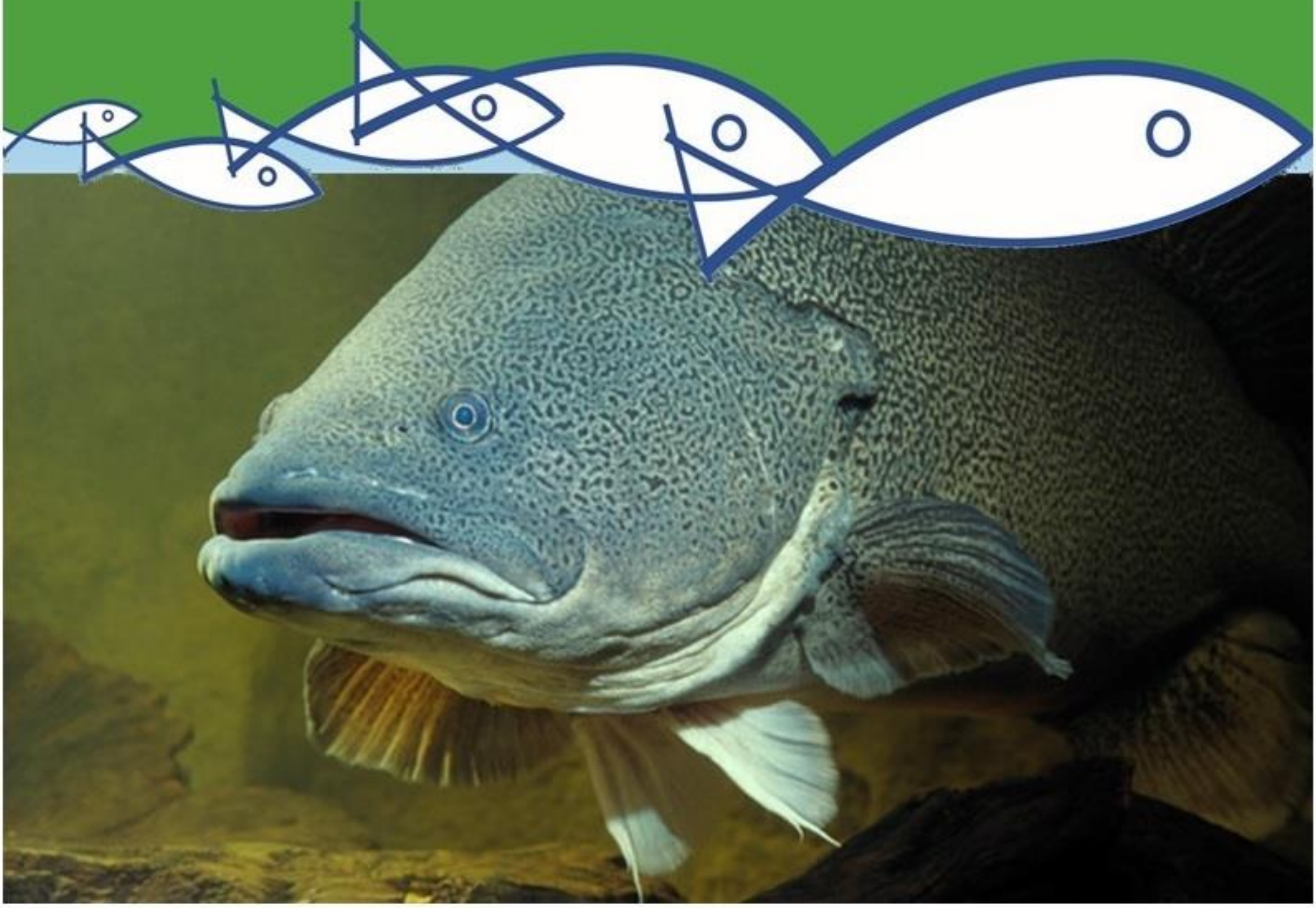
Fish and Flows in the Northern Basin:

responses of fish to changes in flow in the Northern Murray–Darling Basin



Valley Scale Report

prepared for the Murray–Darling Basin Authority

June 2015

NSW GOVERNMENT Department of Primary Industries

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MURRAY–DARLING BASIN AUTHORITY

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Front cover image: The threatened Murray Cod, a key native fish species of the Northern Murray–Darling Basin (photo credit – Gunther Schmida).

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Executive summary

Alteration of the natural flow regime across the majority of valleys in the Northern Murray–Darling Basin has had significant impacts on the hydrological, hydraulic and ecological conditions that native fish rely on for recruitment success and survival. The degradation of instream processes and habitat features across most major systems has resulted in the majority of fish communities of the Northern Basin being in poor to moderate condition.

Fish and Flows in the Northern Basin will improve the understanding of environmental water requirements for fish in the Northern Murray–Darling Basin, with a focus on the Barwon–Darling, Condamine–Balonne, and regulated systems in NSW. To achieve this, existing information related to fish and flow interactions and requirements has been reviewed and compiled for specific valleys in the Northern Basin, including the Barwon–Darling, Condamine–Balonne, Border Rivers, Gwydir, Namoi and Macquarie. Initial analysis of this information has been considered in the context of water management, habitat condition and fish community status for the Northern Basin, and enhanced by the involvement of relevant expert knowledge and latest research findings to progress environmental water requirements for fish in the Northern Basin.

Current activities across the Murray–Darling Basin, especially those related to water management, provide opportunities for fish communities to recover from detrimental impacts associated with river regulation. Management actions need to be developed based on best available science and knowledge in an adaptive framework. *Fish and Flows in the Northern Basin* has achieved this for overarching water management in the Northern Basin, with water requirements and management outcomes for fish able to be progressed through the consideration of six key outcomes:

1. Six functional groups of fish have been developed for the Northern Basin that are based on biological, hydrological and hydraulic requirements of fish for spawning, recruitment and movement.
2. Overarching conceptual flow models have been developed that identify the importance of certain flow characteristics (e.g. no-flow, baseflow, in-channel freshes and overbank) and hydrological variability for life history outcomes related to each functional group of species.
3. The overarching conceptual flow models can be used to develop specific water requirements for species where key hydrological and hydraulic information exists (including access to habitat), allowing particular flow attributes such as magnitudes, velocities, volumes and, rise and fall heights to be adapted from the conceptual models.
4. A broad range of published information, grey literature, primary data and knowledge sources relevant to fish and flows in the Northern Basin have been identified and collated. This knowledge base represents a significant step forward in building linkages between Northern and Southern fish work for a range of current and future activities.
5. Knowledge gaps still exist that limit the application of conceptual flow models to develop specific environmental water requirements, and additional activities would help gain a better understanding of habitat/flow interactions across the Northern Basin, allowing critical flow thresholds to be identified that strengthen water management actions.
6. Coordinated and targeted complementary actions also need to be considered in an adaptive management framework that incorporates rigorous scientific monitoring and evaluation, to ensure the most efficient and effective use of environmental water.

CONTENTS

1 Introduction

1.1 Background and objectives

The Sustainable Diversion Limits in the Basin Plan are required to reflect an Environmentally Sustainable Level of Take (ESLT), which is defined as the level at which water can be taken without compromising key environmental assets, key ecosystem functions, the productive base and key environmental outcomes.

To inform the ESLT, the MDBA determined Environmental Water Requirements (EWRs) for 11 sites in the Northern Basin that are considered to be 'umbrella environmental assets'. The philosophy underpinning the use of umbrella environmental assets was that a set of sites (assets) could be selected for which the flow-ecology relationships are relatively well understood and for which flow requirements are likely to reflect the needs of a broader set of assets in the reach or catchment. The flow requirements were then specified at a fixed gauge location as a set of flow indicators that collectively represent a flow regime that supports the achievement of site-specific ecological targets (including for fish).

The flow requirements were described using the magnitude (volume), duration, timing and frequency of flows. Flow volume thresholds were defined based on known flow–ecology relationships (e.g. the flow required to inundate a certain channel, area or floodplain feature). The duration, frequency and timing were based on the known requirements of each specific ecosystem component.

Where available, the flow requirements of fish species were used to inform the EWRs. MDBA observed that flows that connect the river channel to the floodplain and in-channel flow variability are important for sustaining fish populations throughout the Basin. However, during Basin Plan development, the MDBA found that there was a limited amount of information on the flow–ecology relationships for fish.

Accordingly, the site specific flow indicators for fish were expressed in general terms and focused on providing key fish species with greater access to habitats by wetting benches, banks and in-stream habitat, as well as facilitating opportunities for native fish migration and recruitment. For example, the in-channel flow indicators for the Barwon–Darling include a 10 day duration based on the time for adhesive Murray Cod eggs to be laid, hatch, and get into the main stream.

During a review into the scientific basis of the EWRs in the Condamine–Balonne and Barwon–Darling (Sheldon *et al*. 2014), flow-ecology relationships for fish was identified as a key knowledge gap that required further investigation. This project attempts to address this knowledge gap by improving the understanding of EWRs for fish in the Northern Basin, and ensuring that the science underpinning EWRs for fish species in the Northern Basin is current and based on the best available science.

This document outlines part of the Stage 2 outcomes for the Fish and Flows in the Northern Basin project (contract MD2867). The project is being carried out by NSW Department of Primary Industries (DPI) on behalf of the Murray–Darling Basin Authority (MDBA). The project has been developed to assist the MDBAs Northern Basin Review, which aims to conduct research and investigations into aspects of the Basin Plan in the Northern Basin.

The Fish and Flows in the Northern Basin project aims to improve the understanding of EWRs for fish in the Northern Murray–Darling Basin, with a focus on the Barwon–Darling, Condamine–Balonne and other regulated systems in the Northern Basin where there is sufficient information to support the project. Based on research and information generated to date, proposed additional systems include the Border Rivers, Gwydir, Namoi, and Macquarie–Castlereagh.

The project has been developed in three stages:

1. Stage 1 – Literature review and project planning (completed)
2. Stage 2 – Valley scale (the focus of this report) and preliminary reach scale assessments.
3. Stage 3 – Reach scale assessment.

Stage 2 of the project was composed of three main components:

1. Establish a Northern Basin Expert Panel to identify relevant 'grey literature' and unpublished work, as well as provide expert judgement to inform the development of functional groups and conceptual flow models, and the identification of priority reaches to be further investigated during Stage 3 of the project. As part of this component, a workshop was held resulting in a number of positive outcomes (Appendix A), including:
   - Identifying a body of additional information sources and facilitating conversations between scientists and managers in the Northern and Southern Basin.
   - Establishing a general framework for functional groups, based on recent work by Mallen-Cooper and Zampatti (2015) and Baumgartner *et al*. (2013), with further validation work undertaken following the workshop to support the development of functional groups.
   - Supporting a 'modified hydrograph' approach for conceptual models based on fish life history responses to flow regimes for each guild and to key parts of the hydrograph.
2. Develop a report for the specified Northern Basin valleys that describe:
   - Fish communities present within the specified systems and the fish functional groups for the Northern Basin (both native and introduced), as well as identifying known Carp 'hotspots'.
   - Conceptual flow models for the identified fish functional groups (including expected ecological outcomes, biological assumptions, and consideration of the types of flows, shape of hydrograph, requirement for periods of no or low flows, connectivity requirements, need for flowing or still water, seasonal requirements etc.).
   - The different flow components that would benefit each fish functional group if reinstated (i.e. the things that would need to be considered to describe an environmental water requirement for fish).
3. A separate short 'Priority Reach' report that identifies priority reaches that will be investigated during Stage 3 of the project.

