recovery of the fish community from hypoxic blackwater events that occurred in the lower Murrumbidgee River (zone 3) in 2010-11.

Additional augmentations to the standard SRA protocol will be:

- The LTIM Project subsampling procedure of measuring the first 20 individuals per shot/net/trap will be utilised in place of the SRA's subsampling procedure.
- The individual weight of the first 50 individuals measured for length of each species will be recorded.

Fish will be collected using the SRA protocol where twelve replicates of 90 second electrofishing shots (Smith-Root Model 7.5KVa electrofishing units) will be completed at each site. Additionally, ten unbaited bait-traps (minimum of 1.5 hr soak) will be set to capture any small-bodied fish not efficiently sampled during routine electrofishing. At the completion of each electrofishing and netting operation, all fish will be identified, counted, measured and weighed (maximum of 50 individuals per species per shot). Use of the SRA protocol enables comparison with long term datasets collected using similar methods, as well as cross validation with the intensive Category 1 reach, it also offers a rapid, cost-effective and robust approach and allows for monitoring of fish communities at a broader spatial scales.

Important points of difference to LTIM Project standard riverine fish sampling methods are that:

- Small-meshed fyke nets will not be used.
- Only 18 to 20 minutes of electrofishing sampling effort will be used per site (depending on electrofishing equipment used).
- No otolith samples will be retained

### 5.7.3 Data analysis framework against evaluation questions

***Condition***

The collection of length and weight data at all sites will enable calculation of a condition index for each fish. This data will be analysed using PERMANOVA to identify the differences in fish condition in relation to watering regimes among zones and over time. It is important to note that fish with a high condition score are typically more resistant to negative environmental factors and have greater reproductive potential.

***Recruitment***

Annual age data will be collected from Zone 2 (Darlington point to Carrathool) using standard methods (Hale et al. 2014). Ageing will be conducted annually for two opportunistic species and, in years one and five, for periodic and equilibrium species. This enables age-length curves to be generated for six species (two from each guild) to examine the effect of the hydrological regime among years on year class strength, and hence recruitment into the population.

Additionally, fish length structure will be compared among zones for each species (where sample sizes permit) using Kolmogorov-Smirnov tests to examine changes in length distribution. Increased recruitment would be expected in years where the hydrological regime facilitated successful reproduction and provided suitable conditions conducive to growth and survival of larvae.

***Native fish diversity and abundance, native fish biomass, recovery of the fish community***

Fish community data will be summarised to compare results to three main SRA indicators (these are fully explained in Robinson 2012). The SRA derived indicators will be: (1) *expectedness* (provides a comparison of existing catch composition with historical fish distributions), (2) *nativeness* (combination of abundance and biomass describing the proportion of the community comprised of native fish), and (3) *recruitment* (provides a proportion of the entire native fish population that is recruiting within a zone). Recruitment will be further divided into recruiting taxa (proportion of native species present recruiting) and recruiting sites (proportion of sites where recruitment occurs). These indicators produce a score that is related to reference conditions, and receive a condition rating (Extremely Poor (0-20), Very Poor (21-40), Poor (41-60), Moderate (61-80), Good (81-100). Changes to SRA condition ratings will be examined in years with and without environmental water, with an overall expectation that condition ratings will improve over time.

Fish community structure will likely differ among zones and over time (years). To investigate the zone- and species-specific responses to environmental watering fish community structure (species specific abundance and biomass) will be analysed using PERMANOVA (PRIMER, with zone (1-3) and year as fixed factors). Tests will be performed using 999 Monte Carlo randomisations to calculate approximate probabilities. This will enable identification of whether peaks in abundance and biomass occur in years that environmental watering occurred or in succeeding years.

## 5.8 Larval fish

The larvae stage is the most critical and fragile part of a fish's life history. Successful spawning of native freshwater fish requires high survival to ensure persistence of populations over the long term. Larval survival is highly dependent on environmental conditions (Rolls, Growns *et al*. 2013), which can be dramatically influenced by flows, including habitat availability (Copp 1992), water temperature (Rolls, Growns *et al*. 2013), dispersal (Gilligan and Schiller 2003), microinvertebrate abundance at first feed (King 2004) and nest site inundation (Baumgartner, Conallin *et al*. 2013). Using environmental water allocations to provide positive outcomes for these factors will lead to increased reproductive opportunities, greater larval survival, and hence, recruitment to the population.

In the Murrumbidgee River, regulation of the flow regime has reduced the timing, frequency and magnitude of high flow events, in the frequency of reconnections between the Murrumbidgee River and mid-Murrumbidgee wetlands, as well as causing a decline in water permanence of wetlands. Consequently several small-bodied fish species such as the Murray hardyhead (*Craterocephalus fluviatilis*), olive perchlet (*Ambassis agassizi*), southern pygmy perch (*Nannoperca australis*) and southern purple spotted gudgeon (*Mogurdna adspersa*) that historically utilised wetland habitats as critical spawning grounds are now rare (Gilligan 2005).

Other native fish species have also declined throughout the catchment. Golden perch and silver perch, both periodic species with flow dependent migration strategies and drifting larval stages, have declined substantially. Murray cod, a nesting species, is threatened by highly variable flow regimes which can expose nests and limit larval survival (Lake 1967). Understanding the critical links between flow and early life history survival are crucial to provide more natural hydrological regimes which can support and improve populations of these species. The recovery of substantial volumes of water, for environmental use, is a major opportunity to facilitate recovery throughout the Murrumbidgee catchment.

Recent literature syntheses provide guidelines for the provision of environmental water to support the reproduction and recruitment of native fish (Baumgartner, Conallin *et al*. 2013, Cameron, Baumgartner *et al*. 2013). Collectively, these works suggest that environmental water, using a specifically designed hydrograph, could benefit groups of species based on similar reproductive strategies. For example, environmental water releases at or above bankfull result in a re-connection of the river and wetlands, providing an opportunity to access spawning and nursery habitat during inundation. The newly inundated habitat should lead to an increase in microinvertebrate abundance, which will provide a food source for larvae spawned within wetlands and as such optimising survival.

Providing a spawning event alone is not a sufficient outcome from an environmental water delivery perspective. If there are insufficient food sources available at the time of first feed, larvae will perish. Any fish spawning event must be subsequently paired with a plankton production (Chlorophyll a and microcrustacean) event to obtain maximum ecological benefit.

### *CED refined*

Commonwealth environmental water allocations have the ability to control habitat accessibility and water quality in a way that cannot be achieved during standard regulated flow conditions. The provision of Commonwealth environmental water should aim to improve habitat, connectivity and cues to improve the quantity and quality of spawning habitat, access to spawning habitat and the abiotic conditions likely to stimulate reproduction, native fish spawning responses to each of these factors are likely to vary based on life-history strategies. In the Murrumbidgee River the timing, frequency and magnitude of flow delivery will further influence responses (Cameron, Baumgartner *et al*. 2013). These factors were not captured in the original CED, nor were adult population parameters (sex ratios, age structure, abundance and overall 'health') (see next section). These factors are critical because they may influence whether a particular species responds to a water delivery event as well as the predicted magnitude of the response, and subsequently our ability to detect a response. We also recognise that the effect of environmental flows on breeding cues, connectivity and habitat can influence movements of fish to suitable locations for spawning. We have subsequently refined the generic CED (Figure 17) for larval fish (Gawne, Brooks *et al*. 2013a).

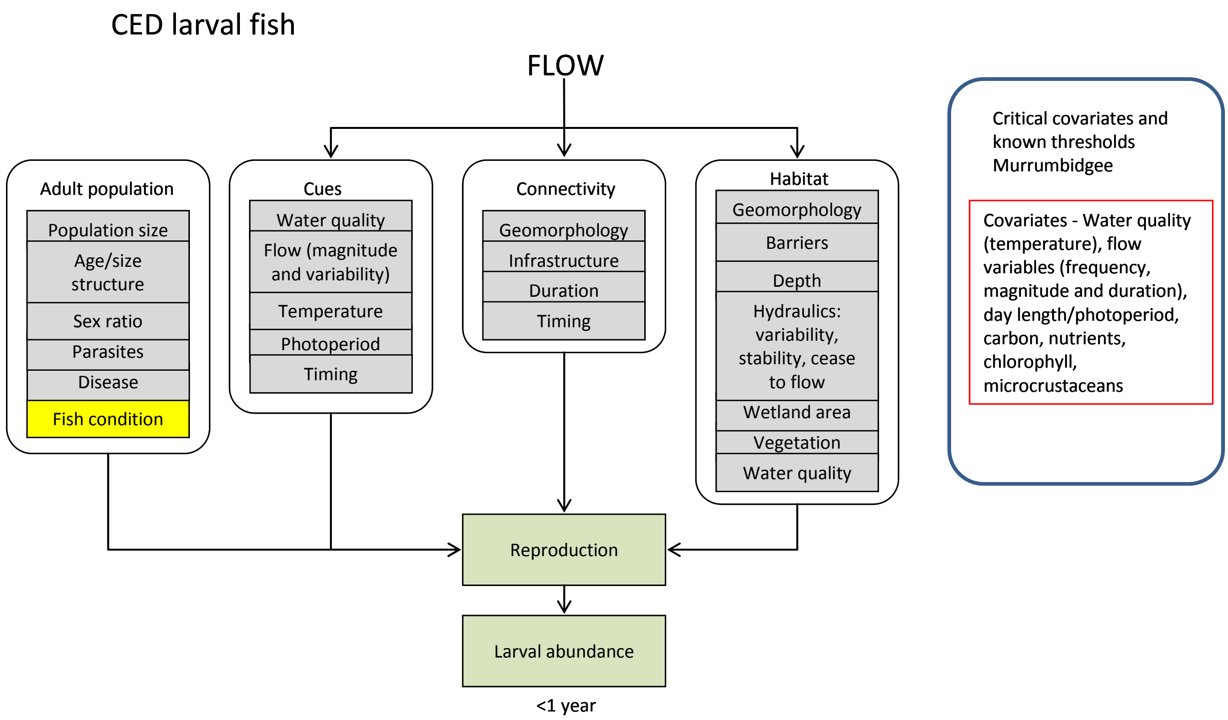


Figure 17 Modified larval fish CED diagram. The yellow box indicates another CED.

### 5.8.1 Evaluation Questions

***Basin scale evaluation questions:***

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to native fish populations?

What did Commonwealth environmental water contribute to native fish species diversity?

*Short-term (one year) questions:*

What did Commonwealth environmental water contribute to native fish reproduction?

What did Commonwealth environmental water contribute to native larval fish growth?

What did Commonwealth environmental water contribute to native fish survival?

***Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to native fish reproduction?

***Flow types:*** baseflow, freshes, bank full, overbank

***Predictions:***

- Native fish reproduction will be dependent on the shape of the hydrographs and the timing of flow delivery.
- In-channel base flows (stable water levels) delivered in late spring and summer provide suitable conditions for the reproduction of equilibrium species (Murray cod and trout cod)
- In-channel freshes and bankfull events delivered in late spring and summer stimulate golden perch and silver perch reproduction
- Wetland inundation and in-channel base flows contribute to opportunistic species reproduction

| LTIM Project indicators | Evaluation questions | Metrics | Critical covariates/ Other data sources | Sampling regime |
|---|---|---|---|---|
| Fish (larvae) Cat 1 | Long term: What did Commonwealth environmental water contribute to native fish populations?<br>What did Commonwealth environmental water contribute to native fish species diversity?<br><br>Short term: What did Commonwealth environmental water contribute to native fish reproduction?<br><br>What did Commonwealth environmental water contribute to native larval fish growth?<br><br>What did Commonwealth environmental water contribute to native fish survival? | Species abundance CPUE<br><br>Daily age of periodic species | Hydrology (River)<br>Hydrology (Wetland)<br>Turbidity<br>Covariates required for area evaluation<br>Water quality,<br>Water temperature<br>day length,<br>nutrients,<br>chlorophyll a,<br>microinvertebrates<br><br>Complementary monitoring: native fish recruitment, native fish diversity and abundance.<br>Existing datasets from two years of monitoring using same methods and overlapping sites in both zones 1 and 2 | Murrumbidgee River (Carrathool reach): 3 in-channel river sites<br>In-channel: Light traps (10)<br>Drift nets (8)<br>(flowing sites 100m apart)<br><br>Wetland:<br>Light traps (10)<br>Larval trawls (3 × 5 min) |
| Fish (larvae) SA | | Species abundance CPUE | Hydrology (River)<br>Hydrology (Wetland)<br>Turbidity<br>Covariates required for area evaluation<br>Water quality,<br>Water temperature<br>day length<br>nutrients,<br>chlorophyll a,<br>microinvertebrates<br>native fish diversity and abundance | Murrumbidgee River (Narrandera Reach): 3 in-channel river sites.<br>In-channel: Light traps (10)<br>Drift nets (8)<br>(flowing sites 100m apart) |

### 5.8.2 Methods

***Site selection***

Category 1 larval fish sampling in the river channel will be conducted within the Carrathool with sites aligned with Category 1 riverine fish community monitoring as per the standard method. In addition to the category 1 larval fish monitoring zone we propose to sample an additional zone (Narrandera) to address Selected Area reporting needs. The hydrograph in the Narrandera zone differs considerably from the Carrathool zone (Category 1 zone), with periods of high discharge coinciding with peak spawning periods of many native fish species. The addition of three larval sampling sites in the Narrandera zone allows for cross validation between zones and provides us with an ability to examine the combined effects of irrigation flows and environmental water. Furthermore, native fish abundance and species richness differ between these zones (Wassens, Spencer *et al*. 2014). It is likely that a combination of both factors (hydrology and adult native fish abundance) will be reflected by differences in the timing and abundance of larval fish collected from these zones. Comparing the timing and intensity of native fish reproductive events across both of these zones enables feedback into effective zone-specific water management.

***Rationale for sampling effort***

In this section we present an analysis of detection probabilities, derived from a series of occupancy models, for larval cod in the Murrumbidgee River using the program Presence (Hines 2006). The aim of the analysis was to quantify the probability of detecting larval cod within the Murrumbidgee River with a given survey effort (number of nets) (see appendix 1 for details of analysis).

Analysis was undertaken on larval fish data collected in 2012/13 using 12 nets per site at six sites within the Murrumbidgee River (*see* Wassens et al. 2013). Based on this analysis between 6 and 8 nets are required to achieve a detection probability of greater than 0.98 (Figure 18) for cod (*Maccullochella* spp.) larvae. Any additional replication beyond this point does not result in a significant increase in the likelihood of detecting the spawning response. The current Category 1 method is for (three drift nets per site (Hale, Stoffels *et al*. 2013) and based on our analysis this level of effort would not have sufficient power to detect the presence of larval cod with a desired level of confidence. We therefore need to increase the sampling intensity at all sites

(Category 1 and Selected Area sites) from three nets to eight nets in order to maximise the effectiveness of our sampling effort.

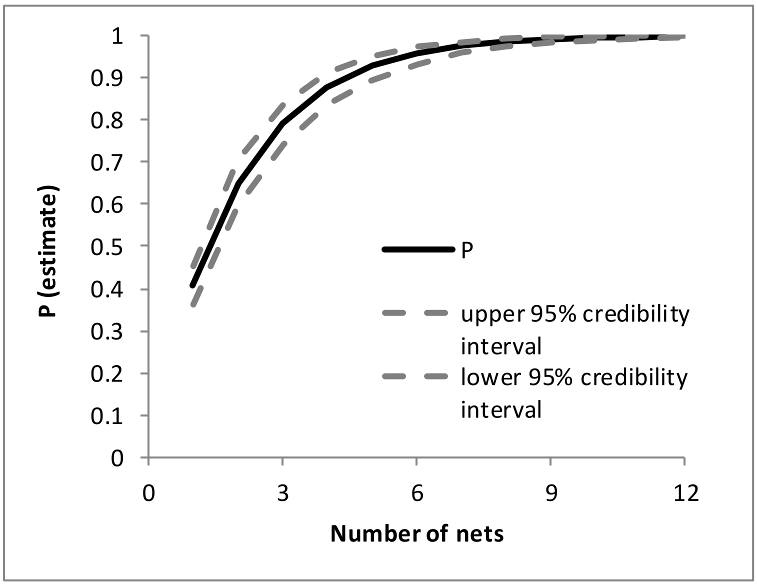


Figure 18. Detection probability of larval cod, where P is the probability of detecting cod (*Maccullochella* spp.) larvae when present at a site, using n larval drift nets.

### *Sample design*

Category 1 larval fish sampling will be conducted in the Carrathool zone at three in-channel sites as per the standard methods outlined by (Hale, R. et al. 2014). Given the low probability of detecting the target species using the standard method alone (see above), we propose to increase the number of drift nets from three to eight at each in-channel site given that sites will be treated as replicates for Selected Area evaluations rather than pooled. The same design will be used to sample three channel sites in Narrandera zone. Each site will be sampled once per fortnight for three months each year (6 trips) as per the standard methods (Hale, R. et al. 2014) and including the additions described above (eight larval drift nets per site instead of three).

*Larval drift*

Larval drift during periods of high discharge can occur over a large spatial extent (Gilligan and Schiller 2003). To compensate for long drifting distances in the Murrumbidgee (which has higher discharge then many of the other LTIM Project Selected Areas), sites will be spaced to cover the greatest distance possible within each zone > 25km where practical. In addition larval sites will be sampled in a downstream-upstream order on each sampling occasion to avoid the possibility of sampling the same water (and hence larvae from the same hatch) at each site.

***Covariates***

At each site and during all larval sampling events we will collect microcrustaceans chlorophyll a, nutrients and water quality data to enable linkages with ecosystem responses to environmental watering, which can suggest whether larval survival was expected and can be used to inform recruitment results.

### 5.8.3 Data analysis framework against evaluation questions

Dependent variables for analysis include:

- Abundance of larvae, standardised to catch per unit effort (CPUE) (as required by standard methods),
- Number of larvae captured per megalitre of water in drift nets and tows, and
- Number of larvae per net night for light traps.

To identify the timing of spawning by periodic species in relation to targeted watering events daily age will be determined for larvae captured from periodic species (golden and silver perch) to provide direct linkages with water delivery (hatch date). In addition, a before-after, control-impact (BACI) design will be used to identify periodic species responses to the timing of environmental flow delivery.

To determine the timing of spawning relative to season, and to examine species-specific spawning responses to targeted flows for equilibrium and opportunistic species, a change point analysis will be used to identify periods of significant change in the abundance of larvae.

To examine the effect of multiple water indices on larval fish abundance (likely equilibrium and opportunistic species), a Generalized Linear Regression modelling approach will be used. Using a model selection approach enables quantification of the magnitude and direction of change in larval fish abundance driven by key covariates including water temperature, discharge and water level.

## 5.9 Wetland fish communities

Historically, small-bodied fish species such as the Murray hardyhead (*Craterocephalus fluviatilis*), Olive perchlet (*Ambassis agassizi*), Southern pygmy perch (*Nannoperca australis*) and southern purple spotted gudgeon (*Mogurdna adspersa*) utilised wetland habitats of the Murrumbidgee River (Anderson 1915). These species presumably moved into wetlands during connection (high flows and floods), taking advantage of the highly productive wetland nursery habitats to spawn and recruit, and successfully re-colonised in-channel habitats during re-connection to the main channel. The change to flow variability within the Murrumbidgee River has led to a major decline in the frequency of reconnections between the Murrumbidgee River and connected wetlands as well as a decline in water permanence, which is one of the primary causes of major declines of many native fish species.

Prior to major regulation of the Murrumbidgee River, many native fish species utilised off-channel habitats such as wetlands and floodplains due to the increased habitat diversity and food availability that these habitats provide (Lyon, Stuart *et al*. 2010). Small-bodied native fish actively moved into wetland habitats upon commencement of filling (Lyon, Stuart *et al*. 2010) and used this habitat to successfully spawn and support larval development and recruitment. Environmental watering in the Murrumbidgee to fill mid-Murrumbidgee wetlands will introduce flow variability into the mid-Murrumbidgee region, allowing for native fish species to spawn and reproduce in a productive wetland environment and also disperse via the main channel. As for riverine fish, pulses of nutrients and emergence of microinvertebrates during wetland inundation provides a key food source for larvae spawned within wetlands and can play a strong role in influencing recruitment outcomes (see Figure 15, Figure 16, Figure 17).

***Rationale for sampling effort***

In this section we present a comparison of detection probabilities, derived from a series of occupancy models, for a range of native and introduced fish species in wetlands using the program Presence (Hines 2006). The aim of the analysis was to quantify (a) the probability of detecting wetland fish species with a given survey effort and (b) provide an overview of abundance upon which to base replication.

Data was drawn from five years of monitoring (October 2008–December 2013) across all wetland types included in the LTIM Project area (Oxbow lagoons in the mid-

Murrumbidgee, large open quaternary lakes west of Lowbidgee (Western Lakes) and shallow, black box lignum and riverred gum spike rush wetlands across the Lowbidgee floodplain (Lowbidgee). Within each water-year, wetlands were surveyed in October, December, February and April. The monitoring commenced during an extreme drought period (2008-2009) and included a significant flood event (2010-11). As a result the number of wetlands containing water in a given year was extremely variable and not all wetlands were sampled on all survey occasions (see appendix 1 for details of data analysis).

The selected survey method must ensure that sufficient numbers of individuals are collected to allow for estimates of size frequencies (as a proxy for population structure). Estimates of abundance per net and mean CPUE were generated using 222 individual large fyke nets and 259 small fyke nets across all habitats and years. Using a combination of paired large and small fyke nets with mesh sizes of 5mm and 12mm respectively we obtained a mean abundance of carp gudgeon of 22.93 individuals in large fyke nets and 146.18 individuals in small fyke nets (Wassens et al 2013). This demonstrates the differing detection probabilities of large and small fyke nets, in this case for small-bodied fish.