This report focuses on Parts 1 and 2 of the Stage 2 components, but both reports to be produced as part of Stage 2 are clearly linked to earlier stages of the project, including the Stage 1 literature review and outcomes of the Expert Panel workshop (documents the use of expert opinion, key assumptions/limitations and knowledge gaps). Findings detailed in this report and the accompanying priority reach document will also be used during Stage 3 to undertake reach scale assessments of flow requirements for fish.

2. Background

2.1 Northern Basin

The Northern Murray–Darling Basin includes more than half of the Murray–Darling Basin, and is defined by the catchment area of the Barwon–Darling River and its tributaries upstream of Menindee Lakes (Figure 1). The Northern Basin can be divided in the three main geographic zones of montane, slopes and lowlands (Nichols *et al*. 2012).

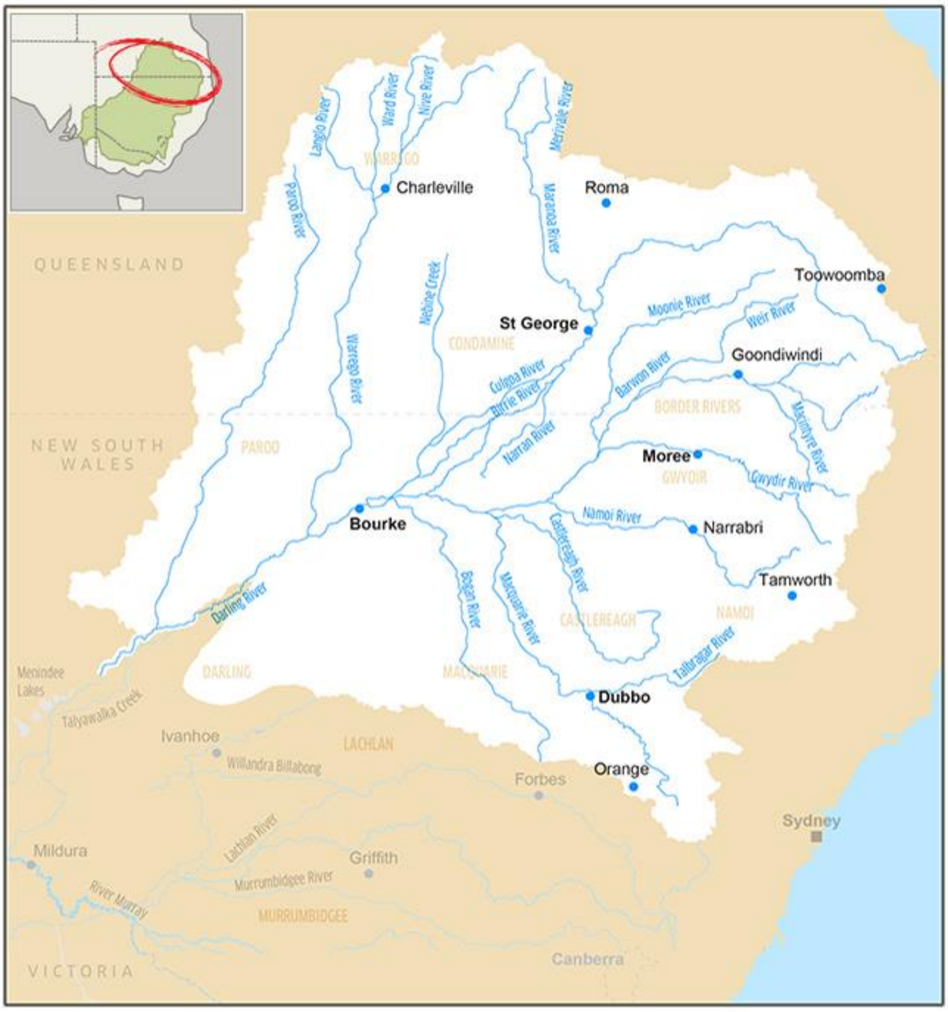


Figure 1: Map of the Northern Basin as defined by the MDBA and for the purposes of the Fish and Flows in the Northern Basin project (source: MDBA, 2011).

While differences should not be overstated, the Northern Basin does have some important distinguishing features from the Southern Murray–Darling Basin, including:

- The Northern Basin is generally flatter and drier than the Southern Basin, meaning that it has a much lower gradient and leads to the formation of major wetland areas in lower areas.
- Rainfall in the Northern Basin is lower overall and more variable than in the south.
- The Northern Basin generally receives high rainfall during summer and early autumn, experiencing high evaporation rates and floods that spread across larger areas of the floodplain, whilst the south has high rainfall during the winter.
- Water temperatures in the Northern Basin are also often higher on average than for Southern Basin systems. For example, winter water temperatures in Queensland parts of the Basin may remain above 10°C, while parts of the NSW Northern Basin also have relatively high winter minimum temperatures (Hutchison *et al*. 2011). Increased flows in Northern Basin systems may also coincide with higher water temperatures, creating optimum conditions for fish breeding (NSW DPI, 2013a). This is reflected in a slightly earlier spawning season for Murray Cod in some Northern Basin systems (e.g. the Border Rivers catchment), where the species may spawn in August to September rather than mid to late spring spawning for Southern Basin systems (Wilson and Ellison, 2010; NSW DPI, 2012a).
- Northern Basin catchments are generally less regulated and have a more variable flow, especially during summer and early autumn. Annual river flow may range from just 1% to over

1000% of the annual mean, and periods of no flow can extend from months to years (Saintilan and Overton, 2010).

- Much of the Northern Basin is sparsely populated and remote. The total population of the Northern Basin is estimated at around 590,000 (based on cumulative totals from specified catchments), compared to around 2.1 million in the Basin as a whole (Australian Bureau of Statistics, Australian Bureau of Agricultural and Resource Economics and Bureau of Rural Sciences, 2009).
- Understanding of aquatic ecosystems and fish-flow interactions in the Northern Basin is also more limited when compared to the Southern systems (partly due to factors identified above).

To address these limitations, the MBDA is undertaking the Northern Basin Review, conducting research and investigations into aspects of the Basin Plan.

Major tributaries that contribute to the Barwon–Darling River include the Condamine–Balonne, Macintyre, Gywdir, Namoi, Castlereagh and Macquarie Rivers, which enter the system upstream of Bourke, and the Paroo and Warrego Rivers that contribute intermittent flows downstream of Bourke during high rainfall periods (MDBA, 2012a). These systems can generally be described as either:

- Perennial – characterised by continuous flows, but may experience short periods of low or no flow during droughts or extended dry spells. The best examples of 'perennial' systems in the Northern Basin are the Border Rivers and Namoi catchments.
- Occasionally intermittent – generally semi-arid, experiencing some zero flows on a long-term basis. An example of an 'occasionally intermittent' system is the Barwon–Darling.
- Highly intermittent – arid systems, experiencing significant zero flows on a long-term basis. Examples of highly intermittent systems in the Northern Basin include the Paroo and Warrego rivers.

Overarching information on aquatic habitat condition and fish community status for the Northern Basin is discussed below. This is followed by information on fish and flows in the Northern Basin, including identification of functional groups, an assemblage-based analysis of EWRs and development of conceptual models for fish and flows in the Northern Basin (Section 3). Concise valley-based information for the Barwon–Darling, Condamine–Balonne, Border Rivers, Gwydir, Namoi and the Macquarie–Castlereagh are also provided, detailing information on fish barriers in the catchment, relevant Basin-Wide Environmental Watering Strategy (BWS) objectives, aquatic habitat information and fish community status (Section 4).

2.2 Aquatic habitat of the Northern Basin

The flow regime of the Northern Basin is one of the most variable in the world, playing a vital role in the ecology of the aquatic and riparian environment of the system (MDBA, 2012a). The variability of flows across the Basin has helped create habitat diversity and availability in the system, as well as controlled the supply of nutrients and food production available to aquatic communities (Rolls *et al*. 2013). The freshwater environment of the northern catchments is comprised of an extensive range of aquatic habitats including deep channels, swamps, floodplains, and wetlands (NSW DPI, 2007). Within these broad habitat types, niche habitats such as deep pools, riffles, benches, snags, gravel beds, aquatic vegetation and riparian vegetation are present, diversifying the habitat available to aquatic species in the Northern Basin (MDBA, 2012a).

Floodplain wetlands are a key feature of the Northern Basin landscape, including billabongs, anabranches and distributary channels. There are a number of nationally important wetlands located in the Northern Basin, including the Talyawalka Anabranch and Teryaweynay Creek system, the Lower Balonne system, Narran Lake, Gwydir Wetlands, Macquarie Marshes and Currawinya Lakes (MDBA, 2012a). These extensive wetland areas and associated smaller systems provide many important ecosystem functions, including filtering sediments, releasing nutrients and providing important breeding and nursery habitats for native fish (Beesley *et al*. 2012; Górski *et al*. 2013).

Main-channel rivers and creeks of the Northern Basin also provide significant areas of quality in-stream habitat, including deep pools, benches and large woody debris (NSW DPI, 2007). This habitat is important for native fish in the system, providing areas for refuge, breeding, feeding and shelter. Inset-floodplain benches also play an important role in riverine ecology providing areas of varying levels that facilitate the accumulation of debris, sediment and nutrients, allowing the cycling of carbon, nutrients and food in the system (Southwell, 2008; Foster and Cooke, 2011).

In recognition of how important a healthy Northern Basin is to the local communities and native fish populations of the Murray–Darling Basin, the Barwon–Darling system has been recognised as a High Conservation Value Aquatic Ecosystem, and the aquatic ecological communities of the lowland Darling River, which includes the Barwon–Darling River and major tributaries has been recognised as an Endangered Ecological Community in NSW (NSW DPI, 2006a; NSW DPI, 2007; NSW DPI, 2011).

2.3 Fishes of the Northern Basin

The Northern Basin has a distinct fish assemblage supported by the extensive and diverse range of aquatic habitat across the region, with slightly different communities in upland, midland and lowland zones. A total of 21 native fish species and six introduced fish species are expected to occur in the Northern Basin (Table 1; NSW DPI, 2012b). A number of these fish species found in the Northern Basin do not occur in the South, including Rendahl's Tandan and Hyrtl's Tandan. These species are likely to be especially adapted to the warmer temperatures, more ephemeral and variable flows and climate of the Northern Basin.