This finding was reflected in the clear differences of the capacity of different net types to detect individual species (Figure 19 and Figure 20). Overall, large fyke nets had a higher probability of detecting bony herring, golden perch, Murray-Darling rainbowfish, redfin perch and goldfish, while small fyke nets were slightly more effective for carp gudgeon, and Gambusia. The remaining species; Australian smelt, flat-headed gudgeon, weatherloach and carp were detected at similar rates in large and small nets.

An estimate of the change in detection probability (p) with increasing number of large and small fyke nets was determined for each species (Figure 19). Using the best method for the vast majority of species, two nets is sufficient to obtain a detection probability greater than 0.85. Rarer species such as golden perch had a detection probability of 0.844 (median model) using two double winged large fyke nets with 12mm mesh. For target native species, bony herring, golden perch and Murray-Darling rainbow fish suitable detection probabilities can be obtained using two large fyke nets, with three large fyke nets giving detection probabilities close to one. Importantly small fyke nets are never likely to achieve a suitable detection rate for these three species regardless of how many nets are deployed.

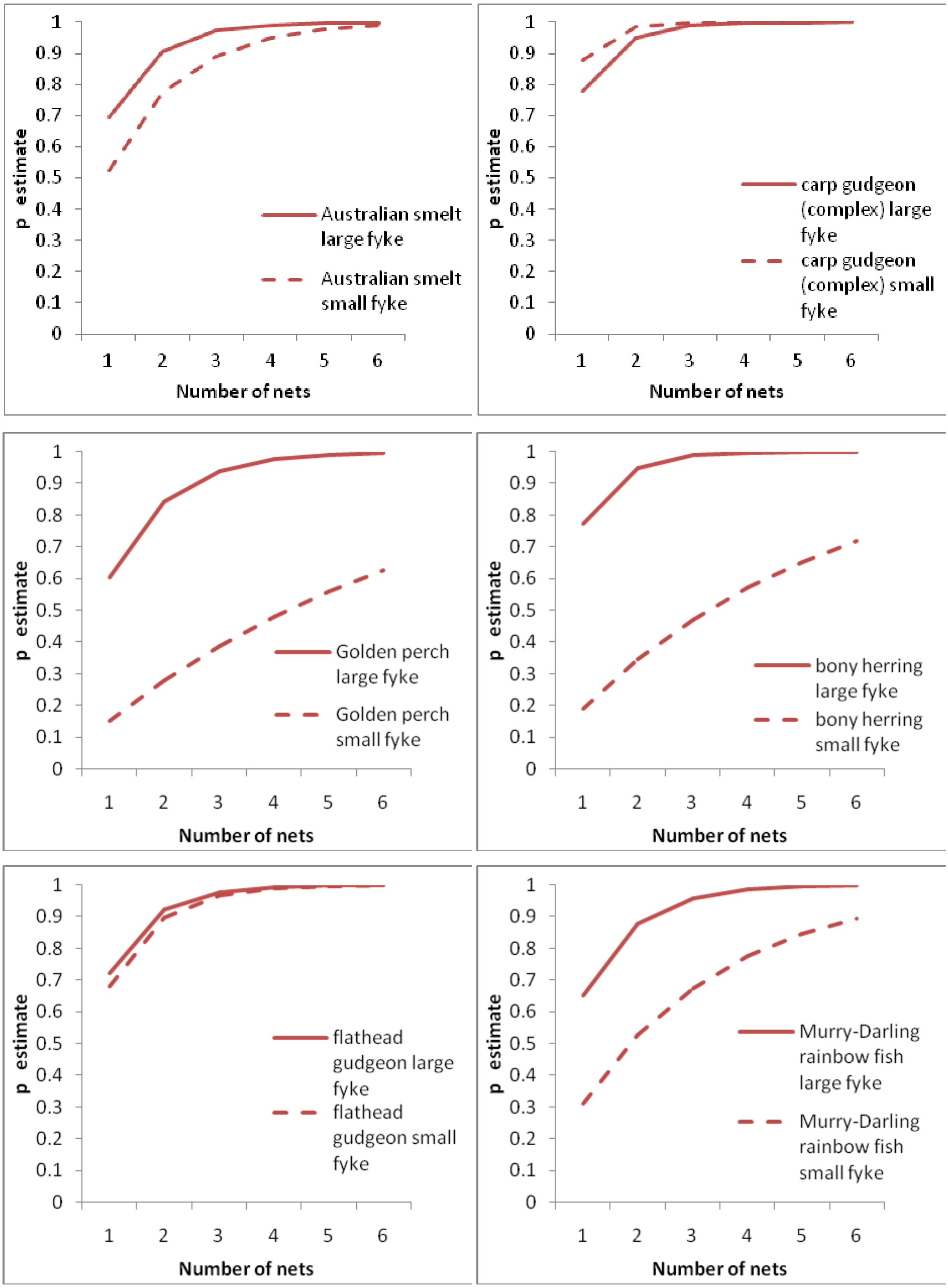


Figure 19 Change in detection with a given number of large and small nets. P (estimate)- assumes the median model middle) for native fish species in wetlands of the Murrumbidgee

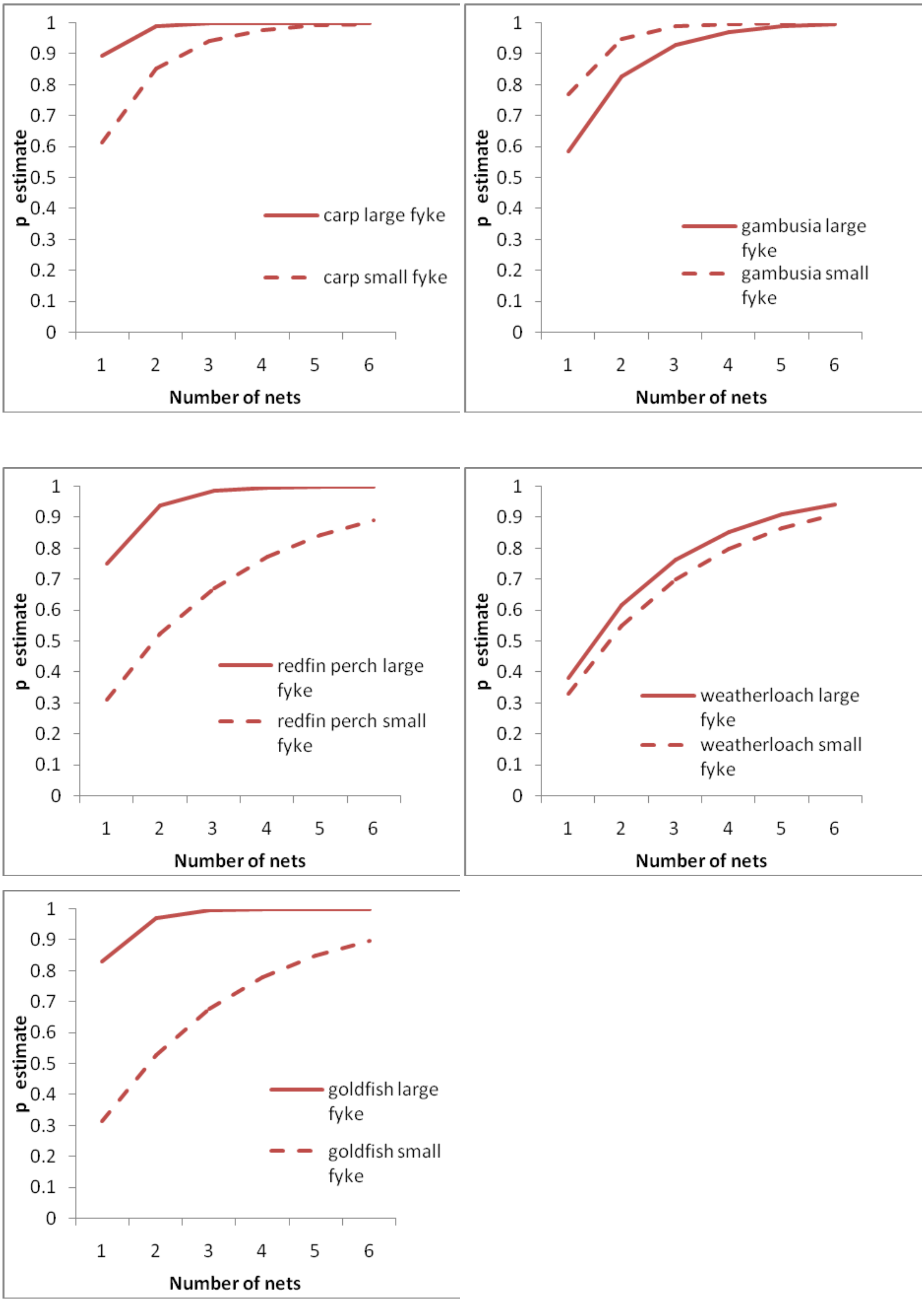


Figure 20 Change in detection with a given number of large and small nets. P (estimate)- assumes the median model middle) for exotic fish species in wetlands of the Murrumbidgee

### 5.9.1 Evaluation questions

***Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to native fish populations and native fish diversity?

What did Commonwealth environmental water contribute to native fish community resilience and native fish survival?

***Flow type:*** Overbank

***Predictions:***

- Increase in native fish diversity in wetlands targeted for Commonwealth environmental watering between year 1 and 5
- Increase in native fish recruitment (Young-Of-year) within and between water years
- Increase contribution of wetland fish recruitment to sustain riverine fish populations through fish movement from wetlands to the river during return flows
- Increase in distribution of native species across wetlands within the wetlands of the Murrumbidgee Selected Area

| LTIM Project indicator | Evaluation questions | Metrics | Critical covariates/ Other data sources | Sampling regime |
|---|---|---|---|---|
| **Wetland fish SA** | Long term: What did Commonwealth environmental water contribute to native fish populations and native fish diversity?<br><br>Short term: What did Commonwealth environmental water contribute to native fish community resilience and native fish survival? | Species diversity and abundance of large and small-bodied fish (CPUE)<br><br>Population structure: size frequency<br><br>Species occupancy patterns and changes in spatial distribution<br><br>Community composition (proportion of native species)<br><br>Demographic structure<br><br>Age daily growth of young of year | Hydrology (Wetland) (Cat 1)<br><br>Antecedent conditions<br>Day length<br>water temperature<br>Water depth<br>Connection days<br>Microinvertebrates community composition, abundance and size structure (food availability for larval fish)<br>Water quality<br>Nutrients, carbon and Chlorophyll-a | Three zones – Fixed: Mid-Murrumbidgee 4 sites:<br>4 (Nimmie-Caira ( 4 sites), Redbank (4 sites) 2 replicates sets of 12 mm double winged large fyke (80cm hoops) or 2 replicates 12mm mesh double winged 50cm hoop (shallow wetlands) and 2mm (double wing) fyke nets (50cm hoops) optimised methods. |

### 5.9.2 Methods

Wetland fish monitoring is integrated with assessment of wetland recruitment (fish and other vertebrates (frogs and turtles) as well as critical covariates including: water quality, nutrients, primary productivity and microinvertebrate communities.

#### *Site selection*

Twelve fixed monitoring locations (n=12) will be established at wetlands that are expected to retain water throughout the monitoring period (four wetlands in each target zone where practical). Over the five year program there may be some inter-annual variability in the number of sites.

***Field methods***

Assuming the use of double winged fyke nets we proposed to use a combination of two large and two small fyke nets, at the remaining wetland sites which should ensure high detection rates for the target species and will provide robust data for assessment of community composition, population size structure, the presence of exotic species and changes of demographic structure, including identification of young-of-year following Commonwealth environmental watering actions.

As wetlands dry, it becomes difficult to place large fyke nets as water is too shallow to cover the hoops. As small (fine mesh) nets are likely to bias against a number of key native species, large fyke nets will be replaced by 5 m double winged 50 cm D-bottom fyke nets with 12 mm mesh. Recording wing width and depth will allow for correction of CPUE circulations to account for smaller net size.

### 5.9.3 Data analysis framework against evaluation questions

*Community composition*

The change in fish community composition within (including before and after Commonwealth environmental watering actions) and between water years will be assessed using Plymouth Routines in Multivariate Ecological Research (PRIMER). Analyses will include consideration of both fish abundance (CPUE) and biomass estimates for sites sampled to determine changes. A vector analysis will be used to demonstrate how species contributed to any observed groupings. Statistical differences in Bray-Curtis transformed fish abundances and biomass data will be investigated using two-way crossed Analysis of Similarities (ANOSIM) using region, sampling period as factors.

*Change in population structure*

Length-frequency distributions of fish species with higher relative abundances (more than 50 individuals) will be quantified using a Kolmogorov-Smirnov goodness of fit test to determine whether there were significantly larger or smaller individuals (length) among sampling trips (as an indicator of potential recruitment).

## 5.10 Other vertebrates - Frogs, tadpoles and turtles (Selected Area)

The vulnerable Southern bell frog (*Litoria raniformis*) is an iconic wetland species in the Lowbidgee floodplain. Environmental watering is critical for the persistence of both Redbank and Nimmie-Caira Southern bell frog populations (Spencer, Wassens *et al.* 2012) and is therefore a priority for the Selected Area evaluation. Monitoring of recruitment of the southern bell frog and other frog species within the mid and Lowbidgee wetlands will follow the Category 3 standard method (See appendix 3). Tadpole monitoring is fully integrated with Category 1 and 3 wetland fish surveys and therefore does not represent an additional cost to the project.

Frogs are sensitive to changes in wetland flooding regimes and respond strongly to environmental releases with large increases in breeding activity. Higher levels of tadpole abundance and recruitment are commonly recorded during managed flood events, e.g (Spencer and Wassens 2010a, Spencer, Thomas *et al*. 2011b, Wassens, Watts *et al*. 2011, Wassens, Watts *et al*. 2012a: Spencer, 2010 #3271: Spencer, 2011 #2983). In many areas managed environmental watering is critical for the persistence of flood sensitive frog species. For example, key populations of the vulnerable (EPBC Act 1999) Southern bell frog were successfully maintained using environmental watering in the Lowbidgee floodplain between 2007 and 2010 (Wassens 2010a).

Frogs exhibit three key responses to flooding: (1) calling activity, (2) tadpole abundance and development, and (3) metamorphosis. Calling activity is a useful measure of the distribution of frogs with respect to underlying hydrological regimes and wetland characteristics (Wassens 2010b, Wassens, Hall *et al*. 2010). That is, it is an indicator of whether a specific environmental watering event has created conditions suitable for *attempted* breeding by resident species. Monitoring tadpole communities and defining development stages is important when managing water levels, because it allows for estimation of how close tadpoles are to reaching metamorphosis and, as such, can provide an early indicator on the need for top-up watering. Size structure within populations has proven to be a useful indicator as it provides a measure of the number of individuals recruiting into the adult population (Figure 21).

While not a specific target of the monitoring program, freshwater turtles are important members of riverine and wetland communities and are frequently collected during wetland fish surveys. There are three turtle species occurring in the Murrumbidgee Catchment: the broad shell-turtle (*Chelodina expansa*) (listed as threatened in Victoria and considered to be near threatened in NSW), the eastern long-neck turtle (*Chelodina longicollis*) and the Macquarie turtle (*Emydura macquarii*). While all three species occur within the main river channel, neighbouring wetlands are particularly important as feeding and nursery habitats for turtles (Chessman 1988, Chessman 2011).

Conceptual links

- The composition of frog communities within individual wetlands is influenced by past filling and drying regimes and connectivity.
- Calling and breeding by the southern bell frog is triggered by water rise within wetlands that inundates fringing and aquatic vegetation. Breeding by other species, including by *Litoria peronii* is likely to occur during wetland draw down.
- Tadpole development and survival is influenced by the timing of inundation, the composition of resident fish communities and the length of time that water remains pooled within wetlands.
- The distribution of freshwater turtles is determined by distance from the main river channel or permanent waterbodies. Floodwaters can facilitate the movement of highly mobile species such as the long-necked turtle between permanent refugia and temporary wetland habitats which have abundant food resources.
- Reduced flooding frequency impact the survival of adult turtles and breeding activity. Information on size distributions of turtles can indicate whether turtles are breeding and levels of recruitment into local populations.

### 5.10.1 Evaluation Questions

***Selected Area evaluation questions:***

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?

*Short-term (one year) questions:*

What did Commonwealth environmental water contribute to breeding and recruitment of other vertebrates?

What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?

What did Commonwealth environmental water contribute to the maintenance of refuge habitats for other aquatic vertebrates?

***Flow type:*** Overbank

***Predictions:***

- Increase in tadpole abundance at wetlands receiving Commonwealth environmental water (within year)
- Increase in abundance of key species (including Southern bell frog) between year 1 and year 5
- Increase in distribution of frogs species across wetlands targeted with Commonwealth environmental water

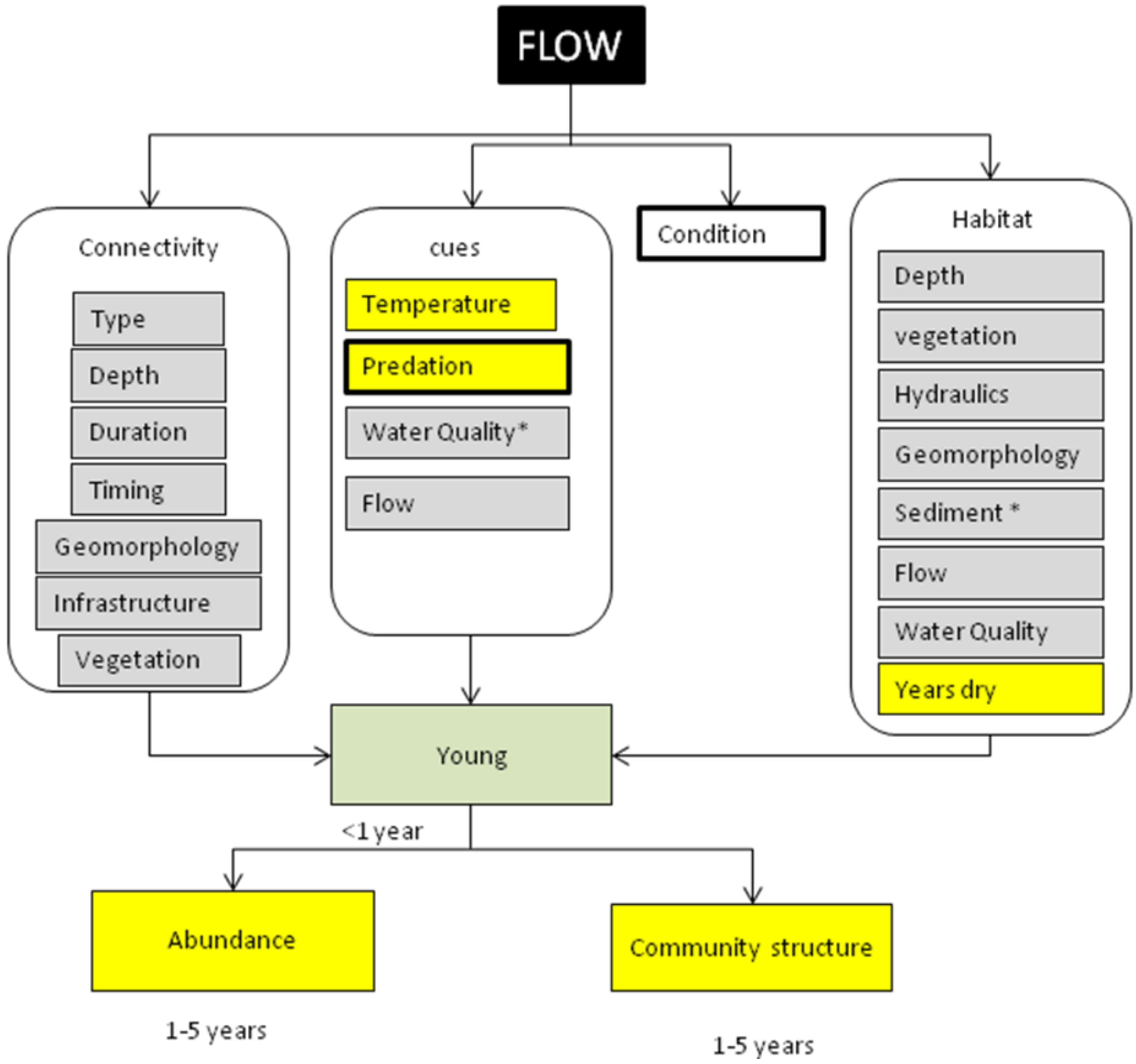


Figure 21 Modified CED for the response of frogs and their tadpoles to Commonwealth environmental water

| Evaluation questions | Metrics | Critical covariates/ Other data sources | Sites |
|---|---|---|---|
| What did Commonwealth environmental water contribute to the provision of habitat to support breeding and recruitment of other vertebrates?<br><br>What did Commonwealth environmental water contribute to other aquatic vertebrates (frog and turtle) diversity and populations?<br><br>What did Commonwealth environmental water contribute to the maintenance of refuge habitats? | Tadpole abundance (CPUE)<br>Tadpole development stage<br>Adult size structure (selected species)<br>Calling activity<br>Adult abundance<br>Community composition<br><br>Turtle community composition<br>Sex<br>Size structure (Shell length and width and<br>and plastron length | Aligned with wetland fish:<br>Hydrology<br>Antecedent conditions<br>Day length<br>water temperature<br>Water depth<br>Water quality<br>Nutrients, carbon and Chlorophyll-a<br>Vegetation cover and complexity<br>Fish abundance | Aligned with wetland fish monitoring sites ( see previous section)<br><br>Fixed locations: Mid-Murrumbidgee 4 sites, Nimmie-Caira (4 sites), Redbank (4 sites). 4<br>Tadpoles and turtles Undertaken during wetland fish surveys (see previous section) 2 replicates sets of 12 mm double winged large fyke (80cm hoops)<br>(Single wing) and 2mm (double wing) fyke nets (50cm hoops)<br>Four surveys per year<br><br>Calling<br>3x 2 minute audio surveys ( taken at 10 minute intervals) Four surveys per year<br><br>Adults<br>40 minute nocturnal transect surveys<br>Record snout-vent length of target species ( 20 individuals per transect)<br>Four surveys per year |

### 5.10.2 Methods

Note that to reduce costs monitoring of tadpoles will be undertaken during wetland fish surveys (see previous section) and does not include any additional cost to the program. The methodology will follow that used previously in the Lowbidgee and mid-Murrumbidgee (Spencer, Thomas *et al*. 2011b, Wassens, Watts *et al*. 2011, Wassens and Spencer 2012, Wassens, Watts *et al*. 2012a, Wassens, Jenkins *et al*. 2013b). Intensive monitoring of adult frogs, size structure, tadpole development and recruitment will be undertaken in association with wetland fish (SA) and will include 12 fixed sites - mid-Murrumbidgee (three sites) and Lowbidgee (Redbank (six sites) and Nimmie Caira (three sites)). See SOP in appendix 3.

Adult frogs and metamorphs will be surveyed within each wetland after dark using a 2 x 20 minute visual encounter and a 6x1 minute audio survey (Wassens, Watts *et al.* 2011, Wassens, Watts *et al*. 2012a). A 30 watt spotlight will be used to search for frogs along the wetland edge and into the surrounding terrestrial habitats. A subsample of twenty individuals of *Limnodynastes tasmaniensis* and *L. fletcheri* will be measured (snout-to-vent length) to give an indication of demographic structure and presence of recent metamorphs. This methodology was trialled in the Mid-Murrumbidgee between October 2011 and April 2012 with success. Audio surveys involve listening for the distinct calls of resident frog species, general estimates of the number of calling individuals will be determined using the methodology described in (Wassens *et al.* 2011).

Tadpoles are monitored in association with wetland fish communities. A combination of sampling methods targeting different habitats within each wetland will be employed to survey for fish and tadpoles. Including two small (2 x 2 m wings, 2 mm mesh) and two large (10 m wing, 12 mm mesh). Wing width and depth (m) will be recorded at each site. Tadpoles will be identified to species and the development stage of the first 50 individuals from each net will be assessed by visual examination of limb development, with remaining individuals identified to species and then counted. Turtles will be identified to species as per (Chessman 2011) and the length and width of the carapace will be measured to the nearest mm.

### 5.10.3 Data analysis framework against evaluation questions

Community composition

The change in frog and tadpole communities within and between water years, and between zones will be assessed using Plymouth Routines in Multivariate Ecological Research (PRIMER). Analyses will consider of both tadpole and adult abundance (CPUE) and biomass estimates for sites sampled to determine changes. A vector analysis will be used to demonstrate how species contributed to any observed groupings. Statistical differences in Bray-Curtis transformed fish abundances and biomass data will be investigated using two-way crossed Analysis of Similarities (ANOSIM) using region, sampling period as factors.

*Occupancy patterns of frogs*

Occupancy patterns are determined in the form of a Boolean presence–absence values for each site–season–species combination, from which detection history is derived (MacKenzie, Nichols *et al*. 2005). There were two key modeling steps. (1) Single site covariate models, or simple models (2) Individual covariates of high predictive value are combined in complex models. *Akaike information criterion* AIC, model weightings (see Mackenzie and Bailey (2004)) are used to rank models. Goodness of Fit tests are carried out using 100 parametric bootstraps and a model considered to be a poor fit to the data if the p-value (probability of obtaining a test statistic ≥ observed) ≤ 0.05. A p-value approaching 1 indicates over-fitting (MacKenzie, Nichols *et al*. 2006).

## 5.11 Waterbird breeding and recruitment (costed as an optional component)

**Note that this component of the M&E Plan is included as an optional indicator to be undertaken via contract variation as required.**

Waterbird breeding can provide a useful index of the effectiveness of environmental water delivery, because successful waterbird breeding is heavily dependent on adequately timed flows of sufficient frequency, duration, depth and extent to inundate breeding habitat and stimulate sufficient food resources (Scott 1997, Kingsford and Auld 2005). Environmental flows can be delivered to initiate and support annual small-scale waterbird breeding or to extend or build on natural flows to support large-scale waterbird breeding.

The timing and duration of flooding is important as breeding success is maximised when flooding coincides with spring and summer months, when food availability is optimal (Scott 1997). Most waterbirds commence breeding in spring, however, the stimuli for breeding is usually a combination of season, rainfall and water, with the timing of inundation influencing the lag time between the start of flooding and the commencement of nesting (Briggs and Thornton 1999). Overall, breeding habitats need to be inundated for long enough to allow birds to achieve pre-breeding condition, pair up, build nests, lay eggs, and raise and fledge their young (Scott 1997) (Figure 22, Figure 23).

Colonial-nesting waterbird species usually nest in dense, mixed species colonies and frequently re-use breeding sites. Different species have specific nesting requirements, with straw-necked ibis *Threskiornis spinicollis* trampling down lignum *Duma florulenta*, to build nests while egrets, herons and cormorants generally prefer to construct nest in floodplain trees such as river red gums *Eucalyptus camaldulensis*. For most species, ensuring water levels are stable underneath nesting birds is essential as rapid falls in water levels can lead to perceived declines in food availability and/or increases in predation risk, leading to nest abandonment (Brandis, Ryall *et al*. 2011a, Brandis, Kingsford *et al*. 2011).

The Lowbidgee floodplain provides significant habitat for waterbirds in the Murray-Darling Basin, and is widely recognised for supporting important breeding habitat for colonially-nesting waterbirds, including species listed on international bilateral migratory bird agreements, JAMBA and CAMBA. In particular, during major flooding stands of lignum in the Nimmie-Caira zone can support some of the largest colonies of straw-necked ibis and glossy ibis *Plegadis falcinellus* in Australia (Lowe 1983, Brandis, Ryall *et al*. 2011b). The river red gum forests in Yanga National Park and nearby private properties in the Redbank zone also provide important breeding habitat for significant numbers of nesting egrets, herons and cormorants (Maher 2006, Spencer, Thomas *et al*. 2011a) and the mid-Murrumbidgee wetland zone historically provided nesting habitat for darters, cormorants, herons, egrets and spoonbills (Briggs, Thorton *et al.* 1997, Briggs and Thornton 1999).

We propose to undertake two monitoring approaches to evaluate waterbird breeding responses to Commonwealth environmental watering actions in wetland habitats across the Murrumbidgee Selected Area:

1. *Waterbird Breeding (Category 1)* targeting large ibis colonies in the Nimmie-Caira zone to support Basin-scale evaluation.
2. *Waterbird Breeding (Category 3)* targeting known egret, heron and cormorant breeding sites in the Redbank, Nimmie-Caira and mid-Murrumbidgee wetland zones to support the Murrumbidgee Selected Area evaluation.

### 5.11.1 Evaluation Questions

***Basin scale evaluation questions:***

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to waterbird populations?

*Short-term (one year) and long-term (five year) questions:*

What did Commonwealth environmental water contribute to waterbird breeding?

What did Commonwealth environmental water contribute to waterbird chick fledging?

What did Commonwealth environmental water contribute to waterbird survival?

***Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to waterbird breeding?

What did Commonwealth environmental water contribute to waterbird chick fledging and waterbird survival?

***Flow type:*** Overbank

***Predictions:***

- Local increases in non-colonial waterbird breeding activity (total number of breeding species and total number of broods) following Commonwealth environmental watering
- Initiation of nesting activity in ibis, egret, heron and cormorant colonies as a result of watering actions targeting known colony sites
- Maintenance of stable water levels in colony sites using Commonwealth environmental water to support successful fledging of waterbird chicks Maintenance of water levels in feeding habitats using Commonwealth environmental water to support successful fledging of waterbird chicks.

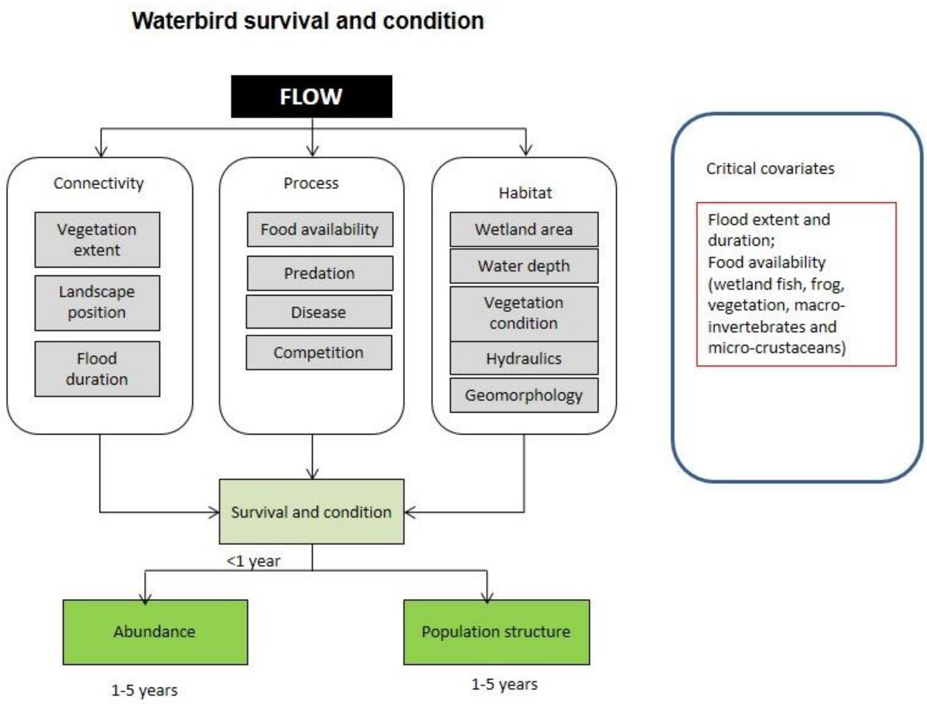


Figure 22 Cause and effect diagram depicting the influence of flow on waterbird survival and condition.

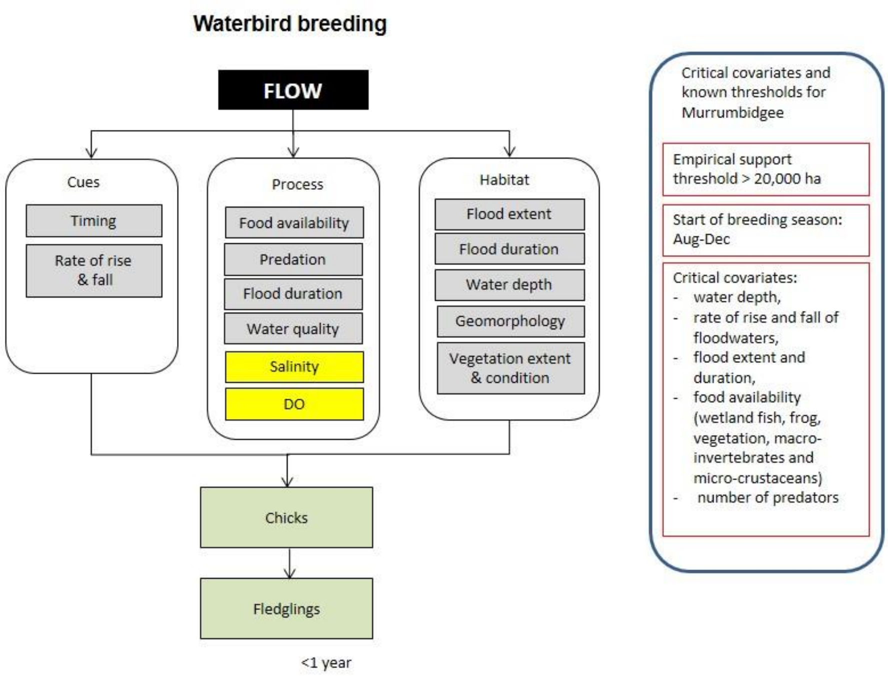


Figure 23 Cause and effect diagram depicting the influence of flow on waterbird reproduction and recruitment. Yellow boxes indicate other CEDs.

| LTIM Project Indicators | Evaluation questions | Metrics | Critical covariates | Survey methods |
|---|---|---|---|---|
| Waterbird reproduction (Cat 1) Optional component | What did Commonwealth environmental water contribute to:<br><br>- waterbird populations?<br>- waterbird breeding?<br>- waterbird chick fledging?<br>- waterbird survival? | Colony extent<br>Start and end of breeding<br>Number of nests (pairs) per vegetation type<br>Number of nests in each nesting stage (eggs, early & late nestling stages)<br>Estimate of number of nests successfully fledged and mean number of chicks | Inundation extent (ha)<br>Water depth<br>Diversity and abundance of food resources (e.g., fish, frog, and micro-crustaceans)<br>Habitat heterogeneity<br>Vegetation type & condition<br>Water quality (DO, salinity)<br>Total waterbird species richness (including non-colonial species)<br>Number of predators | Cat 1 methods for large ibis colonies<br>repeat fortnightly ground surveys over a three month breeding season<br>Continuous measurement of water depth (as per Hydrology (Wetland) standard method)<br>Adhoc observations of waterbird diversity and predators (birds of prey, pigs, foxes, cats)<br>Eulimbah Swamp and/or Telephone Swamp in Nimmie-Caira zone |
| Waterbird survival and condition (Cat 1) Optional component | | Number of breeding events<br>Number of active colonies<br>Number of breeding species<br>Number of adults of each species | | |
| Waterbird reproduction (SA - Murrumbidgee Selected Area) Optional component | | Colony extent<br>Start and end of breeding<br>Number of nests (pairs) per vegetation type<br>Number of nests in each nesting stage (eggs, early & late nestling stages) | | SA sites: 5 out of 5 years (Sep-Apr)<br>Aerial reconnaissance surveys in spring and fortnightly ground surveys where required in major egret colonies using SA methods<br>Ground surveys at start and end of breeding period for smaller colonies Multiple sites - egret, heron and cormorant colonies in Redbank, Nimmie-Caira, and mid-Murrumbidgee wetland zones |

### *Justification for monitoring approach*

The most significant challenge in developing a monitoring framework for colonial waterbird breeding is determining when, where, what and how many nesting pairs are likely to establish over a five year period. Analysis of long-term data improves our capacity to make sensible predictions about the size, location and frequency of waterbird breeding given the available water inflows. In this section we consider data collected over a 30 year period as part of the Annual Aerial Waterbird Survey of Eastern Australia now coordinated by the University of NSW, which has surveyed the Lowbidgee floodplain each spring since 1983 (Kingsford, Porter *et al*. 2012), and through ground surveys of active colonies from 1989-2013 (Maher 1990, Magrath 1992, Maher 2006, Childs, Webster *et al*. 2010, Spencer and Wassens 2010a, Brandis, Ryall *et al*. 2011a, Spencer, Wassens *et al*. 2011, Wassens, Spencer *et al*. 2014).

### *Location and type of breeding*

Rookery sites for a range of colonial nesting species, including ibis, cormorants, darters, and egrets occur through the mid-Murrumbidgee wetlands and Lowbidgee floodplain (Figure 24, Table 8). The highest density of waterbird breeding occurs in the Lowbidgee floodplain, where ibis colonies containing 20,000 - 50,000 pairs have established in two sites in the Nimmie-Caira zone (Eulimbah and Telephone swamps) and smaller colonies (50 - 4,000 pairs) of egrets, herons and cormorants can occur throughout the Nimmie-Caira and Redbank zones (Figure 25).

### *Frequency of waterbird breeding*

Our analysis of the long-term aerial survey data and ground surveys for the Lowbidgee floodplain indicate that prior to 1990 some waterbird breeding could occur annually (Figure 26). Floodplain development and increasing consumptive water demand through the 1990s resulted in a significant reduction in the frequency and extent of floodplain inundation and a subsequent reduction in the frequency and abundance of waterbird breeding (Kingsford and Thomas 2004). The millennium drought resulted in further reductions in total wetland area and breeding frequency. Despite the extended drought over the last decade, waterbird breeding was initiated in three years (in 2000, 2005 and 2010) with these breeding events occurring during periods of lower wetland area (10,000 and 40,000 ha) compared to the previous two decades(Figure 27).

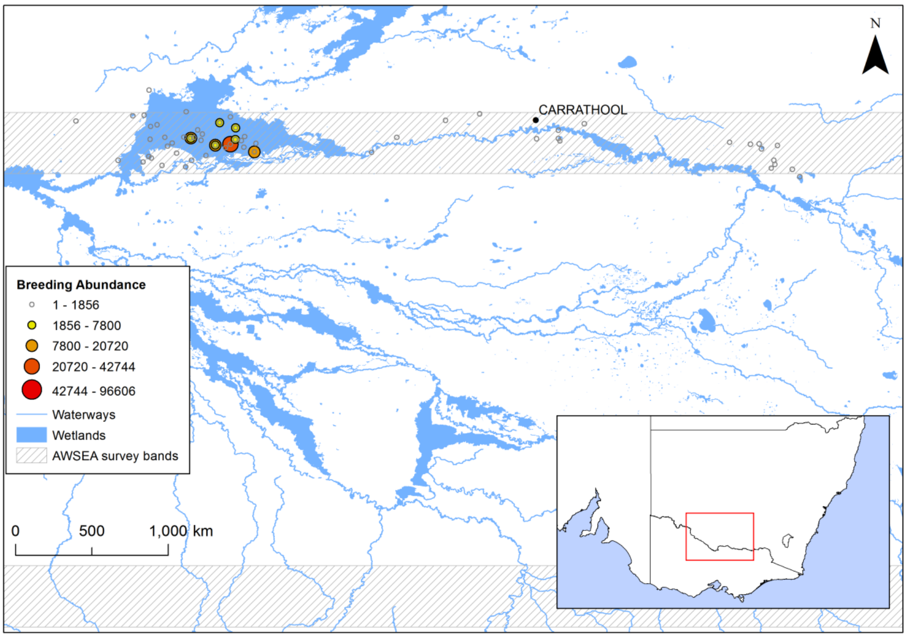


Figure 24 Location and size of waterbird breeding observations in the Murrumbidgee River System recorded during the Annual Aerial Waterbird Survey of Eastern Australia (AWSEA) between 1983-2012 (Kingsford, Bino *et al*. 2013).

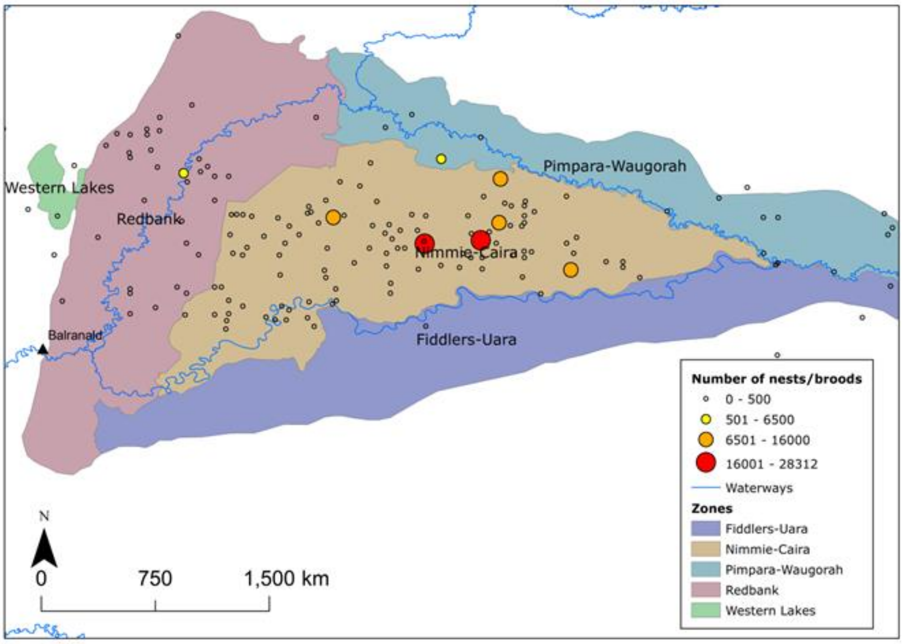


Figure 25 Location and size of waterbird breeding events in the five wetland zones in the Lowbidgee floodplain recorded during the Annual Aerial Waterbird Survey of Eastern Australia between 1983-2012 (Kingsford, Bino et al. 2013). Note that the Nimmie-Caira zone can support large ibis colonies (>15,000 nesting pairs) in Telephone and Eulimbah Swamps.