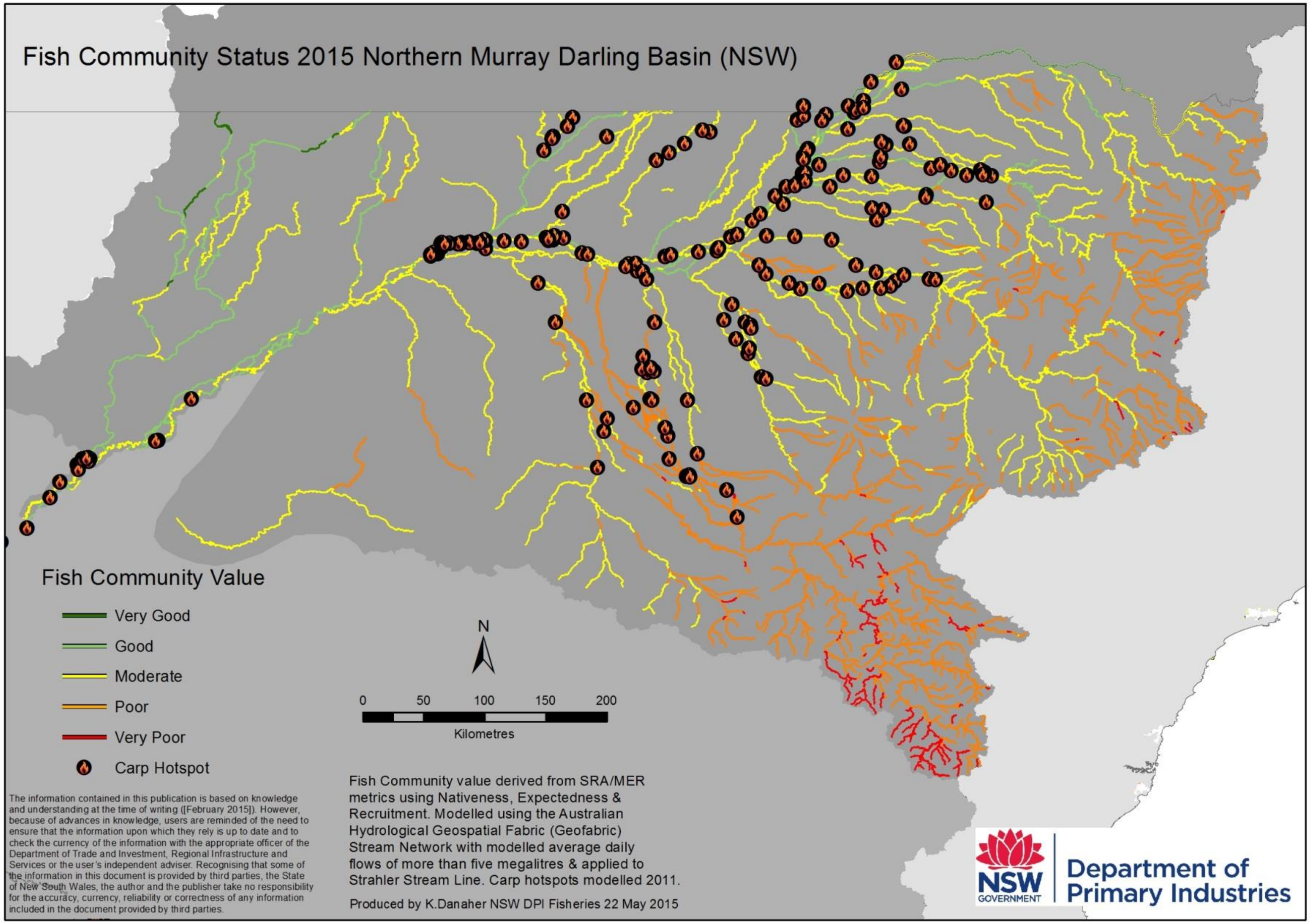
In addition to this, some fish species that are considered under threat in the Southern Basin, such as Olive Perchlet and Purple Spotted Gudgeon also have more healthy populations in the Northern Basin. The reasons for this are unclear, but may relate to lower levels of river regulation, relatively low Carp populations in areas where these species occur, lower turbidity and greater presence of macrophytes in both in-stream and off-channel habitats (Mallen-Cooper, 2015, pers. comm.).

The native fish of the Northern Basin have suffered significant impacts since European settlement (Boys and Thoms, 2006; Boys, 2007; NSW DPI, 2007; Davies *et al*. 2012; NSW DPI, 2015). Recent analysis of freshwater fish research data for NSW completed as part of the Fish Community Status Project has consolidated data collected over twenty years of biological surveys, combining this data with spatial distribution models to provide a delineation and spatial recognition of the condition of fish communities and threatened species across NSW (NSW DPI, 2015). The overall Fish Community Status was derived from the three condition indicators of Expectedness, Nativeness and Recruitment, with outcomes partitioned into five equal bands to rate the condition of the fish community; Very Good, Good, Moderate, Poor, or Very Poor (NSW DPI, 2015; Figure 2).

The Expectedness Indicator represents the proportion of native species that are now found within NSW, compared to that which was historically expected based on expert opinion. The Expectedness Indicator is derived from two input metrics; the observed native species richness over the expected species richness at each site, and the total native species richness observed within the zone over the total number of species predicted to have existed within the zone historically (NSW DPI, 2015). The Nativeness Indicator represents the proportion of native versus alien fishes within the river, and is derived from three input metrics; proportion native biomass, proportion native abundance and proportion native species (NSW DPI, 2015). The Recruitment Indicator represents the recent reproductive activity of the native fish community within each altitude zone. The Recruitment Indicator is derived from three input metrics; the proportion of native species showing evidence of recruitment at a minimum of one site within a zone, the average proportion of sites within a zone at which each species captured was recruiting, and the average proportion of total abundance of each species that are new recruits (NSW DPI, 2015).

Generalised Additive Modelling (GAM) analysis was used to model relationships between the fish assemblage metrics/indicators/index with environmental and River Style® attributes of stream segments. Modelling of the current geographic distribution of each listed threatened freshwater fish species or population was undertaken using MaxEnt 3.3.3 (a widely used species distribution modelling program that utilises presence records to generate probabilities of occurrence based on a suite of environmental variables quantified across the area of interest) with greater than 33% probability of occurrence used to predict presence of threatened species for the Fish Community Status project (NSW DPI, 2015).

Additional analysis of the freshwater fish research data examined Carp recruitment over all major river valleys in the Murray–Darling Basin to determine the spatial arrangement of identified Carp hotspots (Gilligan, in press; Figure 2). Spatial analysis was undertaken on standardised data from Basin scale and valley scale assessments for the distribution of young-of-year (YOY), sub-adult and adult Carp to test if there was a source-sink population structure for Carp at a Basin-wide scale, with further analyses undertaken at the valley scale to further determine if additional localised Carp hotspots existed within other regions of the Basin (Gilligan, in press).



<u>Figure 2</u>: Fish Community Status for the NSW section of the Northern Murray–Darling Basin, highlighting condition of fish communities and Carp hotspots.

There are minimal reaches of waterways in the NSW portion of the Northern Basin that are in good to very good condition, with the majority of reaches classified with this value located in the largely unregulated western systems (Figure 2). Significant stretches of rivers and creeks in the NSW Northern Basin have fish communities in a poor to very poor status, reflecting impacts to environmental conditions, as well as the dominance of alien species in some sections of the Basin. The majority of waterways in the NSW portion of the Northern Basin are in a moderate condition, which demonstrates great potential for recovery if appropriate management actions are developed and implemented (Figure 2).

The results from the Fish Community Status project mostly align with those of the second Sustainable Rivers Audit (SRA) report, which found that the fish community of the majority of valleys in the Northern Basin are in an extremely poor to poor condition, with only the Border Rivers (moderate), Condamine (moderate) and Paroo (good) being in a reasonable condition (Davies *et al*. 2012). Many factors have contributed to the deterioration of native fish in the Northern Basin including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and alien fish species (NSW DPI, 2007).

Eight of the native fish species recorded in the Northern Basin are listed as threatened by either Commonwealth or NSW legislation (Table 1). Flat-headed Galaxias are listed as Critically Endangered under the Fisheries Management Act (FM Act) 1994, whilst Purple Spotted Gudgeon, Freshwater Catfish of the Murray–Darling Basin, and the western population of Olive Perchlet are listed as Endangered under the FM Act 1994; Murray Cod are listed as Vulnerable under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, and Silver Perch, Macquarie Perch and Trout Cod are listed under both the FM Act 1994 and EPBC Act 1999, with Silver Perch being Vulnerable (FM Act 1994) and Critically Endangered (EPBC Act 1999), whilst Macquarie Perch and Trout Cod are listed as Endangered under both Acts. All of these species have an expected distribution in the Northern Basin, with historical records indicating their presence throughout the area.

Of the 28 species that inhabit the Northern Basin, six are alien species that have been introduced into the system from outside their normal range including Carp, Goldfish, Gambusia and Redfin Perch (Gehrke and Harris, 2004; Table 1). The abundance and distribution of alien species in the Northern Basin varies between valleys, with alien species being outnumbered by natives in some catchments, such as the Border Rivers, Condamine, Paroo and Warrego (Davies *et al*. 2012). However, for most catchments, including the Macquarie–Castlereagh, Darling, Namoi and Gwydir, alien species contribute more than 50% of total fish biomass (Davies *et al*. 2012).

Carp is the most common alien fish captured in a number of Northern Basin catchments, including the Darling (representing 10% of all fish captured in the upper and middle zones of the valley), Condamine and Paroo catchments. Eastern Gambusia represents the most common alien fish in other Northern Basin regions, including the Border Rivers, Macquarie–Castlereagh, Namoi and Gwydir (Davies *et al*. 2012). A number of Carp hotspots have been identified in the Northern Basin, including recruitment hotspots in the Macquarie Marshes, Namoi wetlands and Gwydir wetlands, Lower Warrego and lower Boomi River (Gilligan and Faulks, 2005; Gilligan, 2007; Figure 2). Other hotpots based on high YOY abundance include the Barwon and lower reaches of tributary valleys, such as the Bogan, Macquarie, Castlereagh, Namoi, Gwydir, Border Rivers, Moonie and the distributaries of the Lower Balonne Floodplain (Gehrig and Thwaites, 2013). The Darling between Tilpa and Burtundy (including Menindee Lakes) is another potential hotspot but its significance is less clear (Gehrig and Thwaites, 2013; Gilligan, in press).

In addition to the four alien species expected to occur in the Northern Basin waterways, there is potential for another alien fish, Mozambique Tilapia, to spread its distribution into the Darling system (Hutchison *et al*. 2011). The species is currently not found in the Murray–Darling Basin; however, it has established populations in Queensland catchments neighbouring the Basin, and in some places it is only a short distance from waters of the Murray–Darling Basin (Hutchison *et al*. 2011). There is a high risk that this species will be introduced into the Basin, and consideration of its potential impacts may be needed in future water management decisions, as once introduced, Mozambique Tilapia are successful invaders and tend to dominate waterways (Hutchison *et al*. 2011).

Alien fish can have a significant impact on native fish populations, through predation, competition for food and space, introduction of diseases, habitat disturbance and reduction of genetic integrity through hybridisation (NSW DPI, 2009). Carp in particular can cause significant environmental damage, resulting in high levels of turbidity and loss of aquatic vegetation, and often out compete with native fish for food and space as a result of their larger abundances (NSW DPI, 2009). Gambusia also tends to outcompete native fish for resources, especially Purple Spotted Gudgeons, due to their plague proportions (Macdonald and Tonkin, 2008). Gambusia are also an aggressive predator, preying on a wide variety of aquatic and terrestrial species and fin-nipping other fishes, leading to secondary infections (Macdonald and Tonkin, 2008; NSW DPI, 2009). Both Goldfish, a known vector of the Goldfish Ulcer Disease (GUD), and Redfin Perch, a vector of the Epizootic Haematopoietic Necrosis (EHN) virus, also have the potential to introduce diseases to native fish populations. Silver perch is particularly susceptible to the EHN virus (Gehrke and Harris, 2004).