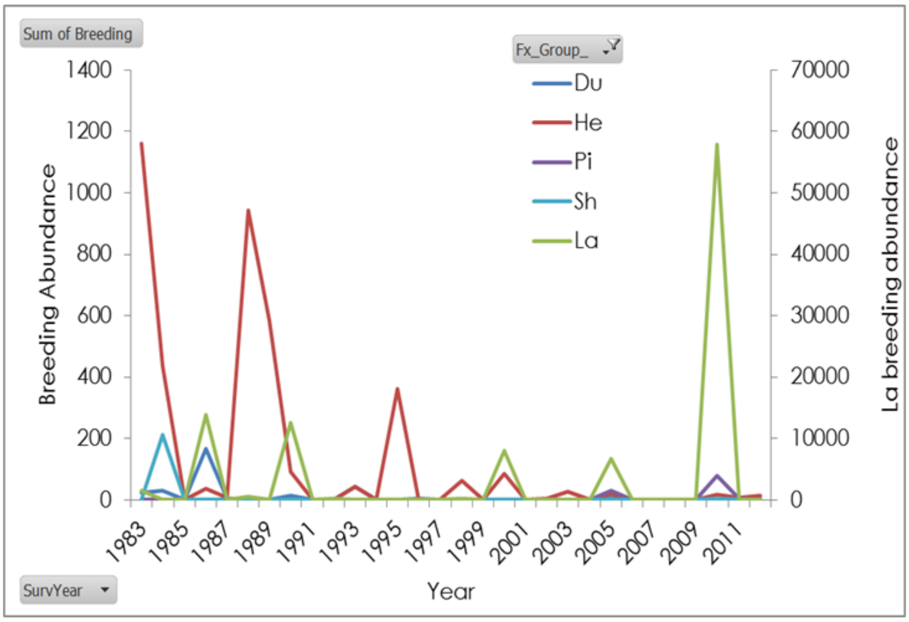


Figure 26 Breeding abundance of functional groups recorded during the Annual Aerial Waterbird Survey of Eastern Australia (1983-2012) Du 0- ducks, He- herbivores, Pi – piscivores (Darters, cormorants), Sh – shorebirds, and La (right) - large wading birds (Ibis)(Kingsford, Porter *et al.* 2012). Note abundances are shown on two different scales.

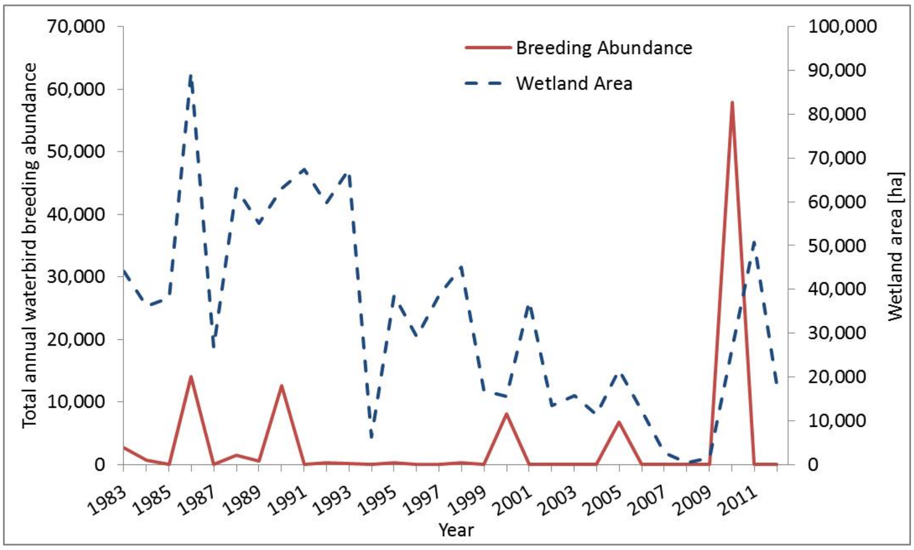


Figure 27 Total number of nesting pairs of waterbirds and estimated wetland area recorded during the Annual Aerial Waterbird Survey of Eastern Australia (1983-2012) (Kingsford, Porter *et al.* 2012).

### *Monitoring breeding success*

As straw-necked ibis are particularly sensitive to sudden changes in water level real-time information on the status of nesting birds and water levels is needed during breeding events to support adaptive management of environmental water (Brandis, Kingsford *et al*. 2011).

Although the Category 1 standard methods request monthly ground surveys, this survey intensity will not provide adequate information to address the short and long-term evaluation questions for waterbird breeding responses in the Murrumbidgee. The breeding period for straw-necked ibis, from laying to chicks leaving their nests and taking short flights (flapper stage), is around 45-53 days (Table 7). If monitoring is scheduled monthly and the first survey is at egg stage, the second survey a month later will be at a development stage where chicks are off the nests and success rates for individual nests cannot be measured. To ensure that Basin and Selected Area objectives can be evaluated, we plan to undertake ground surveys at fortnightly intervals, with the first survey taking place after eggs are laid, thus ensuring accurate estimates of the number of nests successfully fledged and mean number of chicks per nest for a subsample of nests. The three month breeding period is assumed to be a large enough window to cover the period from birds pairing up, laying and incubating eggs, rearing chicks and cover the period of post-fledging dependency in the three ibis species (Table 7). This approach worked effectively during monitoring undertaken by UNSW in the Lowbidgee floodplain in 2010-11 (Brandis, Ryall *et al*. 2011a).

### *Watering options to support waterbird breeding*

Many of the wetlands in the South Redbank and Mid-Murrumbidgee zones are now reserved under NSW National Reserve Estate and a large portion of the Nimmie-Caira is now jointly managed by Commonwealth and NSW governments. As such there are fewer constraints on watering and a wide range of options available for the use of Commonwealth environmental water. The Commonwealth's current water holding in the Murrumbidgee Catchment is more than sufficient to annually inundate breeding and feeding habitats above a minimum threshold of 20,000 ha of wetland to support some waterbird breeding (). Based on the historical waterbird breeding data we expect that some breeding activity will occur annually in some of the smaller cormorant and egret colonies, while large-scale breeding in the large egret (e.g.

Tarwillie, Steam Engine and Two Bridges (Redbank zone)) and ibis colonies (Eulimbah and Telephone (Nimmie-Caira zone)) are expected to occur in three out of five years of the LTIM Project program.

We will undertake intensive monitoring of the ibis colonies in the Nimmie-Caira system where and when they occur using the Category 1 standard methods to support the Basin-scale evaluation. In addition, less intensive monitoring of smaller ibis, egret, heron and cormorant colonies will be carried out annually in all wetland zones using the Category 3 methods outlined below. This approach will ensure comprehensive information on colony locations, colony boundaries, species composition, stage of nesting and estimate of total number of nests are collected to inform the adaptive management of environmental water and the Murrumbidgee Selected Area evaluation.

Table 7 Summary of water requirements for egret and ibis species that breed in the Murrumbidgee Selected Area.

| Species | Foraging habitat | Breeding habitat (nest height in metres) | Breeding season | Breeding duration (days)^ | | | |
|---|---|---|---|---|---|---|---|
| | | | | Laying and incubation | Nestlings | Est. total nesting stage | Post–fledging dependency stage |
| Cattle egret (JAMBA, CAMBA) | Regularly forage away from water on low-lying grasslands, or in shallow open, water meadows with low emergent vegetation | Dead or live trees (eucalypts, casuarinas) in dense woodland or beside swamps, rivers or pools (3–15 m) | Sept–Mar | 31 | 42 | 73 | 14 |
| Little egret | Prefer shallow open water (0.1–0.5 m), but can forage in deep water and aquatic vegetation | In tree canopy near wetlands, often in standing water (3–7 m) | Oct–Mar | 20–25 | 32–46 | 71 | ND |
| Eastern great egret (JAMBA, CAMBA) | Prefer permanent waterbodies on floodplains, semi-permanent swamps with tall emergent vegetation, sewage farms, channels and large farm dams | Trees (eucalypt, casuarinas) standing in water (>7–15 m) | Sept -early May | ND (approx. 30 days) | 42 | 72 | 3–16 |
| Intermediate egret | Prefer to forage in fresh water (<80 mm deep), among dense aquatic and emergent vegetation | Tree canopy (eucalypts) standing in or near water (>1.5–15 m) | Oct–Apr | >26 | 37––53 | 79 | 21 |
| Australian white ibis | Shallow water and soft substrate margins of waterbodies, wide range of wetland types | Large branches of trees (up to 30 m), or flattened reeds, lignum, rushes and cumbungi (0.1–2 m) | Sept–Apr | 22–25 | 30 | 55 | >22 |
| Glossy ibis (CAMBA) | Shallow water and soft substrate margins of waterbodies | Flattened lignum or small trees (0.1–2 m) | Oct–Feb | ND (approx. 25 days) | 25 | 50 | >14 |
| Straw-necked ibis | Grasslands, cultivated land, or in aquatic shallows (<0.25 m) of permanent/ ephemeral wetlands | Flattened reeds, lignum and cumbungi, trees very occasionally (0.1–2 m) | Sep-Apr | 25 | 28 | 45-53 | 14 |

Sources: (Marchant and Higgins 1990, Marchant and Higgins 1993, Brandis, Ryall *et al.* 2011a) Total breeding duration (in days) relates to the time from commencement of nest building, through laying, incubation and hatching, the nestling period and extra care provided by adults during the post-fledging period. Where the total time is stated, this figure only represents an estimate of the minimum time required for the successful completion of breeding. Most species also require a lag period before the commencement of laying and incubation in order to pair up and build up fat reserves before breeding commences. Note that limited information was available for the time required for nest building and egg laying for some species (ND = not determined). JAMBA = Japan-Australia Migratory Bird Agreement; CAMBA= China-Australia Migratory Bird Agreement.

### 5.11.2 Methods

***Site selection***

As noted above there are a large number of locations where colonial nesting waterbirds have bred historically through wetland zones in the Lowbidgee and mid-Murrumbidgee. We propose three levels of monitoring intensity (Table 8) to evaluate waterbird breeding responses to Commonwealth environmental water:

- Category 1 fortnightly monitoring at large ibis colonies where they establish in Eulimbah, Telephone and Suicide Swamps, in the Nimmie-Caira wetland zone (three in five years).
- Selected Area fortnightly monitoring of large egret colonies (including great and cattle egrets listed under JAMBA and CAMBA) in the Redbank wetland zone and Nap Nap swamp in the Nimmie-Caira (three in five years).
- Selected Area low intensity (start and finish) of remaining small colonies through the Redbank and Nimmie-Caira zones (five in five years). Note that the monitoring budget assumes that a subset of these locations will be inundated in each year and that NSW OEH will provide complementary monitoring data for known colony sites in Yanga National Park.

***Aerial surveys (Complementary monitoring by UNSW and NSW OEH)***

The timing of the Annual Aerial Waterbird Survey of Eastern Australia coincides in most years with the initiation of waterbird breeding activity in the Murrumbidgee Catchment. Therefore, the aerial surveys provide key information on the location, size and species composition of active waterbird colonies. NSW OEH also undertakes reconnaissance aerial surveys of the Lowbidgee floodplain during some water years as part of monitoring environmental water delivery and to assess waterbird activity when conditions are thought to be sufficient to trigger colonial waterbird breeding. During NSW OEH's aerial reconnaissance surveys known breeding sites are surveyed and the remainder of the Lowbidgee floodplain is also assessed in case additional colonies have established in wetlands where colonial waterbirds have not previously nested. Information gathered during both types of aerial survey when they occur will be used to direct on-ground survey efforts, where ground access is possible.

Table 8 Summary of known colonial waterbird breeding sites in the Murrumbidgee Selected Area and proposed monitoring coverage. Category 1 (Cat 1) sites will be monitored using the Category 1 standard methods; while reduced intensity of sampling will be carried out at Selected Area (SA) sites (see detailed methodology below).

| **Zone** | **Colony site** | **Dominant nesting species** | **Monitoring category^** | **Survey type required** | **Sampling frequency** |
|---|---|---|---|---|---|
| Nimmie-Caira | Eulimbah Bank | Straw-necked ibis | Cat 1 | Aerial & ground | Fortnightly |
| | Telephone Bank | Straw-necked ibis, glossy ibis | Cat 1 | Aerial & ground | Fortnightly |
| | Suicide Bank | Straw-necked ibis, glossy ibis | SA | Aerial & ground | Fortnightly |
| | Nap Nap Swamp | Cormorants, herons, egrets | SA | Aerial & ground | Fortnightly |
| | Loorica Lake | Cormorants, darters, herons | SA | Ground | Start & end |
| | Avalon Swamp | Cormorants, herons | SA | Ground | Start & end |
| Redbank (South) | Two Bridges Swamp | Egrets, nankeen night-herons | SA | Aerial & ground | Fortnightly |
| | Tarwillie Swamp | Egrets, cormorants | SA | Aerial & ground | Fortnightly |
| | Top Narockwell Swamp | Egrets, cormorants | SA | Aerial & ground | Fortnightly |
| | Mercedes Swamp | Cormorants, darters | SA | Ground | Start & end |
| | Breer Swamp | Cormorants | SA | Aerial & ground | Start & end |
| | Egret Swamp | Egrets | SA | Aerial | Start & end |
| | Tala Swamp | Egrets, cormorants | SA | Aerial | Start & end |
| | Shaws Swamp | Cormorants, herons | SA | Aerial | Start & end |
| | Piggery Lake | Cormorants, darters | SA | Ground | Start & end |
| | Waugorah Lagoon | Cormorants, darters | SA | Ground | Start & end |
| | Waugorah Lake | Cormorants, darters | SA | Ground | Start & end |
| | North Stallion Swamp | Herons, darters, cormorants | SA | Ground | Start & end |
| Redbank (North) | Steam Engine Swamp | Egrets, nankeen night-herons | SA | Aerial & ground | Fortnightly |
| Mid-Murrumbidgee | Yarrada Lagoon | Cormorants, darters | SA | Ground | Start & end |
| | McKennas Lagoon | Cormorants, darters | SA | Ground | Start & end |
| | Dry Lake | Cormorants, darters | SA | Ground | Start & end |
| | Gooragool Lagoon | Cormorants, darters | SA | Ground | Start & end |

### *On-ground surveys (Category 1 and Category 3)*

Ground surveys of accessible colonies identified in the Murrumbidgee Selected Area will be undertaken by two observers each spring (October-November) to assess waterbird breeding activity. Ground surveys will only be required in sites that are inundated which will be determined from information gathered during the spring aerial surveys, consultation with land managers and/or inundation mapping from Landsat satellite imagery (Thomas, Lu et al. 2012) available from NSW OEH's complementary environmental flow monitoring program.

Initial colony assessments will be carried out alongside spring surveys undertaken as part of biannual waterbird diversity monitoring of fixed wetland sites (see Waterbird Diversity section). Subsequent surveys will be undertaken fortnightly at large ibis and egret colonies or for smaller colonies at the end of the breeding period only. Observations of non-colonial waterbird species and their breeding activity will also be assessed to contribute to the Waterbird Diversity monitoring. Where colonies are active the observers will carry out an inspection of the colony to determine species composition, total number of nests in each vegetation type defined under the ANAE classification, vegetation condition (good, moderate and poor) and the stage of chick development (eggs, early (<2 weeks) and late (>2 weeks) stage nestling) as per the *LTIM Project Standard Protocol: Waterbird Breeding*. Where site access permits the colony boundary will also be recorded on foot or by canoe/small boat using a GPS. This information will be used to calculate the size of each colony in hectares

### *Breeding success (Category 1)*

Ground surveys of the ibis colonies will be repeated at fortnightly intervals (seven trips in total) over a three month breeding period to assess breeding success. During the first colony survey, as close as possible to colony establishment, the boundary of the colony will be mapped using a differential GPS mounted on a boat to provide a framework for random sampling of a subset of nesting sites. Where a nesting site is defined as a group of nests on a clump of lignum separated from another clump of lignum by open water or non-flattened vegetation. A total of 200 nests will be monitored for the three month breeding period. All nests will be recorded with GPS and marked using coloured tape and given an unique identifier as per methods developed by (Brandis, Ryall *et al*. 2011a). Selected nests will be monitored throughout the breeding period from egg to fledgling development stages through repeat field surveys by trained observers.

The deployment of fixed cameras (camera traps) for monitoring breeding success are included as an optional method for measuring reproductive success in the Category 1 standard methods. However, repeat visits by field personnel provide a number of advantages over the fixed cameras including eliminating the potential risk of camera failure; allowing for information to be collected on a larger number of nests; the presence of new starters and changes to the colony boundary. (Brandis, Koeltzow *et al*. in press) demonstrated in a comparison of breeding success by repeat visits to straw-necked nests by investigators with the results from analysing images from camera traps that the presence of investigators did not impact breeding success or rates of predation.

In addition to reproductive success data hydrological indicators relevant to waterbird breeding will be measured in the Category 1 sites. These include continuous measurement of water depth (as per *LTIM Project Standard Protocol: Hydrology (Wetland)*) and replicate spot measurements of water quality (dissolved oxygen, turbidity, conductivity, and temperature) at each nesting site.

***Category 3 Waterbird Breeding Monitoring***

Four of the Category 3 colony sites in the Redbank zone which historically have supported large numbers of nesting egrets, including the eastern great egret Ardea modesta (listed under JAMBA and CAMBA) (Table 8). After the completion of the initial colony inspection where a detailed assessment of the colony will be made (to include estimates of colony boundary, total number of nests and stage of nesting) subsequent surveys of the major egret colonies at approximately fortnightly intervals will be restricted to an assessment of the stage of nesting and water levels from a survey point that is representative of conditions across the majority of the colony. This information will be used to inform the need for top-up flows to these sites (Table 9)

The remaining Category 3 sites which historically have supported smaller numbers of nesting cormorants, darters and herons will also be assessed during ground surveys but at the start and end of the breeding period only (approximately six to eight weeks later). Ground surveys at the start of the breeding period will be undertaken to make detailed assessments of each colony and at the end of breeding to make a broad qualitative assessment on whether each colony has been a success or failure. This assessment will be based on a count of total number of fledged birds, and dead birds (if present) recorded in each colony towards the end of the breeding period.

### *Minimising colony disturbance (Category 1 and Category 3)*

All ground surveys of waterbird breeding sites will be limited to two hour periods, either in early morning (6-10 am) or late afternoon (4-8 pm) to avoid causing heat stress to nesting birds and their offspring. This approach has worked effectively in previous studies of large waterbird colonies in the Lowbidgee which recorded high levels of nesting success (Brandis, Ryall *et al*. 2011a). When reporting the results of the Murrumbidgee Selected Area evaluation information on the exact locations of colonies will not be published. This will ensure these sensitive areas are protected from disturbance by the public.

Table 9 Methods that will be employed for measuring the required metrics for the *LTIM Project Standard Protocol: Waterbird Breeding Category 1* monitoring at ibis colonies and the less intensive Category 3 methods proposed for egret, heron and cormorant colonies.

| Metric | Category 1 methods | Category 3 methods |
|---|---|---|
| Location (polygon of the colony) | Colony boundaries (polygons) of ibis colonies in the Nimmie-Caira zone will be mapped using a differential GPS mounted in a small boat at the start of breeding and repeated for any colony expansions. | Colony boundaries (polygons) will be mapped with a GPS on foot for the large egret colonies<br>Locations of smaller or inaccessible egret colonies (the central point) will be recorded with a GPS during ground or aerial surveys. |
| ANAE Wetland Classification | Dominant vegetation type in each colony will be identified as per the LTIM Project Standard Protocol: Ecosystem Type. | |
| Size of wetland surrounding colony (ha) | Inundation mapping from Landsat satellite imagery provided by NSW OEH will be used to calculate inundation extent for each colony and the surrounding floodplain. | |
| Number of nests of each species per vegetation type/structural habitat | Assessment of total number of nests will be determined through a census of each colony by boat and also informed by aerial survey observations (where available). Total number of nests of each species will be determined through ground survey of representative areas of each colony and extrapolated for the entire colony. | Complete census will be undertaken on foot where site access allows during which number of nests of each species in each vegetation type will be recorded. For very large egret colonies total number of nests of each species will be determined through ground survey of representative areas of each colony and extrapolated for the entire colony. |
| Number of nests in each nesting stage for each species | Repeated visits at fortnightly intervals to a subset of marked nests. Estimates for the entire colony will be extrapolated from these results (see detailed methods below). | Estimated at the start and end of breeding only using a complete census where possible or a representative area of each colony. |
| Estimate of number of nests successfully fledged for each species (i.e. one or more chicks fledged per nest) since last survey | Repeated visits at fortnightly intervals to a subset of marked nests. Estimates for the entire colony will be extrapolated from these results (see detailed methods below). | Detailed measures of nest success will not be undertaken, however, total counts of fledglings (birds in non-breeding/immature plumage) and dead birds at the end of the breeding period will provide some qualitative information on breeding success. |
| Estimate of the mean number of chicks thought to have fledged per successful nest for each species, where possible | Repeated visits at fortnightly intervals to a subset of marked nests until chicks are independent of nests. Estimates for the entire colony will be extrapolated from these results. | Detailed measures of nest success will not be undertaken. |
| Number of adults of each species | Determined through ground survey of representative areas of the colony and extrapolated for the entire colony. | Complete census or representative area of the colony surveyed on foot during initial nesting survey where site access allows to estimate total number of adults of each species. |
| Vegetation type, condition scores | Identification of dominant vegetation type and a qualitative assessment of vegetation condition (good, moderate and poor score) will be recorded during the first nesting survey as per the *LTIM Project Standard Protocol: Waterbird Breeding*. | |
| Observations of colony level disturbance (e.g. predators, other disturbance agents, or probable causes of colony desertion) | Continuous measurement of water depth will be recorded as per the *LTIM Project Standard Protocol: Hydrology (Wetland)*. Spot measurements of water quality and the presence and abundance of predators will be recorded. | Measurements of water levels will be recorded from fixed water level gauges where available during repeat visits. The presence and abundance of predators will be recorded. |

### 5.11.3 Data analysis framework against evaluation questions

We will use non-linear (logit) models to assess thresholds for the initiation of waterbird breeding and breeding success using historical data and data collected through the LTIM Project program. Additional modelling will be undertaken to investigate the effect of critical covariates in influencing waterbird breeding responses to Commonwealth environmental watering. This will include total inundated area, flood frequency and duration, wetland fish, frog and microinvertebrate abundance, aquatic vegetation cover, vegetation condition and water quality. This approach will allow for an evaluation of the contribution of Commonwealth environmental water to waterbird populations, waterbird breeding and waterbird chick fledging success in the Murrumbidgee Selected Area within and among water years.

Waterbird breeding success will be calculated for nest sites at three different stages; egg ('egg' stage), early nestling (<2 weeks old) and late nestling (>2-5 weeks old). Net change in eggs, chicks or offspring will be scored as 1 if there was a gain or no change between visits to each nest, or 0 if there was a decline. Each of these measures of nest success will be included as response variables in subsequent modelling. A successful nest will be defined as a nest that produced at least one chick at the end of the observation period. To test for timing, water depth, food availability and predator density effects on breeding success, logistic regression will be used to examine the relationship between the date of nest establishment and offspring success. Where ibis colonies are established at the same time in both Telephone and Eulimbah swamps we will compare breeding success between the colonies. Information from this evaluation process will be used to refine waterbird breeding conceptual models for the Murrumbidgee Selected Area at the end of each water year.

## 5.12 Waterbird diversity

Waterbirds can provide useful indicators of regional-scale wetland availability and of local-scale wetland health, because their abundance, diversity and breeding activity can be related to total wetland area, the health of wetland vegetation and the abundance of food resources e.g., microcrustacea, fish, frogs, and aquatic vegetation. This means that generally wetlands with vegetation in good health and a complex of habitats with varying water depths tend to support the greatest diversity of waterbird species and highest waterbird abundance (Scott 1997, Kingsford and Norman 2002).

Waterbirds are highly mobile and can feed on a wide range of flora and fauna, moving between wetlands in response to these drying and flooding phases to maximise their feeding and breeding opportunities (Kingsford and Norman 2002, Roshier, Robertson *et al*. 2002). The frequency of flooding drives food availability. The importance of some drying period between flooding has been well documented in the management of wetlands for waterbirds (Crome 1988, Frederick and Ogden 2001, Kingsford, Jenkins *et al*. 2004), as the productivity of a wetland is often higher in wetlands that experience a regular drying phase (Jenkins and Boulton 2007). However, where dry conditions are prolonged this has negative impacts on food availability and vegetation condition which in turn impacts the survival and condition of waterbird populations despite many waterbird species having adapted to dealing with droughts as part of a natural boom and bust cycle in Australian wetlands. Management of environmental water can be influential in providing refuge habitat and some limited breeding in years of low water availability, to ensure birds are able to reproduce within their lifetimes allowing population persistence, and buffering potential impacts of climate change, hunting and habitat loss (Figure 28).

### 5.12.1 Evaluation Questions

***Basin scale evaluation questions:***

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to waterbird populations?

What did Commonwealth environmental water contribute to waterbird species diversity?

*Short-term (one year) and long-term (five year) questions:*

What did Commonwealth environmental water contribute to waterbird survival?

***Selected Area evaluation questions:***

What did Commonwealth environmental water contribute to waterbird species diversity?

***Flow type***: Overbank

***Predictions:***

- Local increases in waterbird abundance in response to Commonwealth environmental watering
- Local increases in waterbird diversity in response to Commonwealth environmental watering
- Local increases in waterbird species of conservation significance (i.e. threatened species, JAMBA, CAMBA and ROKAMBA species) in response to Commonwealth environmental watering.

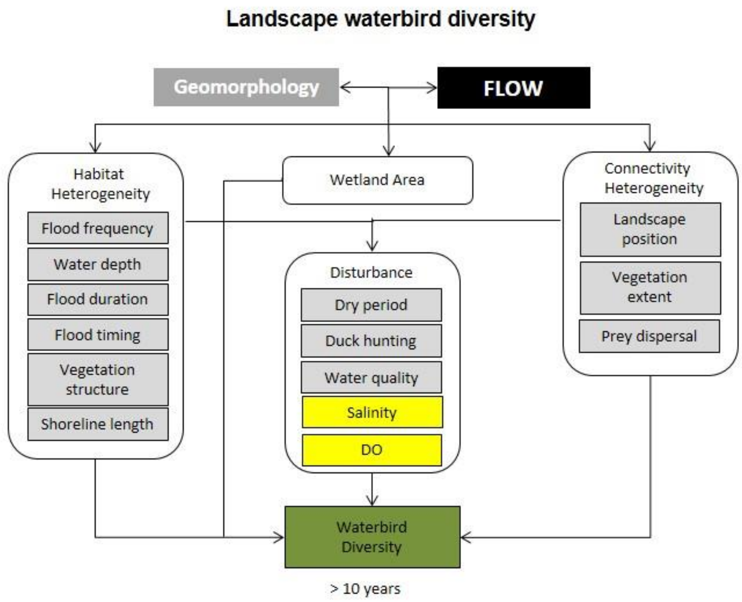


Figure 28 Cause and effect diagram depicting the influence of flow and geomorphology on landscape waterbird diversity. Yellow boxes indicate other CEDs.

| LTIM Project Indicator | Evaluation questions | Metrics | Critical covariates | Survey methods |
|---|---|---|---|---|
| Waterbird diversity | What did Commonwealth environmental water contribute to:<br><br>- waterbird populations?<br><br>- waterbird diversity? | Number of species<br><br>Total abundance of each species<br><br>Number of species of conservation significance<br><br>Species richness per habitat<br><br>Number of breeding species<br><br>Number of broods (non-colonial species) | Inundation extent (ha)<br>Water depth variability<br>Vegetation type & condition<br>Shoreline complexity (plain, low, moderate, high as per Cat 2 methods)<br>Shoreline type proportions<br>Habitat heterogeneity<br>Diversity of food resources: wetland fish, frog and zooplankton community composition<br>Water quality (DO, water temperature, turbidity, salinity) | Quarterly surveys alongside fish-frog wetland surveys (12 fixed sites within water year). |

### 5.12.2 Methods

***Category 2 Waterbird Diversity Monitoring***

Category 2 methods will be employed to survey 12 fixed wetland survey sites in spring and autumn during each water year these surveys are aligned with core wetland monitoring sites. Two replicate ground counts (am, pm) will be conducted over two separate days within each survey period to estimate maximum total waterbird abundance and species diversity in each survey wetland. Birds will be observed using binoculars and/or a telescope. Total counts for each waterbird species, any evidence of breeding activity (including number of nests/ broods/ immatures) will be recorded during each survey. As a minimum two observers will spend 10 minutes at each survey site. The rationale for this approach is that two counts (one in the morning and one in the late afternoon) are more appropriate for estimating maximum total abundance and diversity of waterbird species. For instance some species may only use wetlands as a roosting site in the late afternoon and if the methods were limited to a single survey in the morning in each survey period this would result in low detection for some species and underestimate total waterbird diversity in a given wetland. Undertaking replicate ground counts will align with previous survey data collected in the region by CSU and NSW OEH and Complementary monitoring being undertaken by NSW OEH in the Western Lakes (2012-2015) and Yanga National Park (Spencer, Wassens *et al.*

2011, Spencer, Hosking *et al*. 2014). Preliminary analysis of some of these data has shown this approach results in high detection rates (over 0.90) for a large number of waterbird species (Redman, Hall et al. 2013).

During large-scale flooding of the Lowbidgee floodplain many of the survey wetlands can become continuous, merging with adjacent wetlands which can make it impossible to estimate total abundance for a given site. Many of these wetlands are large and hard to access on foot during widespread flooding which make it difficult to undertake a complete ground survey. During previous ground surveys of the Murrumbidgee we have recorded total survey effort (total survey time and % site coverage based on remotely-sensed imagery and local knowledge of the site) to estimate the total number of abundance of each species per hectare. Where possible as much of the wetland will be surveyed to record total waterbird abundance. Where complete counts are not possible the total survey coverage will be estimated from a GPS track log and NSW OEH inundation mapping to enable number of waterbirds per hectare to be calculated. This approach still meets the requirements for Category 2 methods to support the Basin-scale evaluation and also aligns with monitoring in inland wetlands undertaken by NSW OEH across NSW (Spencer, Hosking *et al*. 2014).

### 5.12.3 Data analysis framework against evaluation questions

Multivariate analyses (PRIMER 2002) will be used to investigate differences in waterbird species assemblages within wetland sites before and after Commonwealth environmental watering, and among sites that receive and do not receive environmental water. This approach will allow for an evaluation of the contribution of Commonwealth environmental water to waterbird populations and waterbird species diversity in the Murrumbidgee Selected Area within and among water years.

Waterbird species will be separated into functional feeding groups as per (Hale, R. *et al*. 2014) to investigate differences in waterbird assemblages among wetlands. Waterbird data (maximum counts averaged across survey periods) will be fourth root transformed to control for multiple zeros and large values present in the data sets (Quinn and Keough 2002). The transformed abundance data will be examined using the Bray-Curtis measure of similarity (Bray and Curtis 1957) and subjected to non-metric Multi-Dimensional Scaling (nMDS) to demonstrate patterns in waterbird assemblages in the wetlands. One-way Analysis of Similarity tests (ANOSIM) will be used to detect significant differences in species assemblages among wetlands and water years. For significant relationships, the contribution made by particular species to identified differences at the sites will be determined by analysis of Similarity Percentages (SIMPER) (Clarke and Warwick 2001).

Additional modelling will be undertaken to investigate the effect of critical covariates in influencing waterbird responses to Commonwealth environmental watering. This will include total inundated area, flood frequency and duration, wetland fish, frog and microinvertebrate abundance, aquatic vegetation cover and structural complexity, and shoreline length. This information will be used to refine conceptual models for the Murrumbidgee Selected Area at the end of each water year.

# 6 Summary of monitoring and evaluation activities, and potential monitoring locations

Considering the range of indicators outlined in the previous section and key wetlands and river locations within the Murrumbidgee Selected Area (section 3), wetlands included in this section represent a subject of sites presented previously in Table 2. Sites have been identified for inclusion in the monitoring program on the bases of:

- Ecological character and representativeness of wetlands within the zone
- Ecological significance (for example presence of threatened species)
- Hydrology, selected sites must contain water for at least 3 months to allow for repeat sampling and be of sufficient depth to allow surveys
- Accessibility, vehicle or boat assess
- Capacity to deliver Commonwealth environmental water.

The tables in this section cover potential locations of fixed sites. Fixed sites are monitored continuously across the five year period, to provide data allowing the evaluation of long-term (five year) outcomes of Commonwealth environmental watering at the Basin (Category 1and 2) and Selected Area level (Table 10 and Table 12). The M&E Plan includes capacity for 12 fixed sites across three of the six wetland zones (Nimmie-Caira, Redbank, and mid-Murrumbidgee) (see Table 10). Establishing fixed sites allows for the deployment of water depth loggers and associated analysis of LIDAR data to support calculation of the Category 1 wetland hydrology metrics, reducing costs associated with continuous redeployment.

Table 10 Summary of sites and activities (wetlands)

| Zone | Site | Wetland nutrients, carbon & chlorophyll a | Microcrustacea | Wetland fish, tadpoles and frogs | Vegetation diversity | Waterbird diversity | Waterbird breeding (Optional potential sites) | Hydrology |
|---|---|---|---|---|---|---|---|---|
| Nimmie-Caira | Eulimbah | | | | | | | |
| | Telephone | | | | | | | |
| | Avalon Swamp | | | | | | | |
| | Nap Nap | | | | | | | |
| Redbank | Two Bridges Swamp | | | | | | | |
| | Mercedes Swamp | | | | | | | |
| | Piggery Lake | | | | | | | |
| | Wagourah Lagoon | | | | | | | |
| Redbank | Riversleigh | **Flow return option** | | | | | | |
| | Paul Coates | | | | | | | |
| | Steam Engine Swamp | | | | | | | |
| Mid-Murrumbidgee wetlands | Yarrada | | | | | | | |
| | McKennas | | | | | | | |
| | Sunshower | | | | | | | |
| | Gooragool | | | | | | | |

Table 11 Summary of sites and activities (rivers)

| Zone | Site | Fish community | Larval fish | Stream metabolism | nutrients, carbon & chlorophyll a | Microcrustacea |
|---|---|---|---|---|---|---|
| Narrandera | Site 7 | SA | SA | | | |
| | Site 8 | SA | | | | |
| | Site 9 | SA | | | | |
| | Site 10 | SA | SA | | | |
| | Site 11 | SA | | | | |
| | Site 12 | SA | | | | |
| | Site 13 | SA | SA | | | |
| Carrathool | Site 14 | Cat 1 | Cat 1 | Cat 1 | | |
| | Site 15 | Cat 1 | | | | |
| | Site 16 | Cat 1 | Cat 1 | | | |
| | Site 17 | Cat 1 | | | | |
| | Site 18 | Cat 1 | Cat 1 | | | |
| | Site 19 | Cat 1 | | | | |
| | Site 20 | Cat 1 | | | | |
| | Site 21 | Cat 1 | | | | |
| | Site 22 | Cat 1 | | | | |
| | Site 23 | Cat 1 | | | | |

# 7 Timeline

This section contains details of the timing of key activities associated with the LTIM Project program include the collection of field data, reporting of Category 1 and 2 metrics, Selected Area evaluation and reporting, community engagement and informing adaptive management each year between 2014-2019 (Table 13).

Table 13 Schedule of monitoring, evaluation and reporting activates Murrumbidgee M&E Plan

| **Indicator Year 1** | **Activity** | **Jul 14** | **Aug 14** | **Sep 14** | **Oct 14** | **Nov 14** | **Dec 14** | **Jan 15** | **Feb 15** | **Mar 15** | **Apr 15** | **May 15** | **Jun 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecosystem Type | Boundary classifications | | | | | | | | | | | | |
| Hydrology Cat 1 and SA | Classification of bathymetry (DEM) | | | | | | | | | | | | |
| | Establish Depth (logger) Array | | | | | | | | | | | | |
| | Derive flow metrics | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Stream Metabolism Cat 1 | Site selection | | | | | | | | | | | | |
| | Logging DO, monthly nutrients | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| River nutrients, DOC, CHLa (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Wetland nutrients, DOC, CHLa (SA) | Field sampling@ wetland fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Microcrustaceans (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Field sampling @ wetland fish sites | | | | | | | | | | | | |
| | Process samples, analysis, transfer | | | | | | | | | | | | |
| Fish community (river) Cat 1 | Annual sampling | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish recruitment Cat 1 | Field sampling | | | | | | | | | | | | |
| | sample processing | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish community (river) (SA) (Yr 1) | Field sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Larval fish Cat 1 and (SA) | Fortnightly collection | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Wetland fish, frogs (SA) | Field sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Vegetation diversity (Cat 2) | Field sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Waterbird diversity (Cat 2) | Field sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Synthesis, evaluation | Analysis, report | | | | | | | | | | | | |
| Reporting | Monthly (year 1 written and verbal) | | | | | | | | | | | | |
| | Quarterly reports | | | | | | | | | | | | |
| | Area evaluation report | | | | | | | | | | | | |
| Communication engagement | Verbal (monthly) (working group) | | | | | | | | | | | | |
| | Annual flow planning | | | | | | | | | | | | |

| Indicator Year 2 | Activity | Jul 15 | Aug 15 | Sep 15 | Oct 15 | Nov 15 | Dec 15 | Jan 16 | Feb 16 | Mar 16 | Apr 16 | May 16 | Jun 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrology Cat 1and SA | Derive flow metrics | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Stream Metabolism Cat 1 | Site selection | | | | | | | | | | | | |
| | Logging DO, monthly nutrients | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| River nutrients, DOC, CHLa (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Wetland nutrients, DOC, CHLa (SA) | Field sampling@ wetland fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Microcrustaceans (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Field sampling @ wetland fish sites | | | | | | | | | | | | |
| | Process samples, analysis, transfer | | | | | | | | | | | | |
| Fish community (river) Cat 1 | Annual sampling | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish recruitment Cat 1 | Sample processing | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Larval fish Cat 1 and (SA) | Fortnightly collection | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Wetland Fish, frogs (SA) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Vegetation diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Waterbird diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Synthesis | Analysis and evaluation | Y1 | Y1 | Y1 | | | | | | | | | |
| Reporting | Area evaluation report | | Y1 D | | Y1 F | | | | | | | | |
| | Quarterly reports | | | | | | | | | | | | |
| | Verbal reporting (monthly) | | | | | | | | | | | | |
| Communication and engagement | Annual flow planning | | | | | | | | | | | | |

| Indicator Year 3 | Activity | Jul 16 | Aug 16 | Sep 16 | Oct 16 | Nov 16 | Dec 16 | Jan 17 | Feb 17 | Mar 17 | Apr 17 | May 17 | Jun 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrology Cat 1and SA | Derive flow metrics | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Stream Metabolism Cat 1 | Site selection | | | | | | | | | | | | |
| | Logging DO, monthly nutrients | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| River nutrients, DOC, CHLa | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Wetland nutrients, DOC, CHLa (SA) | Field sampling@ wetland fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Microcrustaceans (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Field sampling @ wetland fish sites | | | | | | | | | | | | |
| | Process samples, analysis, transfer | | | | | | | | | | | | |
| Fish community (river) Cat 1 | Annual sampling | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish recruitment Cat 1 | Sample processing | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Larval fish Cat 1 and (SA) | Fortnightly collection | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Wetland fish, frogs (Cat 3) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Vegetation diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Waterbird diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Synthesis | Analysis and evaluation | Y2 | Y2 | Y2 | | | | | | | | | |
| Reporting | Area evaluation report | | Y2 D | | Y2 F | | | | | | | | |
| | Quarterly reports | | | | | | | | | | | | |
| | Verbal reporting (monthly) | | | | | | | | | | | | |
| Communication and engagement | Annual flow planning | | | | | | | | | | | | |

| Indicator Year 4 | Activity | Jul 17 | Aug 17 | Sep 17 | Oct 17 | Nov 17 | Dec 17 | Jan 18 | Feb 18 | Mar 18 | Apr 18 | May 18 | Jun 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrology Cat 1 and SA | Derive flow metrics | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Stream metabolism Cat 1 | Logging DO, monthly nutrients | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| River nutrients, DOC, CHLa (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Wetland nutrients, DOC, CHLa (SA) | Field sampling@ wetland fish sites | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| Microcrustaceans (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Field sampling @ wetland fish sites | | | | | | | | | | | | |
| | Process samples, analysis, transfer | | | | | | | | | | | | |
| Fish community (river) Cat 1 | Annual sampling | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish recruitment Cat 1 | Sample processing | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Larval fish Cat 1 and (SA) | Fortnightly collection | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Wetland fish, frogs, turtles (SA) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| Vegetation diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Waterbird diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry and analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Synthesis | Analysis and evaluation | Y3 | Y3 | Y3 | | | | | | | | | |
| Reporting | Area evaluation report Draft | | Y3 D | | Y3 F | | | | | | | | |
| | Quarterly reports | | | | | | | | | | | | |
| | Verbal reporting (monthly) | | | | | | | | | | | | |
| Communication and engagement | Annual flow planning | | | | | | | | | | | | |

| Indicator Year 5 | Activity | Jul 18 | Aug 18 | Sep 18 | Oct 18 | Nov 18 | Dec 18 | Jan 19 | Feb 19 | Mar 19 | Apr 19 | May 19 | Jun 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrology Cat 1 and SA | Derive flow metrics | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Stream Metabolism Cat 1 | Site selection | | | | | | | | | | | | |
| | Logging DO, monthly nutrients | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| River nutrients, DOC, CHLa (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| Wetland nutrients, DOC, CHLa (SA) | Field sampling@ wetland fish sites | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| Microcrustaceans (SA) | Field sampling @larval fish sites | | | | | | | | | | | | |
| | Field sampling @ wetland fish sites | | | | | | | | | | | | |
| | Process samples, analysis, transfer | | | | | | | | | | | | |
| Fish community (river) Cat 1 | Annual sampling | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish recruitment Cat 1 | Field collection | | | | | | | | | | | | |
| | Sample processing | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Fish community (river) (SA) | Annual sampling | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Larval fish Cat 1 and (SA) | Fortnightly collection | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Wetland fish, frogs (SA) | Sampling | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Vegetation diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Waterbird diversity (Cat 2) | Sampling | | | | | | | | | | | | |
| | Processing, data entry, analysis | | | | | | | | | | | | |
| | Information transfer | | | | | | | | | | | | |
| Synthesis | Analysis and evaluation | Y4 | YA | Y4 | | | | | | | | | |
| Reporting | Area evaluation report Draft | | Y4D | | Y4F | | | | | | | | |
| | Quarterly reports | | | | | | | | | | | | |
| | Verbal reporting (monthly) | | | | | | | | | | | | |
| Communication and engagement | Annual flow planning | | | | | | | | | | | | |
| | Newsletter | | | | | | | | | | | | |

| Indicator Year 6 | Activity | Jul 19 | Aug 19 | Sep 19 | Oct 19 | Nov 19 | Dec 19 | Jan 20 | Feb 20 | Mar 20 | Apr 20 | May 20 | Jun 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reporting | Area evaluation report Draft | | DY5 | | F Y5 | | | | | | | | |
| | Quarterly reports | | | | | | | | | | | | |
| | Verbal reporting (monthly) | | | | | | | | | | | | |
| Communication and engagement | Reference group, EWARG, CEWH | | | | | | | | | | | | |
| | Annual flow planning | | | | | | | | | | | | |
| | Newsletter | | | | | | | | | | | | |

# 8 Communication Plan

A broad collaborative approach will be used to effectively engage, consult and collaborate with stakeholders throughout the project. The project team will draw widely on the existing structures, expertise, relationships and local knowledge that exist in the Murrumbidgee to ensure efforts are not being duplicated and communication is efficient and effective. In regard to stakeholder communication behaving in a respectful, collaborative, cooperative and courteous manner (guided by the CEWO LTIM Project code of conduct) will be important.