Once alien species become established in a new habitat it is almost impossible to completely remove them, significantly increasing the pressures affecting native fish populations (Lintermans, 2004; Acevedo *et al*. 2013). Although alien species are already established in the Northern Basin it is important not to increase their proliferation where possible and reduce their distribution to new water bodies within the system. Consideration needs to be given to the potential effect future water management decisions in the Northern Basin have on alien fish populations, weighed against subsequent positive or negative implications for native fish.

Table 1 Fish species expected within the Northern Basin

(Sourced from Beverton and Holt, 1959; Gehrke and Harris, 2004; Lintermans, 2007; Macdonald and Tonkin, 2008; Faulks *et al.* 2011; Baumgartner, 2011; NSW DPI, 2012; Baumgartner *et al.* 2013; Cameron *et al.* 2013; Koehn *et al.* 2014, and reviewed and modified as required by expert knowledge as part of the Expert Panel workshop.)

Type	Species	Status	River type	Longevity (years)	Migratory species	Spawning season	Spawning temp	Spawning method	Fecundity	Hatch time	Egg morphology	Larval drift?
Large-bodied native species	Murray Cod	Threatened	Slopes, lowland	Long-lived (60)	Yes	Sept–Nov	>18 degrees	Nesting, parental care	Low (10,000-90,000)	13 days	Sticky, demersal	Yes
Large-bodied native species	Trout Cod	Threatened/Endangered	Montane, slopes	Long-lived	Yes	Sept–Nov	>15 degrees	Nesting, parental care	Low (1200-11,000)	5–10 days	Sticky, demersal (may prefer a hard substrate)	Yes
Medium-bodied native species	Bony Herring	Common	Slopes, lowland	Medium-lived (<5)	Yes	Oct–Feb	>20 degrees	Serial	High (33,000-800,000)	7 days	Buoyant, pelagic	Yes
Medium-bodied native species	Freshwater Catfish	Threatened (MDB population)	Montane, slopes, lowland	Medium-lived (8)	Yes	Sept–March	>20 degrees	Nesting, parental care	Low	7 days	Non-sticky, demersal	Yes
Medium-bodied native species	Golden Perch	Relatively common	Slopes, lowland	Long-lived (>26)	Yes	Oct–April	>17 degrees	Serial	High	3 days	Buoyant, pelagic	Yes
Medium-bodied native species	Hyrtl's Tandan	Rare (locally common in Qld)	Lowland	Medium-lived (3–9)	Yes	Sept–March	>26 degrees	?	High	3 days	Non-sticky, demersal	Yes
Medium-bodied native species	Macquarie Perch	Threatened	Montane	Long-lived (up to 20)	Yes	Oct–Dec	>16 degrees	Batch?	Low (50,000–108,000)	11 days	Non-sticky, demersal	No
Medium-bodied native species	Northern River Blackfish	Threatened	Montane, slopes	Medium lived (3–9)	No	Oct–Jan	>16 degrees	Nesting, parental care	Low (200-500 eggs)	14 days	Sticky, demersal	No
Medium-bodied native species	Rendahl's Tandan	Rare	Slopes, lowland (Condamine–Balonne)	Medium-lived (3–9)	Yes	? (Nov–Dec?)	?	?	Low (900–3465)	?	?	?
Medium-bodied native species	Silver Perch	Threatened	Slopes, lowland	Long-lived (>26)	Yes	Oct–April	>19 degrees	Serial	High (200,000–300,000)	5 days	Buoyant, pelagic	Yes
Medium-bodied native species	Spangled perch	Common	Slopes, lowland	Medium-lived (< 5)	Yes	Nov–Feb	>20 degrees	Serial	Low (24,000-113,000)	2 days	Non-sticky, demersal	Yes
Small-bodied native species	Australian Smelt	Common	Montane, slopes	Short-lived (3)	Yes	Sept–Feb	>11 degrees	Batch	Low (100–1,500)	10 days	Sticky, demersal	Yes
Small-bodied native species	Carp Gudgeon	Varies (rare to common)	Montane, slopes, lowland	Medium-lived (< 5)	Yes	Sept–April	>20 degrees	Nesting, parental care	Low (100–2,000)	2 days	Sticky, demersal	No
Small-bodied native species	Darling River Hardyhead	Rare (locally common)	Montane, slopes	Medium-lived (3–9)	Yes	Sept–April	Unknown	Batch	?	?	Sticky, demersal	No
Small-bodied native species	Dwarf Flat-headed gudgeon	Unknown (Condamine only)	Slopes, lowland	Medium-lived (5)	Yes	Unknown	19–22 degrees (in captivity)	Batch, parental care	Low	4-6 days	Sticky, demersal	?
Small-bodied native species	Flat-Headed Gudgeon	Unknown (only in Macquarie valley)	Montane, slopes	Medium (up to 5)	Yes	Sept–Feb	>18 degrees	Batch, parental care	Low	6 days	Sticky, demersal	Yes
Small-bodied native species	Mountain Galaxias	Common	Montane, slopes	Medium-lived (3–9)	No	Sept–Dec (small proportion also spawns in Autumn)	7–11 degrees	Batch	Low (50–400 eggs)	21 days	Sticky, demersal	No

Type	Species	Status	River type	Longevity (years)	Migratory species	Spawning season	Spawning temp	Spawning method	Fecundity	Hatch time	Egg morphology	Larval drift?
Small-bodied native species	Murray–Darling Rainbowfish	Relatively common	Slopes, lowland	Medium-lived (5)	Yes	Sept–Feb	>20	Batch	Low (35–350)	7 days	Sticky, demersal	Yes
Small-bodied native species	Murray Jollytail (Flat-Headed Galaxias)	Threatened	Montane (Macquarie valley), lowland	Short-lived (<2)	may move upstream Nov/Dec	Aug–Sept	>10.5 degrees	Batch?	Low (2,300–7,000)	8–9 days	Sticky, demersal	No
Small-bodied native species	Olive Perchlet	Threatened (western population)	Slopes, lowland	Medium-lived (4)	?	Oct–Dec	>22 degrees	Serial	Low (200–2,350)	7 days	Sticky, demersal	?
Small-bodied native species	Purple Spotted Gudgeon	Threatened	Montane, slopes, lowland	Medium-lived (10)	?	Sept–Feb	>20 degrees	Batch, parental care	Low (200–1,300)	9 days	Sticky, demersal	No
Small-bodied native species	Unspecked Hardyhead	Common	Slopes, lowland	Short-lived (<2)	Yes	Sept-April	>18 degrees	Batch	20–100	7 days	Sticky, demersal	No
Alien species	Brown trout	Common exotic	Montane	Medium-lived (3–9)	Yes	April–Aug	<25 degrees	Batch	Low	6–20 weeks	Sticky, demersal	No
Alien species	Carp	Common exotic	Montane, slopes, lowland	Long-lived (>65)	Yes	Sept–March	>17 degrees	Serial	High (100,000–1,000,000	6 days	Sticky, demersal	Yes
Alien species	Gambusia	Common exotic	Montane, slopes, lowland	Medium-lived (<3)	Yes	Sept–May	>16 degrees	Batch	Low (1–375)	N/A	Live young	N/A
Alien species	Goldfish	Common exotic	Montane, slopes, lowland	Medium-lived (<10)	Yes	Oct–Jan	>15 degrees	Serial	High	7 days	Sticky, demersal	No
Alien species	Rainbow Trout	Common exotic	Montane	Medium-lived (3–9)	Yes	Aug–Oct	<22 degrees	Batch	Low (400-3000)	3–12 weeks	Sticky, demersal	No
Alien species	Redfin Perch	Common exotic	Montane	Long-lived (up to 22)	Yes	Sept–Dec	>12 degrees	Batch	High (up to 100,000)	1–2 weeks	Sticky, demersal	No

3. Fish and flows in the Northern Basin

River regulation and increased water diversion and extraction in the Northern Basin has changed the natural hydrology of the system, generally resulting in lower average daily river flows that have less defined seasonal peaks (MDBA, 2012a-g). Changes to water management in the Northern Basin have, on average, reduced connectivity between the main channel and wetland habitat by 40% in some locations along the Barwon–Darling, affecting ecological functions within the system (Brennan *et al*. 2002). The frequency of in-channel freshes that promote fish spawning, recruitment and dispersal have also been significantly reduced across the Northern Basin. For example there has been a 66% reduction in in-channel freshes in the Barwon–Darling system at Bourke under current conditions as compared to without development (based on modelled flow data from 1896-2008), greatly affecting native fish populations (NSW DPI, 2013a)[1].

Native fish of the Northern Basin have evolved in a highly variable system that is characterised by extreme environmental conditions (Humphries *et al*. 1999; Baumgartner *et al*. 2013). From diverse wetting and drying cycles, to fluctuating temperatures, these conditions provide important seasonal cues for native fish, with hydrological variability in particular playing an integral role in influencing the structure and diversity of aquatic communities (Baumgartner *et al*. 2013; Rolls *et al*. 2013). A variety of life history and recruitment styles have been developed by different fish species in response to the range of environmental conditions experienced across the Basin and there is a need to cater for these differences across various spatial and temporal scales (see Section 3.2).

Flows, habitat and connectivity are essential for healthy native fish populations, with flows playing a range of important roles, including:

- The creation of hydrodynamic diversity needed for fish habitat (particularly for species that rely on flowing habitats, such as Murray Cod, Silver Perch, Trout Cod and Macquarie Perch).
- Maintaining health of in-stream and emergent vegetation and other habitat features needed by many fish species.
- Influencing quality, size and persistence of refuge habitats in dry periods.
- Inundation of benches and floodplains to support carbon and other nutrient cycling, which is important for system productivity and fish maintenance, recruitment and condition.
- Enabling access to a range of aquatic habitats and providing cues that stimulate movement, such as for spawning or larval dispersal, with movement opportunities including upstream or downstream, and lateral movement into off-channel habitats such as wetlands (MDBA, 2014a; p.41; Figure 3).

[1] In this context, in-stream freshes were defined as falling within the 15 to 30%ile, measured as between 3,600-11,500 ML/day at Brewarrina; 8,200-14,500 ML/day at Bourke, and; 5,900-9,200 ML/day at Louth (NSW DPI, 2013b; pp.6,10-11).