The aim of the engagement plan is to:

- Foster existing partnerships and develop new partnerships and collaborations,
- Aid the Commonwealth where appropriate to regularly communicate the results of environmental water monitoring activities to key stakeholders and the public more broadly,
- Communicate results and recommendations for future and current e-water management to the Commonwealth and other key stakeholders, including delivery partners and environmental water groups,
- Increase transparency and dispel myths in regard to environmental water outcomes, and
- Build a solid foundation for adaptive management of environmental water through strong partnership and clear regular communication.

The Murrumbidgee environmental water community includes a broad range of stakeholders all with various roles identified below.

| Stake Holder/ individual/Group | Role |
|---|---|
| MDBA | Development of the environmental watering strategies and plans. |
| CEWO (Department of the Environment) | Preparation of environmental water planning and watering strategies with input from state government and the MDBA.<br>Operate and deliver Commonwealth environmental water in accordance with the environmental watering plan. |
| NSW Office of Water | Implementation of environmental watering strategies and plans<br>Implementation of the Water-Sharing Plan and preparation of Water Resource Plans when water-sharing plans expire.<br>Management of planned environmental water. |
| NSW OEH | Implementation of environmental watering strategies and plans.<br>Management of adaptive environmental water and discretionary water.<br>Riverbank program (acquisition of water licences).<br>Preparation of Water-Use Plan for the management of adaptive environmental water (statutory document).<br>Preparation of Annual Environmental Water Plan with input from senior environmental water management officers and the Environmental Water Allowance Reference Group. |
| State water corporation | River and dam operator that manages the regulated river on a daily basis.<br>Delivery along the main river channel and to Lowbidgee and Mid-Murrumbidgee Wetlands, and the Yanco Creek system.<br>Transmission forfeit along the river channel.<br>Conduct daily forecasting of tributary contributions to base flows, and losses, based on the previous day's data. |
| Irrigation Corporations (MI, Murray Irrigation and Coleambally Irrigation) | Water delivery<br>MI—Mirrool Creek floodplain<br>Coleambally Irrigation—Yanco Creek, Forest Creek, Billabong Creek<br>Murray Irrigation Limited—Yanco Creek, Forest Creek, Billabong Creek<br>Rice growers Australia |
| Environmental Water Allowance Reference Group (EWARG) | To assimilate a range of knowledge and experience to advise on both planned and adaptive environmental water in NSW that can be actively managed |
| General public | Be provided with opportunities for knowledge sharing |
| Landholder where monitoring occurs | Be provided with opportunities for knowledge sharing |
| Landcare | Community group - be provided with opportunities for knowledge sharing |
| Murrumbidgee Field Naturalists | Community group - be provided with opportunities for knowledge sharing |
| Fivebough and Tuckerbill wetland advisory group | Oversee the management of Fivebough and Tuckerbill Ramsar sites - be provided with opportunities for knowledge sharing |

Table 12 Outline of the approach to ensure all levels of engagement are effectively undertaken (note: activities will be undertaken with approval from CEWO)

| **Action** | **Stakeholders** | **Tools** |
|---|---|---|
| INFORM | General public<br>Landholders<br>Community groups<br>Schools and Youth groups<br>Aboriginal Community | Factsheets and news stories<br>Input to Media Releases<br>Interviews |
| CONSULT | Community groups<br>Landholders and Land managers (Private and Public lands)<br>Agricultural industry groups (e.g. Murrumbidgee Irrigation Area, Coleambally Irrigation Area, Rice growers Australia)<br>Local government<br>Aboriginal Community | Community meetings<br>workshops<br>Input to Media Releases |
| INVOLVE | Environmental water managers (NSW OEH, CEWH)<br>Environmental water delivery agency (NSW OEH, State Water, Office of Water)<br>Riverina Local Land Services (LLS)<br>Environmental Water Allowance Reference Groups (Murrumbidgee EWARG)<br>Landholders and Land managers (Private and Public lands)<br>Agricultural industry groups (e.g. Murrumbidgee Irrigation Area, Coleambally Irrigation Area, Rice growers Australia)<br>Local government<br>Catchment managers<br>Aboriginal Community | Real-time verbal and written information to inform adaptive management<br>Update reports<br>Planning teleconferences<br>Monitoring reports<br>Volunteer/In-kind contributions<br>Input to Media Releases<br>Act in accordance with the CEWO code of conduct |

## Key Engagement activities

### *Murrumbidgee Working Group*

The Murrumbidgee Working Group has existed as an informal group for a number of years, with membership formalised as part of Stage 1 for the Murrumbidgee LTIM Project with membership approved by CEWO. The working group has members from key stakeholder groups including environmental water managers and ecologists in NSW OEH (including NSW National Parks and Wildlife Service), NSW Office of Water, State Water, CEWO Delivery team members, and team members from CSU, NSW OEH. Riverina LLS, UNSW and DPI. In addition to core group members the group Chair has the capacity to call on experts to provide specific advice to assist in monitoring, water management and flow planning. The group's primary function is to provide support and advice in relation to the strategic direction of the Murrumbidgee LTIM Project, advice and comment on annual flow planning, day to day operations of Commonwealth environmental water and adaptive management. Importantly the working group provides a forum for the rapid exchange of information relevant to environmental watering actions through the Murrumbidgee.

During operation of the LTIM Project the working group will meet Quarterly in July, October, January (all via teleconference) and April (face to face meeting). The annual face to face meeting in April will allow for members to workshop watering options and monitoring strategies for the coming water year. In addition to these scheduled meetings, additional teleconference can be called at any time by CEWO, NSW OEH environmental water managers or the Chair to address specific water actions, opportunities or developing risks.

***Murrumbidgee flow planning adaptive management***

Previously during Murrumbidgee flow events, technical advisory groups have been established by NSW and Commonwealth water managers. As in previous years, the members of the Murrumbidgee LTIM Project team participate in both state and Commonwealth environmental flow planning as needed to enable effective event based adaptive management. The timing and frequency of meetings reflects the decision making framework and can be as frequent as weekly during complex flow deliveries. It is expected that meetings will be held primarily via teleconference.

***Murrumbidgee Environmental Water Allowance Reference Group (EWARG)***

It is recognised that intervention monitoring is the primary means for understanding the outcomes from the use of Commonwealth environmental water, and the ability to communicate these outcomes back into established management groups will be vital to successful management at several scales, including:

- real time improvements to event management,
- annual water use options planning, and
- longer term strategies (e.g. five year time scales).

The Murrumbidgee Environmental Water Allowance Reference Group (EWARG) has an important role in that it synthesises a range of knowledge and experience to advise both planned and adaptive environmental water in NSW that can be actively managed. The group is key to bringing stakeholders together to advise on environmental water use. Membership of this group includes representatives from the Riverina LLS (Chair), NSW OEH, DPI, NSW Office of Water, State Water, Aboriginal community, Lowbidgee League, Murrumbidgee Customer Service Committee, Murrumbidgee Field Naturalists and Nature Conservation Council. The LTIM Project program can help build the capacity of the group through the presentation of monitoring outcomes over the five year program.

It is proposed to formalise a regular update to the EWARG during quarterly meetings (with the approval of the Commonwealth) so information from the LTIM Project and environmental watering outcomes are regularly shared. Additionally, in order to assist in achieving real adaptive management goals, various members of the LTIM Project team will be available to sit in on Technical Advisory Group meetings for the EWARG and other teleconferences when required to assist with adaptively managing both annual and specific environmental water use.

***Quarterly reports and other media***

News circulars are an import way of communicating the outcomes of the monitoring program to the general public, landholders and other stakeholders. We propose to prepare two newsletters each year that will provide an accessible, summary of information contained in the annual reports. The newsletters' authors will liaise closely with the CEWO to share basic information about the project and advise of upcoming events.

The group, led by Dr Skye Wassens, will participate as necessary in approved media events. The group will also advise the CEWO of any identified media opportunities.

***Landholder and land manager relationships***

The importance of the cooperation and collaboration offered freely by private landholders and public land managers where environmental water is being delivered cannot be understated. The value to liaising with landholders to receive local advice regarding access, constraints, monitoring, and opportunities for watering and other vital local information is significant to the success of the project. In regard to this the project team place high importance on the LTIM Project code of conduct delivering safe, collaborative, cooperative, courteous and respectful behaviours to build these relationships.

# 9 Project management and reporting

### 9.1.1 Project leadership, management and administration

Associate Professor Wassens will be responsible for organising the project into one or more sub-projects, managing the day-to-day aspects of the project, resolving planning and implementation issues and communicating monitoring outcomes to inform adaptive management, as well as scheduled reporting. The Institute of Land Water and Society will undertake project administration, contracts, workplace health and safety and project auditing. Associate Professor Wassens (project leader) will be assisted by an assistant project leader (Dr Spencer) who will assume the role of project leader as required ensuring continuity in project delivery (Table 13). Team leaders will be responsible for communicating monitoring and evaluation activities (Table 14) and ensuring that strong links are maintained with complementary projects run within their organisations. The project leader will report to the CEWH at regular intervals and manage client, partner and stakeholder relationships. Murrumbidgee LTIM Project Reporting

Reporting processes are vital to stakeholder engagement. Timely reporting of monitoring information is a key step to sharing this knowledge which in turn aids better water delivery through adaptive management.

***Monthly progress reports***

A total of 63 verbal progress reports (monthly) will occur from project inception (July 2014) to the submission of the final report (October 2019). In year one, written and verbal progress reports will be undertaken, in years 2 to 5 verbal progress reports will be delivered to CEWO via teleconference. During the teleconferences the team will provide summaries of field trips, including any relevant recommendations and any landholder or community concerns that the team have been made aware of.

**Quarterly written project status/progress reports**

A written progress report, summarising tasks completed since the last report, tasks planned for the upcoming period and other emerging issues will be provided to the CEWO on the last business day of September, December, March and June each year.

### *Annual Area evaluation report*

The Annual Area evaluation report is a cumulative evaluation of the outcomes of Commonwealth environmental water at each Selected Area, prepared in accordance with this Plan that is delivered annually to the CEWO (Draft 30 Aug, Final 31 October). The report will written in plain English with easily understandable science and be suitable for publication on CEWO website.

### *Annual Forum*

Four members of the Murrumbidgee project team will attend each Annual Forum. It is expected participation in the forums will provide a opportunities to discuss and collaborate on lessons learned and so assist in continual improvement and knowledge sharing between Selected Areas. Annual forum's will run for two days and take place in Sydney in July. A total a five annual forums over the project duration, with first forum taking place in July 2015 and the last in July 2019.

### *Biannual leaders' teleconferences*

The Murrumbidgee leaders' teleconferences in November and March will be attended by Dr Skye Wassens (or assistant project leaders). A total of ten teleconferences will take place over the project duration, with the first taking place in November 2014 and the last in March 2019.

Table 13 Core project team and responsibilities

| Name | Organisation | Project Role | Responsibility- evaluation and reporting |
|---|---|---|---|
| Associate Professor Skye Wassens | CSU | Project Leader CSU Team Leader | Report lead, Wetland fish, frogs |
| Dr Andrew Hall | CSU | CSU team member | Hydrology and ecosystem type |
| Dr Ben Wolfenden | CSU | CSU team member | Stream metabolism, return flows, wetland nutrients |
| Dr Kim Jenkins | CSU | CSU team member | Microinvertebrates, assistant project leader |
| Dr Jennifer Spencer | NSW OEH | NSW OEH team leader (assistant project leader) | Waterbird diversity and breeding, assistant project leader |
| Rachael Thomas | NSW OEH | NSW OEH team member | Hydrology and ecosystem type |
| Dr Yoshi Kobayashi | NSW OEH | NSW OEH team member | Stream metabolism |
| Dr Jason Thiem | NSW DPI | DPI Team leader | Riverine Fish, larval fish and fish movement |
| Dr Gilad Bino | UNSW | UNSW team member | Data analysis, process modelling and synthesis |
| Dr Kate Brandis | UNSW | UNSW team leader | Waterbird breeding |

Table 14 Summary of primary responsibilities for each monitoring, evaluation and reporting of each activity outlined in the M&E Plan

| LTIM Project Indicators | Monitoring coordination – data collection | Evaluation and reporting |
|---|---|---|
| Ecosystem Type | Wolfenden/Hall | Wolfenden/Hall |
| Hydrology Cat 1<br>Stream metabolism Cat 1 and SA<br>Return flows (optional) | Wolfenden/Hall<br>Wolfenden<br>Wolfenden | Hall/Thomas<br>Wolfenden/Kobayashi<br>Wolfenden/ Kobayashi |
| Wetland nutrients, | Wolfenden | Wolfenden/ Kobayashi |
| Microcrustaceans<br>Fish community (river) Cat 1<br>Fish recruitment Cat 1<br>Fish community (river) SA | Jenkins<br>Thiem<br>Thiem<br>Thiem | Jenkins<br>Thiem<br>Thiem<br>Thiem |
| Larval fish Cat 1 and SA<br>Fish movement (Cat 2 and 3)<br>Wetland Fish, tadpoles SA | Thiem<br>Thiem<br>Wolfenden | Thiem<br>Thiem<br>Wassens/Wolfenden |
| Wetland frogs | Wolfenden | Wassens/Wolfenden |
| Vegetation diversity (Cat 2) | Wassens | Wassens |
| Waterbird diversity (Cat 2 and 3) | Spencer | Spencer |
| Waterbird breeding (Cat 1) | Spencer/Brandis | Spencer/Brandis |
| Waterbird breeding (SA) | Spencer/Brandis | Spencer/Brandis |
| Project management | | Wassens |
| Synthesis and evaluation | | Wassens/Bino |
| Reporting | | Wassens |
| Progress reports | | Wassens |
| Communication and engagement | | Wassens |
| Auditing/administration | | CSU Research Office/ Institute Land Water and Society |

# 10 Other documents associated with this M&E Plan

This document is accompanied by three additional documents:

- The Quality management plan- which details the quality management processes to be used throughout the project, including project management, data management and QA/QC processes
- The Risk management plan – which outlines major risks to the project and progress of mitigation action implementation
- The Workplace Health and Safety Plan (WHS) which has been developed to ensure all work undertaken as part of the M&E Plan comply with the Commonwealth Work Health and Safety Act 2011 (WHS Act), Work Health and Safety Regulations 2011 (WHS Regulations), Work Health and Safety Codes of Practice 2011.

# 11 References

Agostinho, A. A., Gomes, L. C. and Pelicice, F. M. (2007). Ecology and management of fish resources in reservoirs in Brazil. Eduem.

Anderson, H. K. (1915). "Rescue Operations on the Murrumbidgee River." The Australian Zoologist 1: 157-160.

Anderson, M., Gorley, R. N. and Clarke, K. R. (2008). Permanova+ for Primer: Guide to Software and Statistical Methods. Plymouth., PRIMER-E

Balcombe, S., Lobegeiger, J., Marshall, S., Marshall, J., Ly, D. and Jones, D. (2012). "Fish body condition and recruitment success reflect antecedent flows in an Australian dryland river." Fisheries Science 78(4): 841-847.

Balcombe, S. R. and Humphries, P. (2006). "Diet of the western carp gudgeon (*Hypseleotris klunzingeri Ogilby*) in an Australian floodplain lake: the role of water level stability." Journal of Fish Biology 68: 1484-1493.

Baumgartner, L. J., Conallin, J., Wooden, I., Campbell, B., Gee, R., Robinson, W. A. and Mallen-Cooper, M. (2013). "Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems." Fish and Fisheries.

Beesley, L., Price, A., King, A., Gawne, B., Nielsen, D. L., Koehn, J. D., Meredith, S., Vilizzi, L. and Hladyz, S. (2011). Watering floodplain wetlands in the Murray-Darling Basin for native fish. Canberra, National Water Commission

Bino, G., Steinfeld, C. and Kingsford, R. T. (2013). "Maximising colonial waterbirds breeding events, using identified ecological thresholds and environmental flow management." Ecological Applications In press.

Brandis, K., Ryall, S. and Kingsford, R. T. (2011). Lowbidgee 2010/2011 Colonial Waterbird Breeding. Sydney Final report prepared for the Lowbidgee League. Australian Wetlands and Rivers Centre, University of New South Wales.

Brandis, K. J., Kingsford, R. T., Ren, S. and Ramp, D. (2011). "Crisis water management and ibis breeding at Narran Lakes in arid Australia." Environmental Management 48(3): 489-498.

Brandis, K. J., Koeltzow, N., Ryall, S. and Ramp, D. (in press). "Assessing the use of camera traps to measure reproductive success in Straw-necked Ibis breeding colonies." Australian Field Ornithology.

Bray, J. R. and Curtis, J. T. (1957). "An ordination of the upland forest communities of southern Wisconsin." Ecological Monographs 27: 325-349.

Briggs, S. V. and Thornton, S. A. (1999). "Management of water regimes in River Red Gum Eucalyptus camaldulensis wetlands for waterbird breeding." Australian Zoologist 31(1): 187-197.

Briggs, S. V., Thorton, S. A. and Lawler, W. G. (1997). "Relationships between hydrological control of River Red Gum wetlands and waterbird breeding." Emu 97: 31-42.

Brock, M. A., Nielsen, D. L., Shiel, R. J., Green, J. D. and Langley, J. D. (2003). "Drought and aquatic community resilience: the role of eggs and seeds in sediments of temporary wetlands." Freshwater Biology 48(7): 1207-1218.

Cameron, L. M., Baumgartner, L. J. and Maguire, J. (2013). Management plan to use environmental water to enhance the Murrumbidgee River system for native fish. , NSW Department of Primary Industries, Cronulla.

Chessman, B. (1988). "Habitat Preferences of Fresh-Water Turtles in the Murray Valley, Victoria and New-South-Wales." Wildlife Research 15(5): 485-491.

Chessman, B. (2003). Integrated monitoring of environmental flows:State summary report 1998-2000. NSW, NSW Department of Infrastructure, Planning and Natural Resources.

Chessman, B. C. (2011). "Declines of freshwater turtles associated with climatic drying in Australia's Murray-Darling Basin." Wildlife Research 38(8): 664-671.

Childs, P., Webster, R., Spencer, J. and Maguire, J. (2010). Yanga National Park - 2009-10 Environmental Watering: Waterbird Surveys Final Report. Final report to the Commonwealth Environmental Water Holder and NSW Department of Environment, Climate Change and Water (National Parks and Wildlife Service). Western Region, Griffith.

Clarke, K. R. and Gorley, R. N. (2006). PRIMER v6: User Manual/Tutorial. Plymouth, PRIMER-E.

Clarke, K. R. and Warwick, R. M. (2001). Changes in marine communities: An approach to statistical analysis and interpretation. Plymouth, UK, PRIMER-E:.

Commonwealth Environmental Water (2013). The Environmental Water Outcomes Framework. Canberra, Commonwealth Environmental Water Holder for the Australian Government.

Copp, G. (1992). "Comparative microhabitat use of cyprinid larvae and juveniles in a lotic floodplain channel." Environmental Biology of Fishes 33(1-2): 181-193.

Crome, F. (1988). "To Drain or Not to Drain? –Intermittent Swamp Drainage and Waterbird Breeding." Emu 88(4): 243-248.

CSIRO (2008a). Water availability in the Murrumbidgee. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO: Canberra.

CSIRO (2008b). Water Availability in the Murrumbidgee: A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. Canberra, CSIRO.

Cunningham, S. C., Read, J., Baker, P. J. and Mac Nally, R. (2007). "Quantitative assessment of stand condition and its relationship to physiological stress in stands of Eucalyptus camaldulensis (Myrtaceae)." Australian Journal of Botany 55(7): 692-699.

David, B. O. and Closs, G. P. (2002). "Behaviour of a stream-dwelling fish before, during, and after high-discharge events." Transactions of the American Fisheries Society 131(4): 762-771.

Downes, B., Barmuta, L. A., Fairweather, P. G., Faith, D. P., Keough, M. J., Lake, P. S., Mapstone, B. D. and Quinn, G. P. (2002). Monitoring Ecological Impacts: Concepts and Practice in Flowing Waters, Cambridge University Press.

Eaton, A. D., Clesceri, L.S., Rice, E. W. and Greenberg, A. E. (2005). Standard methods for examination of water & wastewater. Centennial edition. Washington, USA, American Public Health Association.

Frederick, P. and Ogden, J. (2001). "Pulsed breeding of long-legged wading birds and the importance of infrequent severe drought conditions in the Florida Everglades." Wetlands 21(4): 484-491.

Gawne, B., Brooks, S., Butcher, R., Cottingham, P., Everingham, P. and Hale, J. (2013a). Long term intervention monitoring project monitoring and evaluation requirements Murrumbidgee River system for Commonwealth environmental water. Final report prepared for the Commonwealth Environmental Water Office. Wodonga, Murray-Darling Freshwater Research Centre (MDFRC).

Gawne, B., Brooks, S., Butcher, R., Cottingham, P., Everingham, P., Hale, J., Nielsen, D. L., Stewardson, M. and Stoffels, R. (2013b). Long Term Intervention Monitoring Project: Logic and Rationale Document. Final report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre.

Gilligan, D. and Schiller, C. (2003). Downstream transport of larval and juvenile fish in the Murray River, NSW Fisheries Office of Conservation.

Gilligan, D. M. (2005). Fish communities of the Murrumbidgee catchment: status and trends. New South Wales Department of Primary Industries: Cronulla Fisheries Centre.

Gosner, K. L. (1960). "A simplified table for staging anuran embryos and larvae with notes on identification " Herpetologica 16: 183-189.

Hale, J., R., S., Butcher, R., Shackleton, M., Brooks, S. and Gawne, B. (2014). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project - Standard Methods. Final report prepared for the Commonwealth Environmental Water Office by the Murray-Darling Freshwater Research Centre, MDFRC Publication 29.2/2014.

Hale, J., Stoffels, R., Butcher, R., Shackleton, M., Brooks, S. and Gawne, B. (2013). Commonwealth Environmental Water Office Long Term Intervention Monitoring Project - Standard Methods. Final Report prepared for Commonwealth Environmental Water Office Wodonga, The Murray-Darling Freshwater Research Centre.

Hardwick, L. and Maguire, J. (2012). Environmental water needs of the Lower Murrumbidgee (Lowbidgee) floodplain: Discussion Paper 1 - Approach and ecological considerations, NSW Office of Water.

Hines, J. E. (2006). "PRESENCE2- Software to estimate patch occupancy and related parameters. USGS-PWRC." Retrieved 3 June 2011, from http://www.mbr-pwrc.usgs.gov/software/presence.html.

Hladyz, S., Watkins, S. C., Whitworth, K. L. and Baldwin, D. S. (2011). "Flows and hypoxic blackwater events in managed ephemeral river channels." Journal of Hydrology 401(1–2): 117-125.

Howitt, J. A., Baldwin, D. S., Rees, G. N. and Williams, J. L. (2007). "Modelling blackwater: Predicting water quality during flooding of lowland river forests." Ecological Modelling 203(3-4): 229-242.

Humphries, P. (1996). "Aquatic macrophytes, macroinvertebrate associations and water levels in a lowland Tasmanian river." Hydrobiologia 321(3): 219-233.

Humphries, P., King, A. J. and Koehn, J. D. (1999). "Fish, Flows and Flood Plains: Links between Freshwater Fishes and their Environment in the Murray-Darling River System, Australia." Environmental Biology of Fishes 56(1): 129-151.

Humphries, P., Serafinia, L. and King, A. J. (2002). "River regulation and fish larvae: variation through space and time." Freshwater Biology 47: 1307-1331.

Jackson, D. A., Peres-Neto, P. R. and Olden, J. D. (2001). "What controls who is where in freshwater fish communities the roles of biotic, abiotic, and spatial factors." Canadian Journal of Fisheries and Aquatic Sciences 58(1): 157-170.

Jenkins, K. M. and Boulton, A. J. (2003). "Connectivity in a dryland river: short-term aquatic microinvertebrate recruitment following floodplain inundation." Ecology 84(10): 2708-2723.

Jenkins, K. M. and Boulton, A. J. (2007). "Detecting impacts and setting restoration targets in arid-zone rivers: aquatic micro-invertebrate responses to reduced floodplain inundation." Journal of Applied Ecology 44(4): 823-832.

Jenkins, K. M., Iles, J., Smith, J., Kingsford, R. T., Forrest, M. and Rayner, T. (2013). Monitoring of ecosystem responses to the delivery of environmental water in the Lower Murrumbidgee River and wetlands, 2011-2012, Australian Wetlands, Rivers and Landscapes Centre. Prepared for Commonwealth Environmental Water.

Kéry, M., Dorazio, R. M., Soldaat, L., Van Strien, A., Zuiderwijk, A. and Royle, J. A. (2009). "Trend estimation in populations with imperfect detection." Journal of Applied Ecology 46(6): 1163-1172.

King, A. J. (2004). "Density and distribution of potential prey for larval fish in the main channel of a floodplain river: pelagic versus epibenthic meiofauna." River Research and Applications 20(8): 883-897.

King, A. J., Humphries, P. and Lake, P. S. (2003). "Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics." Canadian Journal of Fisheries and Aquatic Sciences 60(7): 773-786.

Kingsford, R. T. and Auld, K. M. (2005). "Waterbird breeding and environmental flow management in the Macquarie Marshes, arid Australia." River Research and Applications 21(2-3): 187-200.

Kingsford, R. T., Bino, G., Porter, J. and Brandis, K. (2013). Waterbird communities in the Murray-Darling Basin, 1983-2012, Final report by the Centre for Ecosystem Science, University of New South Wales to the Murray-Darling Basin Authority, Canberra.

Kingsford, R. T. and Briggs, H. C. (2012). Strategic adaptive management guidelines for effective conservation of freshwater ecosystems in and around protected areas of the world. Sydney, IUCN WCPA Freshwater Taskforce. Australian Wetlands and Rivers Centre.

Kingsford, R. T., Jenkins, K. M. and Porter, J. L. (2004). "Imposed hydrological stability on lakes in arid Australia and effects on waterbirds." Ecology 85(9): 2478-2492.

Kingsford, R. T. and Norman, F. I. (2002). "Australian waterbirds - products of the continent's ecology." Emu 102: 47-69.

Kingsford, R. T., Porter, J. L. and Halse, S. A. (2012). National Waterbird Assessment. Waterlines Report, 74. Canberra, National Water Commission.

Kingsford, R. T. and Thomas, R. F. (2001). Changing water regimes and wetland habitat on the Lower Murrumbidgee floodplain of the Murrumbidgee River in Arid Australia. Sydney, NSW National Parks and Wildlife Service.

Kingsford, R. T. and Thomas, R. F. (2004). "Destruction of wetlands and waterbird populations by dams and irrigation on the Murrumbidgee River in arid Australia." Environmental Management 34(3): 383-396.

Kobayashi, T., Ryder, D., Gordon, G., Shannon, I., Ingleton, T., Carpenter, M. and Jacobs, S. (2009). "Short-term response of nutrients, carbon and planktonic microbial communities to floodplain wetland inundation." Aquatic Ecology 43(4): 843-858.

Koehn, J. D. and Harrington, D. J. (2006). "Environmental conditions and timing for the spawning of Murray cod (*Maccullochella peelii peelii*) and the endangered trout cod (M. macquariensis) in southeastern Australian rivers." River Research and Applications 22(3): 327-342.

Koehn, J. D., McKenzie, J. A., O'Mahony, D. J., Nicol, S. J., O'Connor, J. P. and O'Connor, W. G. (2009). "Movements of Murray cod (*Maccullochella peelii peelii*) in a large Australian lowland river." Ecology of Freshwater Fish 18(4): 594-602.

Koehn, J. D., Nicol, S. J., McKenzie, J. A., Lieschke, J. A., Lyon, J. P. and Pomorin, K. (2008). "Spatial ecology of an endangered native Australian Percichthyid fish, the trout cod *Maccullochella macquariensis*." Endangered Species Research 4(1-2): 219-225.

Lake, J. (1967). "Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning." Marine and Freshwater Research 18(2): 137-154.

Leigh, S. and Zampatti, B. (2013). "Movement and mortality of Murray cod (Maccullochella peelii) during overbank flows in the lower River Murray, Australia." Australian Journal of Zoology.

Lowe, K. W. (1983). "Egg size, clutch size and breeding success of the Glossy Ibis *Plegadis falcinellus*." Emu 83: 31-34.

Lyon, J., Stuart, I., Ramsey, D. and O'Mahony, J. (2010). "The effect of water level on lateral movements of fish between river and off-channel habitats and implications for management." Marine and Freshwater Research 61(3): 271-278.

MacKenzie, D. I. and Bailey, L. L. (2004). "Assessing the fit of site-occupancy models." Journal of Agricultural, Biological, and Environmental Statistics 9(3): 300-318.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L. and Hines, J. E. (2006). Occupancy estimation and modelling. Burlington, MA, Academic Press.

MacKenzie, D. I., Nichols, J. D., Sutton, N., Kawanishi, K. and Bailey, L. L. (2005). "Improving inferences in population studies of rare species that are detected imperfectly." Ecology 86(5): 1101-1113.

Magrath, M. J. L. (1992). Waterbird study of the lower Lachlan and Murrumbidgee valley wetlands in 1990/91. Prepared for the NSW Department of Water Resources.

Maher, P. N. (1990). Bird survey of the Lachlan/Murrumbidgee confluence wetlands. Report to NSW National Parks and Wildlife Service: Griffith.

Maher, P. N. (2006). Yanga National Park Wetland Surveys and Flood Monitoring. Prepared for the NSW Department of Environment and Conservation Ecosurveys Environmental Consultants: Deniliquin.

Mallen-Cooper, M. and Stuart, I. G. (2003). "Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system." River Research and Applications 19(7): 697-719.

Marcarelli, A. M., Baxter, C. V., Mineau, M. M. and Hall, R. O. (2011). "Quantity and quality: unifying food web and ecosystem perspectives on the role of resource subsidies in freshwaters." Ecology 92(6): 1215-1225.

Marchant, S. and Higgins, P. J. (1990). Handbook of Australian, New Zealand and Antarctic Birds. Oxford University Press: Melbourne.

Marchant, S. and Higgins, P. J. (1993). Handbook of Australian, New Zealand and Antarctic Birds. Oxford University Press Australia: Melbourne.

MDFRC (2013). Long-term Intervention Monitoring - Generic Cause and Effect Diagrams Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre. MDFRC Publication 163pp.

Murray-Darling Basin Authority (2012a). Assessment of environmental water requirements for the proposed Basin Plan: Lower Murrumbidgee River ( in-channel flows). Canberra, Murray–Darling Basin Authority for and on behalf of the Commonwealth of Australia.

Murray-Darling Basin Authority (2012b). Assessment of environmental water requirements for the proposed Basin Plan: Mid-Murrumbidgee River Wetlands. Canberra, Murray–Darling Basin Authority for and on behalf of the Commonwealth of Australia

Murray-Darling Basin Authority (2012c). Assessment of water requirements for the proposed Basin Plan: Lower Murrumbidgee River Floodplain. Canberra, Murray-Darling Basin Authority for and on behalf of the Commonwealth of Australia.

Murray-Darling Basin Authority. (2014). "Preliminary Overview of Constraints to Environmental Water Delivery in the Murray-Darling Basin." Retrieved 1/04/2014, 2014, from http://www.mdba.gov.au/what-we-do/water-planning/managing-constraints/constraints-overview/nsw.

Murray Darling Freshwater Research Centre (2013). Long-term Intervention Monitoring - Generic Cause and Effect Diagrams. Wodonga, Final Report prepared for the Commonwealth Environmental Water Office by The Murray-Darling Freshwater Research Centre, MDFRC Publication.

Murray, P. (2008). Murrumbidgee wetlands resource book. New South Wales, Murrumbidgee Catchment Management Authority.

Murrumbidgee Catchment Management Authority (2009). Lower Murrumbidgee Floodplain: Natural resource management plan. Wagga Wagga, Murrumbidgee Catchment Management Authority

NSW Commissioner for Water (2013). "Adaptive Environmental Water Use Plan for the Murrumbidgee Water Management Area." NSW Office of Environment and Heritage.

PRIMER (2002). PRIMER 5 for Windows. Version 5.2.9. PRIMER-E Ltd.

Quinn, G. and Keough, M. (2002). Experimental design and data analysis for biologists. UK, Cambridge University Press:.

R Development Core Team (2008). R: A language and environment for statistical computing. Vienna, Austria. , Foundation for Statistical Computing

Redman, K., Hall, A., Wassens, S. and McGuiness, H. (2013). A comparison of remote camera and on-ground detection methods for determining water bird species presence. Australian Society Limnology (ASL). Canberra, ACT.

Reynolds, L. (1983). "Migration patterns of five fish species in the Murray-Darling River system." Marine and Freshwater Research 34(6): 857-871.

Robertson, A. I., Bunn, S. E., Boon, P. I. and Walker, K. F. (1999a). "Sources, sinks and transformations of organic carbon in Australian floodplain rivers." Marine and Freshwater Research 50(8): 813-829.

Robertson, A. I., Bunn, S. E., Walker, K. F. and Boon, P. I. (1999b). "Sources, sinks and transformations of organic carbon in Australian floodplain rivers." Marine and Freshwater Research 50(8): 813-829.

Rolls, R. J., Growns, I. O., Khan, T. A., Wilson, G. G., Ellison, T. L., Prior, A. and Waring, C. C. (2013). "Fish recruitment in rivers with modified discharge depends on the interacting effects of flow and thermal regimes." Freshwater Biology 58(9): 1804-1819.

Roshier, D. A., Robertson, A. I. and Kingsford, R. T. (2002). "Responses of waterbirds to flooding in an arid region of Australia and implications for conservation." Biological Conservation 106(3): 399-411.

Scott, A. (1997). Relationships between waterbird ecology and river flows in the Murray-Darling Basin. Technical Report 5/97. CSIRO Land and Water: Canberra.

Sinclair Knight Merz (2011). Environmental Water Delivery: Murrumbidgee Valley. Canberra., Prepared for Commonwealth Environmental Water, Department of Sustainability, Environment, Water, Population and Communities.

Souter, N. J., Cunningham, S., Little, S., Wallace, T., McCarthy, B. and Henderson, M. (2010). "Evaluation of a visual assessment method for tree condition of eucalypt floodplain forests." Ecological Management & Restoration 11(3): 210-214.

Spencer, J., Hosking, T., Ewin, P., Webster, R., Hutton, K., Allman, R., Thomas, R., Humphries, J., Berney, P. and Mullohand, M. (2014). Waterbird Monitoring in Inland NSW: Summary Report 2012-13. Sydney, Leeton, NSW Office of Environment and Heritage, Department of Premier and Cabinet and Pelican Consulting.

Spencer, J., Thomas, R., Wassens, S., Lu, Y., Wen, L., Iles, J., Kobayashi, Y., Hunter, S., Alexander, B. and Saintilan, N. (2011a). Testing wetland resilience: monitoring and modelling of flows in the Macquarie Marshes and Lowbidgee wetlands in 2009-11. Final report to the NSW Catchment Action Program, NSW Office of Environment and Heritage and Charles Sturt University.

Spencer, J., Thomas, R., Wassens, S., Lu, Y., Wen, L., Iles, J., Kobayashi, Y., Hunter, S., Ling, J. and Saintilan, N. (2011b). Environmental flow monitoring in the Lowbidgee wetlands and Macquarie Marshes in 2009-10. Testing wetland resilience: monitoring the response of iconic wetlands to re-flooding following historic drought project. Sydney, NSW Department of Environment, Climate Change and Water.

Spencer, J. A. and Wassens, S. (2010a). Monitoring the responses of waterbirds, fish and frogs to environmental flows in the Lowbidgee wetlands from 2008–10. Final report for the NSW Rivers Environmental Restoration Program. Rivers and Wetland Unit.

Sydney and Wagga Wagga., NSW Department of Environment, Climate Change and Water and Institute for Land, Water and Society, Charles Sturt University.

Spencer, J. A., Wassens, S., Maguire, J., Hardwick, L., Webster, R. and Maher, M. (2012). Draft Management Plan for the Southern bell frog in the Murrumbidgee Catchment. Sydney, NSW Office of Environment and Heritage.

Spencer, J. A., Wassens, S., Thomas, R. F., Lu, Y., Iles, J., Hunter, S. and Kobayashi, Y. (2011). Summary report on results of flow monitoring in the Lowbidgee wetlands in 2010-11., NSW Office of Environment and Heritage, Sydney, and Charles Sturt University, Wagga

Spencer, S. and Wassens, S. (2010b). Monitoring the responses of waterbirds, fish and frogs to environmental flows in the Lowbidgee wetlands (2008-10). Ecological response modelling in the Murray-Darling Basin: Better use of environmental water, Sydney, 11th & 12th of May

Stuart, I. G. and Jones, M. (2006). "Large, regulated forest floodplain is an ideal recruitment zone for non-native common carp (*Cyprinus carpio* L.)." Marine and Freshwater Research 57(3): 333-347.

Taylor, M. K. and Cooke, S. J. (2012). "Meta-analyses of the effects of river flow on fish movement and activity." Environmental Reviews 20(4): 211-219.

Thiem, J. D., Hatin, D., Dumont, P., Van Der Kraak, G. and Cooke, S. J. (2013). "Biology of lake sturgeon (*Acipenser fulvescens*) spawning below a dam on the Richelieu River, Quebec: behaviour, egg deposition, and endocrinology." Canadian Journal of Zoology 91(3): 175-186.

Thomas, R. F., Cox, S. and Ocock, J. (2013). Lowbidgee Wetlands Inundation Mapping Summary 2012-13, NSW Office of Environment and Heritage, Sydney.

Thomas, R. F., Kingsford, R. T., Lu, Y. and Hunter, S. J. (2011). "Landsat mapping of annual inundation (1979–2006) of the Macquarie Marshes in semi-arid Australia." International Journal of Remote Sensing 32(16): 4545-4569.

Thomas, R. F., Lu, Y., Cox, S. J. and Hunter, S. J. (2012). 2012, Inundation response project, executive summary, NSW Rivers Environmental Restoration Program Subprogram II,. Sydney., NSW Office of Environment and Heritage.

Tuckett, R. E., Merritt, D. J., Hay, F. R., Hopper, S. D. and Dixon, K. W. (2010). "Dormancy, germination and seed bank storage: a study in support of ex situ conservation of macrophytes of southwest Australian temporary pools." Freshwater Biology 55(5): 1118-1129.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R. and Cushing, C. E. (1980). "The River Continuum Concept." Canadian Journal of Fisheries and Aquatic Sciences 37(1): 130-137.

Walsh, C. T., Reinfelds, I. V., Ives, M. C., Gray, C. A., West, R. J. and van der Meulen, D. E. (2013). "Environmental influences on the spatial ecology and spawning behaviour of an estuarine-resident fish, *Macquaria colonorum*." Estuarine, Coastal and Shelf Science 118: 60-71.

Warfe, D. and Barmuta, L. (2006). "Habitat structural complexity mediates food web dynamics in a freshwater macrophyte community." Oecologia 150(1): 141-154.

Wassens, S. (2010a). Flooding regimes for frogs in lowland rivers of the Murray-Darling Basin Ecosystem Response Modelling in the Murray-Darling Basin. N. Saintilan and I. C. Overton. Canberra, CSIRO Publishing 213-228.

Wassens, S. (2010b). Frogs. Floodplain wetland biota in the Murray-Darling Basin: Water and habitat requirements. K. Rogers and T. J. Ralph. Canberra, CSIRO Publishing: 253-274.

Wassens, S., Arnaiz, O. L., Healy, S., Watts, R. J. and Maguire, J. (2008). Hydrological and habitat requirements to maintain viable Southern Bell Frog (Litoria raniformis) populations on the Lowbidgee floodplain- Phase 1. Queanbeyan, Department of Environment and Climate Change.

Wassens, S., Bindokas, J., Jenkins, K., Lenon, E., Spencer, J., Watts, R. J., Kobyashi, T., Iles, J., Baumgartner, L., Thomas, R. and Hall, A. (2013). Monitoring the ecological response of Commonwealth environmental water delivered in 2012-13 to the Murrumbidgee River. . Canberra, Commonwealth of Australia 2013.

Wassens, S., Hall, A., Osborne, W. and Watts, R. J. (2010). "Habitat characteristics predict occupancy patterns of the endangered amphibian Litoria raniformis in flow-regulated flood plain wetlands." Austral Ecology 35(8): 944-955.

Wassens, S., Jenkins, K., Spencer, J., Bindokas, J., Bino, G., Kobayashi, T., Watts, R. J., Lenon, E., Thomas, R., Baumgartner, L. and Hall, A. (2014). Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Murrumbidgee River and connected wetlands, 2012-13. Report 2. Albury, Institute for Land, Water and Society, Charles Sturt University.

Wassens, S., Jenkins, K., Spencer, J., Bindokas, J., Kobyashi, T., Bino, G., Watts, R. J., Lenon, E., Thomas, R., Baumgartner, L. and Hall, A. (2013a). Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Murrumbidgee River and connected wetlands, 2012-13. Canberra, Prepared for Commonwealth Environmental Water. Institute for Land, Water and Society, Charles Sturt University.

Wassens, S. and Spencer, J. A. (2012). Monitoring of ecosystem responses to a major natural flood in Autumn 2012 Albury, Institute for Land, Water and Society, Charles Sturt University for Department of Sustainability, Environment, Water, Population and Communities

Wassens, S., Watts, R., Howitt, J., Spencer, J., Zander, A. and Hall, A. (2011). Monitoring of ecosystem responses to the delivery of environmental water in the Murrumbidgee system. Report to DSEWPaC. Albury, Institute of land, Water and Society. Report 1. .

Wassens, S., Watts, R. J., Spencer, J. A., Howitt, J., McCasker, N. A., Griese, V., Burns, A., Croft, R., Zander, A., Amos, C. and Hall, A. (2012a). Monitoring of ecosystem responses to the delivery of environmental water in the Murrumbidgee system. Albury, Institute for Land, Water and Society, Charles Sturt University.

Wassens, S., Watts, R. J., Spencer, J. A., Howitt, J., McCasker, N. A., Griese, V., Burns, A., Croft, R., Zander, A., Amos, C. and Hall, A. (2012b). Monitoring of ecosystem responses to the delivery of environmental water in the Murrumbidgee system. Institute of Land, Water and Society, Charles Sturt University. Report 2, May 2012.