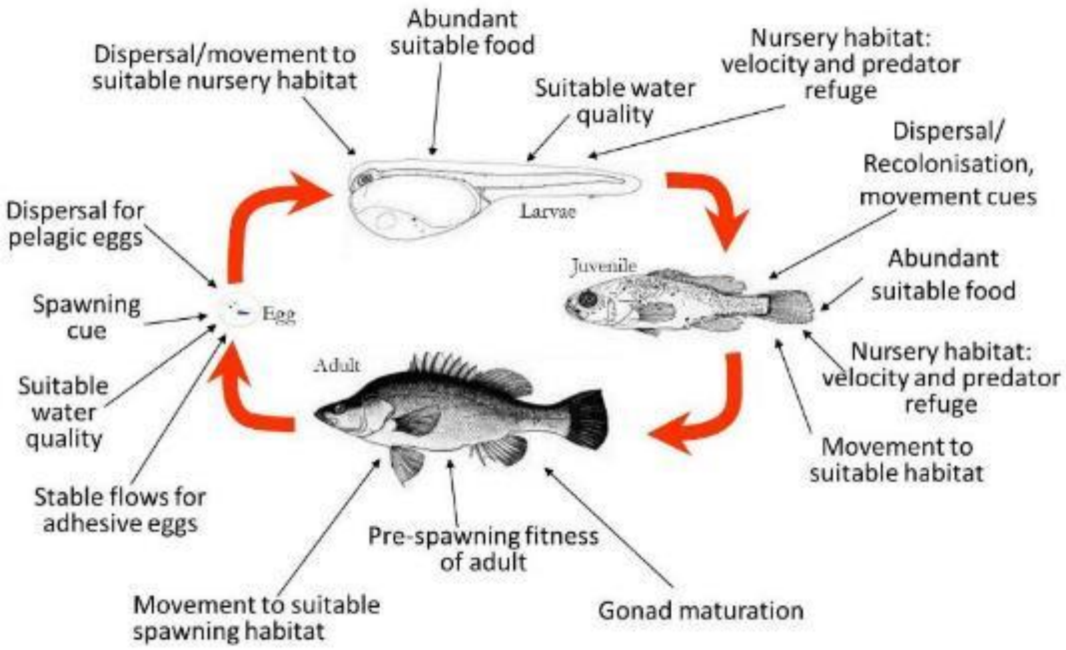


Figure 3: The influence of flows on the different stages within the life-cycle of fish

(Source: MDBA, 2014a courtesy of Arthur Rylah Institute.)

While flow management has often focused on hydrology (water volume or threshold, duration, seasonality and timing), the hydrodynamics of flow is equally important (Mallen-Cooper and Zampatti, 2015). This includes parameters such as flow depth, width, velocity, direction and turbulence. River regulation is particularly detrimental to flow hydrodynamics, often leading to still or slow flowing aquatic environments. In addition to this, water quality is as important as water quantity, including appropriate water temperature, levels of oxygen, pH, salinity, chemical cues and food content, and is equally influenced by river regulation (MDBA, 2014a; p. 41; Mallen-Cooper and Zampatti, 2015). It is possible to establish relationships between hydrology and hydraulics based on gauged stream flow data and stream cross-sectional data (i.e. what type of flow results in velocities greater than 0.3 m/s and weir drown out flow rates for stretches of rivers).

Fish use flows at a variety of scales, from the ‘micro-level’ (less than 100 metres) to medium scale (100s of metres to 10s of kilometres) and macro-scale (from 10s of kilometres to 100s of kilometres) (Mallen-Cooper and Zampatti, 2015). Effective flow management for native fish therefore requires consideration of flow aspects at different spatial scales, as well as the consideration of flow variability, with different parts of the hydrograph playing important roles for fish lifecycles:

- Cease to flows (series of disconnected pools) can create risks to fish in perennial streams, but are a natural feature of intermittent systems. Cease to flow periods can play an important role in these streams by promoting growth of biofilms and productivity. Rates of wetting and drying are important. Cease to flow can also be useful in controlling Carp populations, and would generally occur annually in highly intermittent systems.
- Base flows (not relevant to intermittent systems) are important in maintaining aquatic habitat for fish, plants and invertebrates. They also provide drought refuges during dry periods and contribute to nutrient dilution during wet periods or after a flood event. Base flows may also support winter conditioning and oxygenation through riffle habitats for Blackfish species and Galaxids, and historically may have benefited small-bodied native species in terminal wetlands. Base flows are maintained by seepage from groundwater and low surface flows (MDBA, 2014a). They would generally occur on an ongoing basis in perennial systems.

- Small in-channel pulses (freshes without bench inundation) are generally short in duration and can provide some productivity benefits by replenishing soil water for riparian vegetation, maintaining in-stream habitats and cycling nutrients between different parts of the river channel. They can also inundate key aquatic habitat such as snags and aquatic vegetation. Small pulses may trigger movement or spawning and recruitment for some species (such as Australian Smelt, Bony Herring and Blackfish). Murray Cod and Freshwater Catfish spawning and recruitment could also occur with sufficient hydraulic diversity. Pulses may also trigger hatching for Macquarie Perch and Galaxids. These flow events would generally occur annually for highly intermittent systems and also potentially annually (up to two or three a year) in perennial systems.
- Large in-channel pulses include freshes that provide lateral and longitudinal connectivity and inundation of in-channel features such as benches as well as anabranches with low commence to flow thresholds. These can be important in supporting productivity through inundation of channel benches, riparian zone, anabranches with low commence-to-fill thresholds and flood runners. Large pulses can trigger spawning and recruitment for all species and also promote movement and production (for events of significant duration). These flow events are also important for maintaining refuges and minimising geomorphological impacts of regulation. These events may occur once every two years in highly intermittent systems, and between three and five years for perennial systems.
- Overbank events (including floodplain and off-channel inundation) are important in providing broader connectivity to floodplains and other off-channel habitats and providing for ecosystem 're-setting' and large-scale nutrient and sediment cycling. These are important for spawning, recruitment, movement, productivity, maintenance and condition. These flows can create some risk of Carp movement and breeding, particularly regular long duration events in off-channel wetlands. Overbank events generally occur between two and twenty five years for both intermittent and perennial systems.

3.1 Functional groups of fish in the Northern Basin

The range of spawning and recruitment behaviours evolved by native fish species of the Murray–Darling Basin means that it is highly unlikely a single flow regime will provide equal benefits for the fish community of a system (Baumgartner *et al*. 2013; NSW DPI, 2013a). To enhance native fish outcomes from water management decisions it may be more effective to form functional groups of fishes based on certain flow related attributes (Lloyd *et al*. 1991; Humphries *et al*. 1999; Baumgartner, 2011; Baumgartner *et al*. 2013; NSW DPI, 2013a; Mallen-Cooper and Zampatti, 2015). The method of classifying fish species into functional groups is a valid approach to assist with simplifying flow requirements for fish, maximising water use and environmental benefits (Humphries *et al*. 1999; Growns, 2004; NSW DPI, 2013a; Mallen-Cooper and Zampatti, 2015). The effective and efficient management of water is even more pertinent in systems of the Northern Basin where water availability is limited and exacerbated by competing needs (Thoms *et al*. 2004; NSW DPI, 2013a).

A range of approaches to classifying fish species have been developed across the Murray–Darling Basin, focussing on attributes of different systems and fishes, including recruitment, spawning and movement. Models focused on fish recruitment include the flood recruitment model, which focuses on the role of flooding for recruitment of inland fish species (Lake, 1967; Cadwallader and Lawrence, 1990; Gehrke *et al,* 1995; Humphries, 1995), and; the low flow recruitment hypothesis, which questions the importance of flooding and floodplain habitat for some Murray–Darling Basin species, emphasising the significance of in-channel habitats and flow variability (Humphries *et al*. 1999; Schiller and Harris, 2001; Mallen-Cooper and Stuart, 2003; King *et al*. 2003; Mallen-Cooper *et al*. 2011). Similar recruitment models for arid zone refugia have also been developed, suggesting that spawning and recruitment for some species occurs primarily during zero flows in the channel refugia of arid rivers, similar to those found in the Northern Basin, including the Paroo and Warrego Rivers (Balcombe *et al*. 2006; Kerezsy *et al*. 2011).

Fish groupings based on reproductive attributes have classified fish based on the timing of spawning, method of spawning, larval development, parental care and other life history and reproductive characteristics, including the importance of spawning substrate components (Humphries *et al*. 1999; Schiller and Harris, 2001; King *et al*. 2003; Growns, 2004; Sternberg and Kennard, 2013). In addition to these spawning group approaches, recent work has combined known spawning, recruitment and movement ecology for native fish to classify species into guilds that assist flow management decisions (Baumgartner *et al*. 2013; Cameron *et al*. 2013). Baumgartner *et al*. (2013) classified four functional guilds in the Edward-Wakool system to develop long term watering plans for water managers. Previous work by NSW DPI in the Barwon–Darling adapted this approach with modifications appropriate to the Northern Basin, such as differing temperature tolerances for some species; however further verification and exploration through an expert panel or research was not undertaken, with applicability to other systems in the Northern Basin untested (NSW DPI, 2013a).

Alternative, but not necessarily incompatible, approaches to functional groups have also been undertaken, proposing the development of eco-hydraulic recruitment guilds for fish in the Murray–Darling Basin (Mallen-Cooper and Zampatti, 2015). This approach has questioned the applicability of reproductive groups based on differing ecological responses to the same conditions by species within the same group (Mallen-Cooper and Zampatti, 2015). Instead, the approach recommends that fish groups be developed on the primary features of the river to which fish will respond, most notably hydrodynamics, spatial scale and habitat (Mallen-Cooper and Zampatti, 2015).

The two key characteristics considered during the development of groups under the eco-hydraulic recruitment guild approach were the hydrodynamics of habitats where recruitment occurs, including flowing or still water environments and the influence of flow on the spawning and recruitment response of species in these areas, and; the minimum spatial scale of spawning and recruitment, noting that fish that recruit at small scales may also recruit over larger scales if suitable environmental conditions are achieved, but the reverse is not true (Mallen-Cooper and Zampatti, 2015). However, water temperature and water quality information was not considered in this method as it was believed these factors would dominate the life history characteristics considered in the approach, and as a result there is potential that these guilds would not be applicable in rivers impacted by reduced water temperature or water quality (Mallen-Cooper and Zampatti, 2015).

The range of existing fish functional group approaches were considered during the *Fish and Flow in the Northern Basin* project. Assessment of applicability and relevance for the project was determined through the literature review component and fish expert panel workshop. Through this process it was determined that the use of flow related functional groups for fish species in the Northern Basin would assist the development of specific environmental watering requirements and flow related management actions. The expert panel workshop proposed a hybrid approach utilising elements from both the spawning functional groups described by Baumgartner *et al*. (2013) and the eco-hydraulic recruitment guilds developed by Mallen-Cooper and Zampatti (2015). Elements for consideration included:

- Cues for migration, dispersal and spawning (temperature and/or flow)
- Scale of spawning migration (10s to 100s of m; 100s of m to 10s of km; 10s to 100s of km)
- Whether a nesting species or not
- Scale of larval drift and recruitment
- Spawning in still/slow-flowing water or in fast-flowing habitats
- Egg hatch time (short 1 – 3 days; medium 3 – 10 days; long > 10 days) and egg morphology.

Assessing these physiological and behavioural similarities of freshwater fishes in the Northern Basin, six functional groups were developed and linked to flow aspects, with similar attributes identified for flow management consideration (Table 2). It is important to note that, while there are functional groups that have differing flow needs, it is possible to design a flow regime that meets the needs of multiple fish guilds.

Table 2: Proposed Northern Basin fish guild groupings (based on Baumgartner *et al*. (2013) and Mallen-Cooper and Zampatti (2015), as well as advice from Northern Basin Expert Panel workshop members).

Functional group	Species	Attributes and implications for flow management
Group 1: Flow dependent specialists	Golden Perch Hyrtl's Tandan Silver Perch Spangled Perch	• Flow pulses are needed to generate a spawning response. • Adult fish prepare for spawning in response to increasing water temperatures usually between spring and autumn, with research in the Northern Basin suggesting that the first post-winter flow pulse may be important for pre-spawning condition and migration in some northern systems (Marshall, *et al*. in press), but timing is not predictable. • Adult fish can undertake moderate to large scale migrations (10s of km to over 100s of km) in response to increased flows and temperature, but can delay spawning if conditions are not suitable, with species being medium to long-lived and not necessarily requiring annual spawning and recruitment events. • Flow events do not have to be large pulses, with small, sharp rises in flow also providing benefits and eliciting responses from species (Marshall *et al*. in press). • Eggs are either buoyant and pelagic or non-sticky and demersal with a short hatch time of up to 5 days, relying on flows for dispersal. • Larvae drift downstream over long distances for up to 20 days post spawning in perennial and intermittent systems (potentially shorter in highly intermittent systems with smaller flow pulses), with recruitment relying on flows for dispersal and conditioning.
Group 2: in-channel specialists[2] **(Group 2A: Flow dependent)** **(Group 2B: Flow independent)**	Murray Cod (2A) Trout Cod (2A) Blackfish (2B) Freshwater Catfish (2B) Macquarie Perch (2B) Purple Spotted Gudgeon (2B)	• Adult fish prepare for spawning in response to increasing water temperature. • Adult fish can undertake short to moderate scale migrations (10s of m to 100s of m) for spawning. • Group 2A species have a predictable spawning period from mid-winter to the end of spring, involving movement to increasing temperature and flow, with research suggesting an earlier spawning response is possible in the Northern Basin compared to the Southern Basin (Butler, pers. comms.; Wilson, pers. comms.). Species are long-lived and don't necessarily require annual spawning and recruitment events, but may take many years for noticeable population improvements due to low fecundity. • Group 2B species have a spawning period from spring to autumn, but most commonly between spring and summer, which is independent of flow. Species are medium to long-lived and don't necessarily require annual spawning and recruitment events, but may take many years for noticeable population improvements due to low fecundity. • Nesting species, or have specific spawning substrate requirements (Macquarie Perch and Purple Spotted Gudgeon), with increases in flow helping to maximise breeding opportunities by inundating additional spawning habitat. • Eggs are demersal with a relatively long hatch time of up to 14 days, requiring stable flow events during this period to avoid nest abandonment, desiccation or premature dispersal. • Larval drift over short to moderate scales for up to 10 days, with recruitment relying on flows for dispersal and conditioning.
Group 3: Floodplain specialists	Darling River Hardyhead Flat-headed Galaxias Olive Perchlet Rendahl's Tandan Gambusia (alien species)	• Adult fish prepare for spawning in response to increasing water temperature. • Adult fish undertake short scale migrations (100s of m to 10s of km) for spawning, potentially to off-channel habitats, where spawning takes place in still or slow moving environments. • Relatively short-lived and have low fecundities, requiring regular spawning and recruitment events, with spawning between spring and autumn. • Have specific spawning substrate requirements (aquatic macrophytes), with increases in flow helping to maximise breeding opportunities by inundating additional spawning habitat, especially off-channel, which may also be reliant on water clarity (low turbidity). • Eggs are sticky and demersal, with an estimated hatch time of up to nine days. • Recruitment and dispersal rely critically on flows that reconnect the channel to the floodplain, with large flow events required post spawning.
Group 4: Generalists	Australian Smelt Bony Herring Carp Cudgeon Flat-headed Gudgeon Murray–Darling Rainbowfish Unspecked Hardyhead	• These species are generally more resilient to extended low flow conditions having developed more flexible spawning strategies, and as such may be poor indicators of environmental flow effectiveness (MDBA, 2015); however these species provide an important component of productivity in a system and food source for medium and large bodied species. • Adult fish prepare for spawning in response to increasing water temperature. • Adult fish move short distances (100s of m) over a wide range of hydrological conditions, and are known to recruit under low flows all year round; however spawning is most common between spring and summer. Species are short to medium-lived requiring regular spawning and recruitment events, but may take many years for noticeable population improvements due to low fecundity. • These species may spawn more than once during the year, with low to moderate flow events that inundate in-channel habitat, enhancing spawning conditions and connectivity of drought refuge, providing the greatest benefits to these species. • Eggs are sticky and demersal with a hatch time of up to 10 days. • Larval drift is exhibited by majority of species (except Carp Gudgeon and Unspecked Hardyhead) over short to moderate scales, with recruitment of these species reliant on flows for dispersal and conditioning.
Group 5: Generalists (alien species)	Carp Goldfish Redfin Perch	• Adult fish prepare for spawning in response to increasing water temperature; however species can also spawn during low temperatures (down to as low as 12°C for Redfin Perch). • Adult fish move short to moderate distances (100s of m to 10s of km) over a wide range of hydrological conditions, and are known to recruit under low flows all year round; however spawning is most common between spring and summer. • These species have a high fecundity and may spawn more than once during the year. • For Carp, floodplain connecting flow events (especially repeated and frequent sequences) that inundate areas for an extended period of time provide greatest response, whilst low to moderate flow events that inundate in-channel habitat produce reduced spawning outcomes (Koehn *et al*., 2015). • Eggs are sticky and demersal (with the exception of Gambusia who give birth to live young), with a hatch time of up to 14 days (but can be as low as six days). • Larval drift is exhibited by some species over short to moderate scales, with recruitment relying on flows for dispersal and conditioning.

[2] Inchannel specialists divided into two groups of Flow dependent species, defined as requiring both an increase in temperature and flow to trigger spawning, and Flow independent species, defined as species that generally inhabit inchannel habitats and may benefit from certain flow regimes, but do not have specific flow requirements related to spawning.

Comparison of functional groups developed for the *Fish and Flows in the Northern Basin* project with those of the Edward-Wakool spawning functional groups (Baumgartner *et al*. 2013) and the eco-hydraulic recruitment groups (Mallen-Cooper and Zampatti, 2015) highlights numerous similarities in the grouping of species, which is expected given the consideration of similar system and fish attributes; however differences in the composition of groups can also be identified (Table 3).

Table 3: Comparison of fish functional group species between those developed for the *Fish and Flows in the Northern Basin* project and Baumgartner *et al*. (2013) and Mallen-Cooper and Zampatti (2015) with differences shaded in green (and indicated by an asterisk).

Species	Eco-hydraulic recruitment guild (Mallen-Cooper and Zampatti, 2015)	Habitat guild (Mallen-Cooper and Zampatti, 2015)	Spawning guild (Baumgartner *et al.* 2013)	*Fish and Flows in the Northern Basin* guild
Murray Cod	Meso Lotic	Channel Specialist	Long lived Apex Predator	Inchannel Specialists (flow dependent)
Trout Cod	Meso Lotic	Channel Specialist	Long lived Apex Predator	Inchannel Specialists (flow dependent)
Golden Perch	Macro Lotic	Channel Specialist	Flow Dependent Specialist	Flow Dependent Specialists
Silver Perch	Macro Lotic	Channel Specialist	Flow Dependent Specialist	Flow Dependent Specialists
*Freshwater Catfish	Meso Lotic-Lentic	Generalist	Foraging Generalist	Inchannel Specialists (flow independent)
Bony Herring	Meso Lotic-Lentic	Generalist	Foraging Generalist	Generalists
Macquarie Perch	Meso Lotic	Channel Specialist	Foraging Generalist	Inchannel Specialists (flow independent)
*Spangled Perch	Meso Lotic-Lentic	Generalist	Foraging Generalist	Flow Dependent Specialists
*Hyrtl's Tandan	Micro Lentic	Arid River Specialist	N/A	Flow Dependent Specialists
Northern River Blackfish	Meso Lotic	Channel Specialist	Foraging Generalist	Inchannel Specialists (flow independent)
*Rendahl's Tandan	Micro Lentic	Arid River Specialist	N/A	Floodplain Specialists
Australian Smelt	Micro Lotic-Lentic	Generalist	Foraging Generalist	Generalists
Carp Gudgeon	Micro Lotic-Lentic	Generalist	Foraging Generalist	Generalists
*Darling Hardyhead	Micro Lentic	Arid River Specialist	N/A	Floodplain Specialists
Dwarf flat-headed Gudgeon	Micro Lotic-Lentic	Generalist	Foraging Generalist	Generalists
Flat-headed Gudgeon	Meso-Micro Lotic-Lentic	Generalist	Foraging Generalist	Generalists
Mountain Galaxias	Meso Lotic	Channel Specialist	N/A	N/A
Murray–Darling Rainbowfish	Meso-Micro Lotic-Lentic	Generalist	Foraging Generalist	Generalists

Species	Eco-hydraulic recruitment guild (Mallen-Cooper and Zampatti, 2015)	Habitat guild (Mallen-Cooper and Zampatti, 2015)	Spawning guild (Baumgartner *et al.* 2013)	*Fish and Flows in the Northern Basin* guild
Flat-headed Galaxias	Micro Lentic	Wetland Specialist	Floodplain Specialist	Floodplain Specialists
Olive Perchlet	Micro Lentic	Wetland Specialist	Floodplain Specialist	Floodplain Specialists
*Purple Spotted Gudgeon	Micro Lentic	Wetland Specialist	Floodplain Specialist	Inchannel Specialists (flow independent)
Unspecked Hardyhead	Meso-Micro Lotic-Lentic	Generalist	Foraging Generalist	Generalists
Carp	Meso-Micro Lotic-Lentic	Generalist	N/A	Generalists (alien)
Gambusia	Micro Lentic	Wetland Specialist	N/A	Floodplain Specialists
Goldfish	Micro Lotic-Lentic	Generalist	N/A	Generalists (alien)
Brown Trout	N/A	N/A	N/A	N/A
Rainbow Trout	N/A	N/A	N/A	N/A
Redfin Perch	Micro Lotic-Lentic	Generalist	N/A	Generalists (alien)

Differences in the classification of fish between the three functional group approaches were identified for six species (Table 3). These differences reflect the review of fish species attributes in the context of Northern Basin systems, using expert knowledge and latest research to guide the grouping of species. The most significant shifts in classification occur for Freshwater Catfish, Spangled Perch and Purple Spotted Gudgeon, whilst changes for Hyrtl's Tandan, Rendahl's Tandan and Darling River Hardyhead reflect recent research findings for Northern Basin systems and the location of these species in intermittent and perennial systems.

Freshwater Catfish have been classified as a Flow Independent in-channel Specialist rather than a Generalist species as defined by the other two reviewed approaches as they share similar flow related spawning and recruitment needs to the other species in this group. These include being a nesting species that spawn independent of flow but benefit from increased flow events inundating preferred spawning habitat followed by stable flow conditions for egg development and hatching; undertaking short to moderate scale migrations for spawning, and having drifting larvae that benefit from dispersal flows (Growns pers. comms. 2015).

The grouping of Spangled Perch and Hyrtl's Tandan as Flow Dependent Specialists for the *Fish and Flows in the Northern Basin* project, rather than Generalists and Arid River Specialist respectively, reflects the moderate to large scale migrations these species can undertake for spawning in response to increasing flows and temperature. In addition to this, the short hatch time of non-sticky demersal eggs that these species possess would benefit from rapid rises in water levels, whilst not being impacted by equally rapid recessions if they were to occur as part of a flow event (Ellis *et al*. in press; Balcombe pers. comms. 2015).

Purple Spotted Gudgeon have been included as part of the Flow Independent in-channel Specialist rather than a Floodplain/Wetland Specialist species based predominantly on the habitat preference in the Northern Basin, with the species commonly found in shallow pools or slow flowing backwaters of typically upland, unregulated systems (MDBA, 2012a; Miles, pers. comms. 2014). The species would also benefit from similar flow requirements of other species in the Flow Independent in-channel Specialist group, including the inundation of preferred in-channel habitat (aquatic macrophytes and fringing vegetation) for spawning followed by stable flow conditions for egg development, parental guarding and hatching under little to no flow conditions (Llewellyn, 2006).