Wassens, S. B., J., Jenkins, K., Lenon, E., Spencer, J., Watts, R. J., Kobayashi, T., Iles, J., Baumgartner, L., Thomas, R. and Hall, A. (2013b). Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Murrumbidgee River and connected wetlands, 2012-13. Report 1. Prepared for Commonwealth Environmental Water. Albury, Institute for Land, Water and Society, Charles Sturt University.

Wassens, S. J., K., Spencer, J., Bindokas, J., Bino, G., Kobayashi, T., Watts, R. J., Lenon, E., Thomas, R., Baumgartner, L. and Hall, A. (2014). Monitoring the ecosystem responses to Commonwealth environmental water delivered to the Murrumbidgee

River and connected wetlands, 2012-13. Report 2. Albury, Institute for Land, Water and Society, Charles Sturt University.

Wen, L., Ling, J., Saintilan, N. and Rogers, K. (2009). "An investigation of the hydrological requirements of River Red Gum (Eucalyptus camaldulensis) Forest, using Classification and Regression Tree modelling." Ecohydrology 2(2): 143-155.

Wetzel, R. G. and Likens, G. E. (2000). Composition and Biomass of Phytoplankton. Limnological Analyses, Springer New York: 147-174.

Young, R. G. and Huryn, A. D. (1996). "Interannual variation in discharge controls ecosystem metabolism along a grassland river continuum." Canadian Journal of Fisheries and Aquatic Sciences 53(10): 2199-2211.

Young, R. G., Matthaei, C. D. and Townsend, C. R. (2008). "Organic matter breakdown and ecosystem metabolism: functional indicators for assessing river ecosystem health." Journal of the North American Benthological Society 27(3): 605-625.

## Appendix 1 Data analysis

*Ecosystem process models*

To reduce the number of variables included in the model, critical covariates such as a range of nutrients, chlorophyll, water quality parameters and vegetation indices will be refined by analysing the number of factors to retain as a principal component by examining the Kaiser-Guttman rule, the parallel analysis, and Scree Test. The Kaiser-Guttman rule states that the number of factors is equal to the number of eigenvalues greater than 1. This is because each of those factors will 1) account for at least as much variance as one of the original variables, and 2) have a positive value for coefficient alpha. The Scree Test is used by drawing a line graph to show the relationship between the number of the factor (on the x-axis) and the value of the eigenvalue (on the y-axis). The acceleration factor (AF) corresponds to a numerical solution to the elbow of the scree plot while the optimal coordinates (OC) corresponds to an extrapolation of the preceding eigenvalue by a regression line between the eigenvalue coordinates and the last eigenvalue coordinates. We carried out this analysis using the nFactors package (Raiche, 2010) available within R software(R Development Core Team, 2012).

Explicitly our Generalised Linear Model has the properties of :

1. Distribution: $MacCPUE_i \sim Poisson(\lambda_i)$

2. Link function: log, i.e., $\log(\lambda_i) = \log(E(MacCPUE_i)) = linear\ predictor$

3. Linear predictor:

$$\log(\lambda_i) = \beta 1 \cdot Turbidity + \beta 2 \cdot temp + \beta 3 \cdot Nut.Comp.1 + \beta 4 \cdot Water.level + \beta 5 \cdot EC + \beta 6 \cdot Discharge + \beta 7 \cdot pH + \beta 8 \cdot Chla.Comp.1 + \beta 9 \cdot Zoops + Site + \alpha$$

Our approach will be to examine all possible combinations using all possible predictor combinations. We then followed a model selection process examining model performance using the second-order Akaike Information Criterion (AICc) (Burnham and Anderson 2002). AICc (second order information criterion) takes into account sample size by increasing the relative penalty for model complexity with small data sets. It is defined as:

AICc = -2*(ln(likelihood)) + 2 K * (n / ( n - K - 1))

where likelihood is the probability of the data given a model, K is the number of free parameters in the model and n is the sample size. The model with the lowest AICc reflects the best-fitting model, and all supported hypotheses (i.e., predictor variables) included within 2 AICc units (ΔAICc <2) of the top-supported model are considered comparable (Burnham and Anderson 2002). Predictor coefficients were weighted and averaged for all models that are within ΔAICc <2.

*Analysis of detection probabilities*

The models determined in this study took two forms. Firstly detection probabilities were allowed to vary across the surveys with each survey being associated with a particular survey method. The simplest of the models did not include variables describing survey region or timing i.e. occupancy probability remained constant across sites. The logit link function of the model took the form:

$$\ln\left(\frac{\theta_i}{1-\theta_i}\right) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_3 x_{i3} + \beta_4 x_{14} + \beta_5 x_{15} \quad (1)$$

where θi is the probability of the species being detected on field visit i and xi1 to xi6 are the presence/absence observations, i.e. 1 or 0, of each of the six sampling methods at the *ith* field visit instance. The intercept term, β0, represents the probability of occupancy by the species in the field visit instance. The regression coefficients β1 to β5 represent the probability of detecting the species using each of the two methods, given that the species is present.

The betas of the most parsimonious models for each species were used to calculate p for each survey method and ψ for each habitat and season variable contained in the model, along with their 95% credibility intervals (CI). To further evaluate the efficiency of each survey method for each species, probabilities of detection after n visits (P) were calculated using the equation (Kéry, Dorazio *et al.* 2009),

$$P = 1 - (1 - p)^n \quad (2)$$

# Appendix 2 Standard operating procedures for category 3 components

## Standard Operating Procedure Frogs and Tadpoles

Frogs are sensitive to changes in wetland flooding regimes and respond strongly to environmental releases with large increases in breeding activity. Higher levels of tadpole abundance and recruitment are commonly recorded during managed flood events, e.g (Spencer and Wassens 2010a, Spencer, Thomas *et al*. 2011b, Wassens, Watts *et al*. 2011, Wassens, Watts *et al*. 2012a: Spencer, 2010 #3271: Spencer, 2011 #2983). In many areas managed environmental watering is critical for the persistence of flood sensitive frog species. For example, key populations of the vulnerable (EPBC Act 1999) Southern bell frog were successfully maintained using environmental watering in the Lowbidgee floodplain between 2007 and 2010 (Wassens 2010a).

Frogs exhibit three key responses to flooding: (1) calling activity, (2) tadpole abundance and development, and (3) metamorphosis. Calling activity is a useful measure of the distribution of frogs with respect to underlying hydrological regimes and wetland characteristics (Wassens 2010b, Wassens, Hall *et al*. 2010). That is, it is an indicator of whether a specific environmental watering event has created conditions suitable for *attempted* breeding by resident species. Monitoring tadpole communities and defining development stages is important when managing water levels, because it allows for estimation of how close tadpoles are to reaching metamorphosis and, as such, can provide an early indicator on the need for top-up watering. Size structure within populations has proven to be a useful indicator as it provides a measure of the number of individuals recruiting into the adult population.

***Long-term (five year) evaluation question;***

What did Commonwealth environmental water contribute to other vertebrate community resilience?

What did Commonwealth environmental water contribute to other vertebrate species diversity?

***Short-term (one year) evaluation questions:***

What did Commonwealth environmental water contribute to other vertebrate condition?

What did Commonwealth environmental water contribute to other vertebrate reproduction?

***Relevant ecosystems:***

Rivers, wetlands and floodplains

***Relevant flow types:***

All

***Overview and context***

Frog community responses can be assessed at two spatial and temporal scales: (1) broad scale assessment of occupancy patterns within connected wetlands addressing long-term (five year) objectives) and (2) intensive monitoring of tadpole development and recruitment (can be carried out in association with wetland fish monitoring) at a subset of connected wetlands or in areas where there are known populations of threatened or locally significant species. Note that small and large fyke nets have the highest probability of detecting tadpoles in large wetland systems so tadpole surveys can be run concurrently with fish surveys with tadpoles being identified in the field at the same time as fish. However as tadpoles can be extremely difficult to identify it is recommended that an experienced observer is present for initial surveys to ensure that staff are properly trained.

***Complementary monitoring and data***

**Covariates**

Ecosystem type (Category 1)

Vegetation diversity (Category 2)

Wetland hydrology (Category 1 and Selected Area)

Wetland fish (Selected Area)

**Establishing assessment sites**

*Equipment*

GPS

Map of floodplain wetlands in area or zone

**Selected Area**

Zone

Site

Minimum of three surveys per year (autumn, spring, summer) timing may need to be modified to suit climatic characteristics of the region. Aim to include a minimum of 10 sites per year for adult frog surveys and at least 5 sites for tadpole surveys, if undertaken.

***Monitoring protocol***

Equipment (adult frogs)

- Torch or spotlight with a minimum of 300 Lumens
- Notebook- Pocket notebooks are far easier to manage than A4 datasheets for general surveys
- Callipers (for size measurement)
- Disposable gloves
- GPS
- Watch (record start and finish times)
- Disinfectant ( see NSW OEH hygiene protocol for frogs)
- Optional (handheld temperature/ weather station)

**Other considerations**

All surveyors must adhere to the NSW OEH hygiene protocol for frogs, or other state approved hygiene protocol.
http://www.environment.nsw.gov.au/animals/HygieneProtocolForFrogs.htm

Gloves must be worn when handling frogs as contact with sunscreens and insect repellents can cause irritation.

## Protocol

### *Broad scale*

Broad scale assessment of frog communities can be undertaken every two months from late winter (August-April). Generally timed surveys are easier then set transects because variable water levels over time can make the use of fixed transects impractical. But it is recommend that repeat surveys broadly have the same starting point and surveys are carried out within 20 meters of the waterline.

Adult frogs and metamorphs are surveyed within each wetland after dark using a 2x20 minute visual encounter (person minutes) and a 3 x 1 minute audio survey (Wassens, Watts *et al*. 2011, Wassens, Watts *et al*. 2012a). However 15 minute transects (person minutes) would be sufficient in small systems and in rivers/creek lines if you were not measuring size structures and still achieves greater than 80% detection probability for most species. Use longer transects if the study area contains rare, or difficult to detect species such as *L. raniformis.* Recording start and finish times allows for frog abundance to be standardised as frogs/minute.

A 15-30 watt spotlight or torch can be used to search for frogs along the wetland edge and into the surrounding terrestrial habitats. All individuals observed are identified to species and the number recorded (it is possible to identify individuals without capture).

## Optional

An estimate of breeding activity from common species can be obtained by measuring the snout-vent length of a subset of 20 individuals (in mm) as size structure can give an indication of the number of recently metamorphosed individuals. In the southern basin, *Limnodynastes tasmaniensis* and *L. Fletcheri* and in the northern basin, *L. fletcheri* and *Litoria latopalmata* could be measured (snout-to-vent length) to give an indication of demographic structure and presence of recent metamorphs. This methodology was trialled in the Mid-Murrumbidgee between October 2011 and April 2012 with success.

Audio surveys involve listening for the distinct calls of resident frog species. General estimates of the number of calling individuals will be determined using the methodology described in (Wassens *et al*. 2011).

### Tadpole surveys

Tadpoles are most effectively surveyed as part of wetland fish assessments. Tadpoles should be identified to species when possible and the development (Gosner stage recorded for the first 50 individuals of each species)(Gosner 1960))

### Data analysis and reporting

- Site name
- Lat/long
- Time start- time finished
- Surveyor name
- Number observed ( each species)per minute
- Number calling (each species) mean of replicate counts
- Size structure- Length (mm) of target species ( if undertaken)
- Presence/absence for each timed replicate (allows estimation of detection probability)

### Tadpoles

- Site name
- Lat/long
- Net type and replicate
- Number of individuals of each species
- Development stage subset of 30 individuals per net

### Covariates

- Wetland type
- Hydrology
- Vegetation percent cover and diversity ( we use a rapid assessment of the percent cover of plant functional groups within 10m sections) ( e.g amphibious emergent, amphibian submerged etc)
- Fish
- Water quality (point measurements if not returning to the site)

# Microcrustaceans

***Note: This protocol is a DRAFT prepared by Kim Jenkins***

### *Evaluation questions*

*Long-term (five year) questions:*

What did Commonwealth environmental water contribute to microcrustacean productivity and community composition?

What did Commonwealth environmental water contribute to resilience of microcrustacean egg banks? (comparing year 1 to 5)

*Short-term (one year) questions:*

What did Commonwealth environmental water contribute to the timing of microcrustacean productivity and presence of key species in relation to numbers, growth and survival of larval fish?

What did Commonwealth environmental water contribute to connectivity of microcrustacean communities between the river and wetlands?

What did Commonwealth environmental water contribute to resilience of microcrustacean egg banks? (comparing year 1 to 5)

The process for evaluating these questions is illustrated in Figure 1, with components covered by this protocol highlighted in blue.

### Relevant ecosystem types

Rivers, wetlands.

### Relevant flow types

These methods describe annual monitoring conducted during the period September to March of each year independent of specific watering events. The methods are therefore relevant to all flow types. The sediment sampling methods are conducted during dry or wet conditions in years 1 and 5.

### Overview and context

These standard methods describe monitoring required for the Basin Scale evaluation of microcrustacean productivity and community composition in response to Commonwealth environmental water. The methods describe the sampling design and protocol for microcrustaceans in rivers and wetlands for the LTIM Project. This protocol describes sampling over two timeframes. Firstly, fortnightly from September through to February each year to match the timing of larval fish sampling. Secondly, river and wetlands sites in 1-2 other zones will be sampled bimonthly to match sampling of wetland fish and other vertebrates. Sampling will occur in benthic habitats using a benthic corer to sample the water immediately above the benthic sediments. Pelagic habitats will be sampled using a 10L bucket.

**Establishing assessment sites**

*Equipment*

GPS

Map of floodplain wetlands in area or zone

Possibly a boat, depending on access

Possibly an all-terrain vehicle during floods

*Protocol*

The LTIM Project for Selected Area evaluation has adopted a hierarchical approach to sample design (see Gawne et al. 2013). The spatial hierarchy for microcrustacean monitoring in the river and wetlands is as follows:

**Selected Area**

Zone

Site

*Site placement within zones*

Microcrustacean monitoring will take place at the same sites specified for (a) monitoring of larval fish in the channel and wetlands (see LTIM Project Standard Protocol: Larval Fish; (b) monitoring of fishes and other vertebrates in wetlands (see LTIM Project Standard Protocol: Fish (Wetlands)) and (c) additional river sites sampled bimonthly during the wetland fish and other vertebrate surveys to give a total of 4 river sites to allow assessment of connectivity. The rationale underlying this is to seek as much synergy as possible among the larval fish monitoring component and also the components monitoring other vertebrates and wetland fish that also prey on microcrustaceans. Only a single composite sample (comprised or either 5 benthic cores or 5 pelagic buckets) is taken from each site or flow-habitat within a site. This will reduce the overall number of samples for laboratory processing.

Microcrustacean sampling to match larval fish sampling will occur at 3-6 sites in each zone:

- Three channel sites (also sampled for larval fish)
- Three wetland sites (also sampled for larval fish, other vertebrates, wetland adult fish)
- The subset of sites selected will be determined by Monitoring and Evaluation Providers and should be documented in the Monitoring and Evaluation Plan.

Microcrustacean sampling to match other vertebrate and wetland fish sampling will occur within three to six wetland sites in three to four other zones:

- Three to six wetland sites (also sampled for other vertebrates and adult fish)
- Microcrustacean sampling to assess connectivity between wetlands and river of a minimum of four river sites in one to two other zones:
- Four channel sites (depending on placement of larval fish sites and timing of sampling only 1 additional river site may be needed)
- *Sample placement within sites*

***Channel***

Two different microcrustacean sampling gears will be used within the three channel sites of the zone targeted for Selected Area analyses: benthic corer and a pelagic bucket. Five benthic cores should be randomly allocated within five of the ten slackwater habitats sampled with light traps (see LTIM Project Standard Protocol: larval fish) and then placed in a single bucket to yield a single 'slackwater benthic' composite sample from the site.

Five pelagic buckets should be randomly allocated within flowing edge habitats of each site (associated with locations of five of the drift nets, see LTIM Project Standard Protocol: larval fish) and then poured through a net to yield a single 'flowing pelagic' composite sample from the site.

Microcrustacean samples within a site should be collected before the site is disturbed for other sampling.

***Wetlands***

Two different microcrustacean sampling gears will be used within the wetland sites targeted for Selected Area analyses: benthic corer and a pelagic bucket.

Five benthic cores should be randomly allocated within edge habitats of each site (associated with locations of five of the larval traps, see LTIM Project Standard Protocol: larval fish) and then placed in a single bucket to yield a single 'wetland benthic' composite sample from the site. Five pelagic buckets should be randomly allocated within each site (associated with locations of five of the larval traps, see LTIM Project Standard Protocol: larval fish) and then poured through a net to yield a single 'wetland pelagic' composite sample from the site.

Microcrustacean samples within a site should be collected before the site is disturbed for other sampling.

**Sampling protocol**

*1.6.1 Equipment*

Benthic corer (50 mm diameter x 120 mm long, 250 mL volume) and rubber backed spatula;

Small (4L) bucket with lid for settling benthic cores;

63um mesh sieve;

Squirt Bottle

70% ethanol with rose bengal stain;

Storage jars;

Data sheets

**Protocol**

*Timing of sampling to match larval fish sampling*

At each larval fish sampling site, microcrustacean sampling will take place fortnightly from September through to February inclusive (total of 6 (months) x 2 (weeks per month) = 12 sampling events). These are referred to as the 12 'larval sampling events' below.

*Timing of sampling to match fish and other vertebrate sampling and for connectivity*

At each fish and other vertebrate and river connectivity sampling site, microcrustacean sampling will take place bimonthly from September through to May inclusive (total of 4 sampling events). These are referred to as the 4 'wetland and connectivity sampling events' below.

*Sampling*

The sampling procedure is the same for wetlands and channels. The same make of benthic corer should be used by all Monitoring and Evaluation Providers, to eliminate sampling bias among areas. Benthic corers should be modified slightly from King (2004), the details of which can be found in (Morris 2008). We recommend placing the flange at the bottom of the corer (rather than 1 cm from the bottom) as the aim is to sample the microcrustaceans immediately on or above the benthic sediment rather than to sample the sediment, which makes sample processing difficult. The benthic cores within each site should be collected either in the afternoon or the morning to tie in with other sampling. Collection times should be recorded.

Composite samples (pelagic and benthic) will be collected at each site in association with either larval fish; fish and other vertebrates or connectivity monitoring. Benthic samples will be collected with a corer (50 mm diameter x 120 mm long, 250 mL volume). Five cores will be collected from haphazard locations within each site with replicates spaced at least 20 m apart. The corer is placed onto the sediment surface, the top is then sealed with a plastic cap and the sediment and overlaying water extracted with the aid of a hardened rubber trowel. The contents of the corer will be emptied into a 4 litre bucket and allowed to settle for at least one hour. Once settled, the supernatant will be poured through a 63 µm sieve to retain microcrustaceans. The retained sample will be washed into a sample jar and stored in ethanol (70% w/v) with rose bengal. To assess the pelagic microcrustacean community, a composite sample consisting of 10 x 10 litre buckets was collected at each site. Each bucket was poured through a plankton net (63 µm mesh). Retained samples were stored in ethanol (70% w/v) with rose bengal until time of enumeration.

*Processing*

Entire samples should be preserved individually in 70% ethanol and returned to the laboratory for microcrustaccean identification and enumeration. Whole samples should be examined in bogorov trays and the contents identified to family level (cladocerans), class (copepods) and ostracods. The length (and width) of the first 30 specimens or each taxa should be measured.

**Data analysis and reporting**

*Relative abundance estimation*

Microcrustacean numbers should be expressed as density per litre.

*Community data*

We require density data at the level of the site (taxa by site density matrices). Data should be provided separately for each sampling method: 1. Benthic cores; 2. Pelagic and for each sampling protocol (matching larval fish sampling or fish and other vertebrate sampling or wetland river connectivity sampling).

**Data management**

All data provided for this indicator must conform to the data structure defined in the LTIM Project Data Standard. The data standard provides a means of collating consistent data that can be managed within the LTIM Project Monitoring Data Management System (MDMS). The spatial unit for which data is reported for this indicator is known as an 'assessment unit'. The assessment unit for this indicator is the site (450m of river channel or a wetland/wetland complex). Each row of data provided for this indicator will identify the assessment unit, the temporal extent of the data and a number of additional variables (as guided by this standard method). The exact data structure for this indicator is maintained and communicated in the LTIM Project Data Standard and will be enforced by the MDMS when data is submitted. For review purposes, the contents of the LTIM Project Data Standard have been reproduced below and will be finalised once this method is finalised.

**Assessment unit**

*Microcrustacean* Conceptual definition

This indicator will contain rows of data about an assessment unit that is: *"The site, which may be a length of stream or an area of wetland(s) that meets the criteria* *defined in the standard method."* Each row of data will describe (depending on the data definition used):

*"the numbers and length of an individual microcrustacean measured at the assessment unit in the period defined by the date/time range," or*

Assessment unit linkages

Assessment units for microcrustaceans require the following linkages to other data (where available):

- Assessment unit identifiers for representative hydrological indicator data about the wetland(s) and/or channel
- An assessment unit identifier for the representative larval fish or wetland fish and other vertebrates or wetland river connectivity indicator data, as established as part of the standard method,
- An assessment unit identifier for the representative stream metabolism indicator data, as established as part of the standard method,
- An assessment unit identifier for the representative water quality indicator data,
- ANAE stream identifiers to enable linking with framework datasets for future work.