3.2 Assemblage-based analysis of environmental flow requirements

Comparative statistical analysis of the influence of critical flow components on life history outcomes for native fish was recommended from the Expert Panel workshop to complement and potentially validate the functional group approach of the Fish and Flows in the Northern Basin project (Appendix A). The proposed 'top-down' approach involved using components of the hydrograph as the starting point, and from these it is determined which species and life history strategies stand to benefit from these components or environmental watering events. This process was commenced for Stage 2 of the project, with expert judgement and the latest available information helping to develop a comparative data matrix (Appendix B). The process involved scoring different components of the hydrograph based on their importance in supporting different species life history outcomes as they relate to spawning, recruitment and movement (Table 4 and 5).

Table 4: The flow components considered by an expert panel

(Appendix B presents the scoring according to the importance of the different flow components in supporting the range of life history outcomes across different Northern Basin fish species. Scoring system based on: does the flow feature benefit the fish life history outcome? With 20 = Highly significant benefit; 10 = Significant benefit; 5 = Moderate benefit; 1 = Little benefit; and 0 = No benefit.)

Flow component	Description
Cease to flow	Period of zero flow
Base flow	Low flows which maintain a limited degree of lotic conditions
Small pulse	No off channel connection/meso scale lotic/no bench inundation
Large pulse	Off channel connection e.g. via anabranch/macro scale lotic/bench inundation
Overbank	Beyond upper limits of channel, uncontrolled inundation of floodplain
Event stability	Water levels may increase quickly but must be maintained above a minimum level for sufficient time to maintain habitat (particularly relevant to maintaining demersal egg nests).

Table 5: The life history outcomes considered by an expert panel

Life history outcome	Description
Spawning	Spawning success of fish assuming they have accessed suitable habitat (i.e. spawning occurrence and egg hatching)
Recruitment	Survival of fish from larvae to young-of-year
Movement (adult/juvenile)	Migration (including spawning) of adult fish and dispersal of juvenile fish (i.e. large scale, small scale, no movement as part of life history)

Further analysis of the data matrix will be pursued as part of Stage 3 of the project to complement the Northern Basin fish functional groups developed as part of Stage 2. It is expected that this further analysis will highlight additional species that may benefit from flow components of model hydrographs proposed for specific functional groups. A suite of multivariate analyses (PRIMER package: Clarke and Gorley, 2006) will be used to determine those components of the hydrograph most responsible for supporting important life history outcomes across the entire fish assemblage. To assist with interpretation of the results, the matrix will be split in three: spawning, recruitment and movement, with each matrix analysed separately. For the purposes of the analyses, each unique species/life history outcome will be treated as a sample, and each of the six flow components as the dependent variables. Any species where the Expert Panel could not obtain a score for all flow variables due to insufficient understanding will be excluded from analysis. In addition to this, the overbank flow component will also be removed from analysis as initial work showed that the influence of this component on fish life history outcomes is highly correlated with large pulse events.

As with any guild approach, there are assumptions and limitations that need to be acknowledged when considering their adoption. Knowledge gaps on flow requirements for a number of Northern Basin fish species exist, including Rendahl's Tandan and the Darling River Hardyhead. Assumptions have been made for these species based on requirements of similar species and the limited information that is available. It is also important to acknowledge that whilst flow is critical for healthy fish populations, it is not the only factor influencing life history responses from fish. Complimentary actions need to be considered in addition to flow management aspects include factors influencing water quality and temperature (e.g. cold water pollution impacts), habitat availability and condition (e.g. riparian condition, large woody debris loading), and other aspects such as connectivity (e.g. fish passage barriers) that are largely outside the scope for this project but consideration needs to be given to them during the development of water management actions.

The comparative matrix approach used to complement the Northern Basin functional groupings is also limited by a lack of knowledge on flow requirements for some species and the limitations of a process based on expert opinion, although this is guided by the latest monitoring knowledge and research outcomes. Expert judgement is a valid technique increasingly used in conservation planning, particularly in contexts where information is scarce and management decisions must be made within a short time frame. In these situations, expert judgments may be the only, or the most, credible source of information available for making management decisions (Martin *et al*. 2012). For example, expert opinion may:

- make explicit the published and unpublished knowledge and the wisdom of experts; provide a temporary summary of the limited available knowledge;
- inform policy before conclusive scientific evidence becomes available, and;
- serve as a basis for action when problems are too urgent or stakes too high to postpone measures until more complete knowledge is available (Kangas and Leskinen, 2005; Knol *et al*. 2010; Krueger *et al.* 2012).

As with any approach that draws upon expert judgement, this approach does have some possible limitations, including the potential for bias, poor calibration or to be self-serving (Tversky and Kahneman 1974; Krinitzsky 1993; Martin *et al*. 2012). These aspects have been regarded when considering the development of flow related functional groups for fish species in the Northern Basin through the analysis and review of existing information (including reviewing the existing functional groups and a thorough literature review) and the use of recognised experts in the field. As a result, the proposed fish groups represent the most advance development of flow related guilds based on best available information and current knowledge.

3.3 Conceptual models for fish flows in the Northern Basin

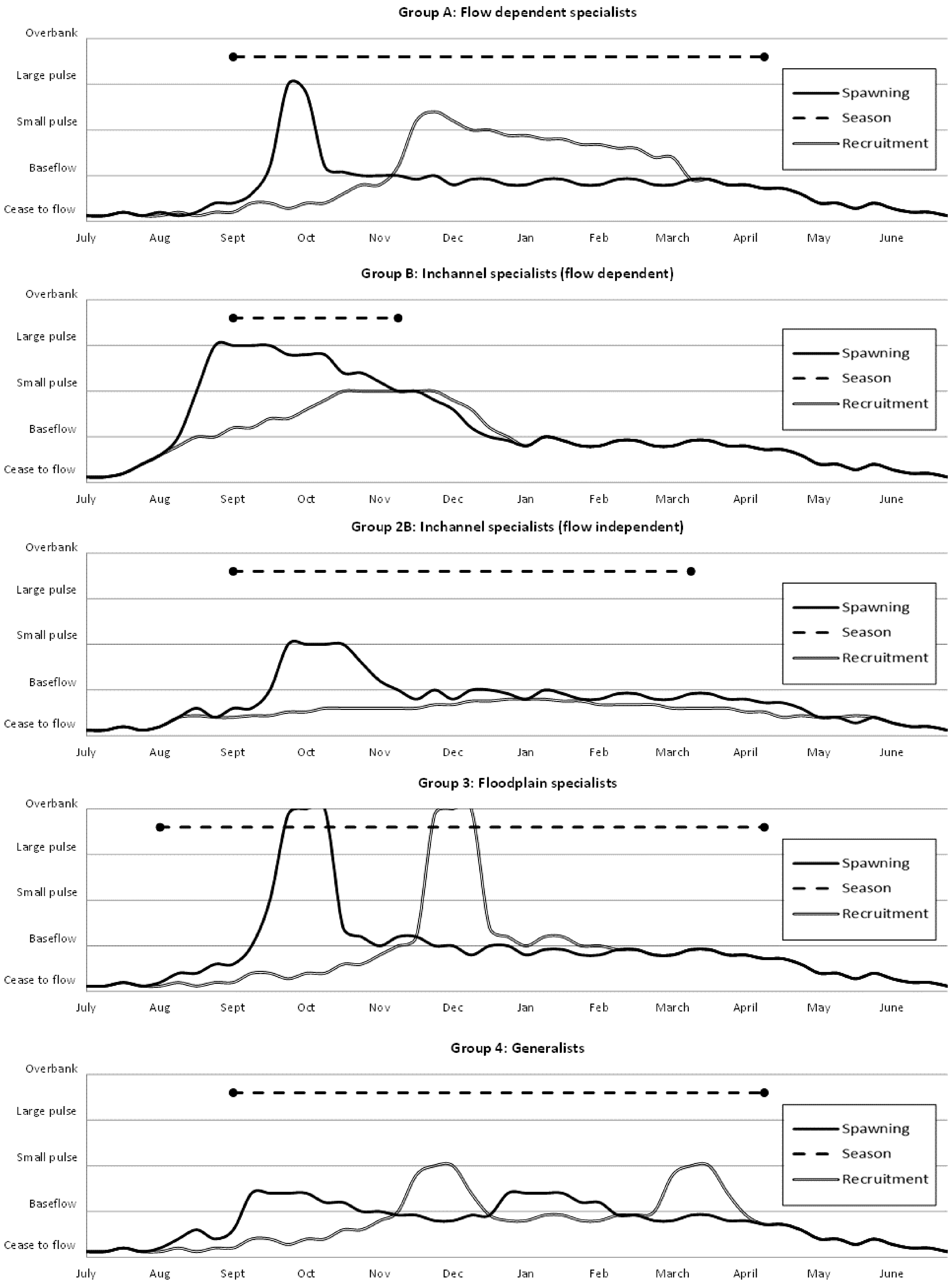
The use of functional groups for freshwater fishes in the Northern Basin can assist with environmental water planning to deliver native fish benefits and develop specific environmental water requirements. However, it is important to acknowledge that each functional group of native fish has different flow requirements related to critical life history outcomes including spawning, recruitment and movement, and that the habitat, connectivity and spatial scale requirements that influence these life history responses, will also differ across functional groups and species (Mallen-Cooper and Zampatti, 2015). The development of watering requirements for one group may not provide benefits for another, requiring flexibility and a long term commitment to deliver benefits to native fish and river health (Baumgartner, 2011; NSW DPI, 2013a).

The development of conceptual flow models for fish need to define the biological assumptions and ecological objectives before developing flow regime requirements and producing model hydrographs for freshwater fish (Baumgartner *et al*. 2013; NSW DPI, 2013a; Table 6). There are a number of basic principles for flow management for fish in the Murray–Darling Basin related to the biological and ecological criteria that need to be considered when developing and implementing management actions for fish outcomes:

- Natural flow regime - one of the important principles considered in the development of conceptual flow models for fish in the Northern Basin is that the natural flow regime provides a strong foundation for the rehabilitation of flows; however the impacts of river regulation, including connectivity, access to habitat, and changes to geomorphology, need to be considered and incorporated into specific planning objectives (Mallen-Cooper and Zampatti, 2015).
- Water quality parameters - the importance of water quality, not just water quantity, also needs to be considered when developing and delivering water requirements, with water temperature driving life history responses from the majority of native species, whilst clarity, dissolved oxygen and productivity (related to chemical, nutrient and plankton composition) also play an important role in maximising benefits to species (Jenkins and Boulton, 2003; Górski *et al*. 2013; Zampatti and Leigh, 2013; Mallen-Cooper and Zampatti, 2015). The influence of water quality parameters on guiding flows for fish will result in management actions primarily occurring in the warmer spring and summer months; however the importance of base flows all year round and late-winter high flow events still need to be considered given their benefits to water quality maintenance and productivity (Robertson *et al*. 2001).
- Fundamental riverine elements – the influence of flow, habitat and connectivity on the dynamics and response of fish populations are inseparable and need to be intimately considered in flow management decisions and actions (Mallen-Cooper and Zampatti, 2015). These three key factors will influence the need for still water or flowing environments, the spatial scale that connectivity and hydraulic complexity needs to be maintained, and the variation in flow needed for habitat access and completion of life history aspects (Mallen-Cooper and Zampatti, 2015).

The use of these principles, as well as biological and ecological information for fish, to develop environmental water requirements can help define what can realistically be achieved with improved hydrological regimes. This will also help establish measureable objectives that can achieve multiple benefits through variability and consider the needs of multiple water users (Baumgartner *et al*. 2013; NSW DPI, 2013a).

Figure 4 identifies different flow requirements that would benefit each functional group. For this, unique overarching flow delivery scenarios were developed for spawning and recruitment outcomes (with movement needs considered and assumed to be met by the proposed flow regimes) in the Northern Basin. These flow scenarios were developed using existing knowledge about native fish responses to flows, spawning and reproductive cycles and methods, recruitment ecology (including habitat requirements and spatial scales), and known distributions of freshwater fish.



<u>Figure 4</u>: Flow scenarios developed to benefit each fish functional group for the Fish and Flows in the Northern Basin project.

(Represented by water level expressed as flow components, which allows the proposed regimes to be adapted to different valleys of the Northern Basin based on specific local information where known. The models represent the best outcome scenario for each group; however proposed flow regimes could be implemented at any point during the 'season' window indicated to achieve spawning and recruitment outcomes.)

Table 6: Flow regime requirements, biological assumptions and ecological outcomes that underpin the development of conceptual flow models for fish functional groups in the Northern Basin.

Flow regime	Regime requirements	Biological assumptions	Expected ecological outcomes
Flood dependent specialists flow	• Spawning response requires rapid rise in flow between spring and autumn for up to 5 days, with first post-winter flow potentially being significant in eliciting greatest benefit. • Relatively rapid recession of flow after peak event to assist with egg dispersal. • Recruitment of larvae and juveniles enhanced from secondary peak event for dispersal and access to habitat and suitable prey sources. • Integrity of flow peaks need to be maintained over long distances (10s to 100s of km) to maximise response.	• Spawning flow coincides with an increase in water temperature above 20°C. • Moderate to large scale migrations and spawning occurs on the first peak event. • Buoyant or non-sticky eggs develop and disperse over long distances during recession of spawning peak. • Spawning will lead to recruitment regardless of floodplain inundation. • Recruitment flow will assist in the dispersal of larvae and juveniles.	• Provide flowing conditions for moderate to large scale fish movement and dispersal throughout the system away from spawning and refuge sites. • Increased habitat availability and maintenance through hydrodynamic complexity in-channel from flow peaks. • Improved productivity throughout the system from flow peaks inundating in-channel benches. • Preference is to have spawning and recruitment events two to three times per decade.
In-channel specialists flow (flow dependent)	• Spawning response requires rise in flow between mid-winter and spring. • Flow peak needs to be maintained for a period greater than 14 days to allow for egg development and hatching. • Recruitment of larvae and juveniles enhanced from secondary peak event for dispersal and access to habitat and suitable prey sources. • Integrity of flow needs to be maintained over moderate distances (10s to 100s of m) to maximise response.	• Spawning flow coincides with an increase in water temperature above 18°C. • Short to moderate scale migrations and spawning occurs in response to increased flow, which inundates preferred spawning habitat, with extended duration at the peak flow allowing site selection and spawning. • Egg development and hatching assisted by stable flow events after initial flow peak. • Spawning will lead to recruitment regardless of floodplain inundation. • Recruitment flow is delivered after larvae have left the nest, and will assist in the dispersal of drifting larvae and juveniles.	• Provide flowing conditions for short to moderate scale fish movement and dispersal throughout the system away from spawning and refuge sites. • Increased habitat availability and maintenance through hydrodynamic complexity in-channel from flow peak. • Improved productivity throughout the system from flow peak inundating in-channel benches. • Preference is to have spawning and recruitment events twice per decade.
In-channel specialists flow (flow independent)	• Spawning occurs independent of flow; however response is enhanced by increase in flow during spring. • Flow peak needs to be maintained for a period greater than 14 days to allow for egg development and hatching, with gradual recession of event required. • Recruitment of larvae and juveniles enhanced from stable low flow period for dispersal, and access to habitat and suitable prey sources. • Integrity of flow needs to be maintained over short to moderate distances (10s to 100s of m) to maximise response.	• Spawning flow coincides with an increase in water temperature above 20°C. • Short to moderate scale migrations and spawning enhanced by increased flow, which inundates preferred spawning habitat, with extended duration of peak flow allowing site selection and spawning. • Egg development and hatching assisted by stable flow events after initial flow peak. • Larvae dispersal and adult movement enhanced by gradual recession of peak. • Spawning will lead to recruitment regardless of floodplain inundation. • Stable low recruitment flow will assist in the dispersal of larvae and juveniles.	• Provide flowing conditions for short to moderate scale fish movement and dispersal throughout the system away from spawning and refuge sites. • Increased habitat availability in-channel throughout the system from flow peak. • Preference is to have spawning and recruitment events twice per decade.
Floodplain specialists flow	• Spawning occurs in suitable habitat independent of flow or in very slow flows; however spawning response is enhanced by overbank flow during warmer seasons (most common timing amongst species between Sept and Oct). • Flow peak needs to be maintained for a period up to 10 days to allow for spawning and egg development, with gradual recession of event required for adult movement. • Recruitment of larvae and juveniles enhanced by secondary peak event for lateral connection and dispersal, which can occur weeks after the initial peak event, with gradual recession of event important for larvae and juvenile movement.	• Spawning flow coincides with an increase in water temperature above 22°C. • Short scale migrations and spawning enhanced by increased flow that connects preferred off-channel habitat, including aquatic macrophytes, which species colonise during the event. • Extended duration of first peak flow and gradual recession enhances lateral connection and allows for adult movement. • Recruitment of larvae and juveniles from nursery habitats (i.e. wetlands) enhanced from secondary peak event, creating reconnection and allowing for dispersal and access to habitat and suitable prey sources in main channel.	• Provide flowing conditions for short scale longitudinal and lateral fish movement and dispersal throughout the system for recolonization of new habitats away from spawning and refuge sites. • Increased habitat availability and maintenance through hydrodynamic complexity, both in-channel and across lateral habitats (e.g. anabranches) from flow peaks. • Improved productivity at off channel and in-channel habitats throughout the system from flow peaks inundating floodplain. • Preference is to have spawning and recruitment events three times per decade.
Generalists flow	• Spawning occurs independent of flow; however response is enhanced by increase in flow during warmer months (most common timing amongst species between Sept and Feb). • Multiple peak events during spawning season provide flexibility in species response, as well as opportunities for multiple spawning events from serial spawning species. • Flow peak needs to be maintained for a period greater than 7 days to allow for egg development and hatching, with gradual recession of event required. • Recruitment of larvae and juveniles enhanced from secondary peak event for dispersal and access to habitat and suitable prey sources.	• Spawning coincides with an increase in water temperature above 20°C. • Short scale migrations and spawning enhanced by moderate increase in flow, which inundates preferred spawning habitat. • Egg development and hatching assisted by stable flow events after initial flow peak. • Larvae dispersal and adult movement enhanced by gradual recession of peak. • Spawning will lead to recruitment regardless of floodplain inundation. • Recruitment flow will assist in the dispersal of drifting larvae and juveniles.	• Provide flowing conditions for short scale fish movement and dispersal throughout the system away from spawning and refuge sites. • Increased habitat availability in-channel throughout the system from flow peak. • Increase in abundance of small bodied natives, providing important food source for medium and large bodied fish. • Preferences to have spawning and recruitment events at least three times per decade, allowing fish to spawn during at least one of the events.

In addition to the development of conceptual flows models for the fish functional groups of the Northern Basin, which provide spawning, recruitment and movement outcomes, similar flow models were also developed for the Northern Basin systems to assist in meeting maintenance and condition life history outcomes for native fish species (Table 7).

'Maintenance' flow focuses on sustaining fish populations by maintaining refuge habitat and longitudinal connectivity, whilst 'Condition' flow is about supporting pre-spawning and general condition of fish, focusing largely on the productivity of a system. These flow regimes were considered the same for all species due to the similar influence of flow on achieving the two life history outcomes, and largely follow the equivalent natural flow regime for Northern Basin systems.

The conceptual flow regimes for fish have been developed as overarching models for fish species and valleys of the Northern Basin. The determination of specific water requirements to target when developing flow scenarios for different functional groups of fish in the Northern Basin is dependent on the availability of key hydrological, habitat and connectivity information for specific systems. Site specific details such as channel capacities and inundation values for critical habitat features, which influence sustainable native fish spawning, recruitment and movement, will allow particular flow magnitudes, flow volumes and river rise heights to be adapted to the conceptual models. Currently much of this knowledge is lacking across the Northern Basin; however, activities being undertaken as part of the Northern Basin Review will assist in meeting some of these knowledge gaps, whilst prioritising additional areas for future focus.

<u>Table 7</u>: Flow regime requirements, biological assumptions and ecological outcomes that underpin the development of conceptual flow models for 'Maintenance' and 'Condition' flows for all species in the Northern Basin.

Flow regime	Regime requirements	Biological assumptions	Expected ecological outcomes
Maintenance flow	• The hydrograph is sufficient to maintain refuge habitat and/or support longitudinal movement in the system. • May require increased flows over summer periods to maintain critical refuge habitat in the system.	• Historically the system would not have received flows each year; however perennial systems would have always had low base flows, whilst cease-to-flow events intermittent systems would've been of short duration (commonly up to 30 days long). • Hydrodynamic complexity has been achieved in the system from other in-channel and overbank pulse events that create/maintain refuge habitats, reducing the impact of sedimentation on refugia and maintenance flows required. • There are no negative effects of delivering other watering requirements over an extended period (such as black water). • Species requiring high flows to spawn and disperse do not require high flows every year. • Low flow species would benefit from this regime.	• May stimulate other aquatic productivity processes, such as propagation and growth of aquatic plants. • Maintenance of critical refuge habitat. • Opportunities for spawning of Group 2B (Inchannel specialists – flow independent) and Group 4 (Generalists) without provision of environmental water. • Preferences to have an event at least twice per decade.
Condition flow	• Late-winter peak inundates in-channel benches and habitat providing pre-spawning productivity and conditioning for species, as well as longitudinal movement benefits. • Summer peaks provide floodplain inundation, as well as in-channel bench and habitat inundation, providing critical productivity for larvae and juveniles, as well as habitat access, and longitudinal and lateral movement benefits.	• Support pre-spawning and general condition of fish, focussed largely on enhancing productivity of the system. • There are no negative effects of delivering watering requirements over an extended period (such as black water). • Response of Carp minimised by avoiding repeated and frequent floodplain inundation.	• Provide flowing conditions for moderate to large scale longitudinal and lateral fish movement and dispersal throughout the system. • Increased habitat availability and maintenance through hydrodynamic complexity, both in-channel and across lateral habitats (e.g. anabranches) from flow peaks. • Improved productivity at off channel and in-channel habitats throughout the system from flow peaks inundating floodplain. • Opportunities for spawning of Group 1 (Flow dependent specialists), Group 2A (Inchannel specialists – flow dependent), and Group 3 (Floodplain specialists). • Preference is to have a component of the regime occur annually, with large overbank flows occurring a maximum of every three to five years.

4. Valleys of the Northern Basin

4.1 Introduction

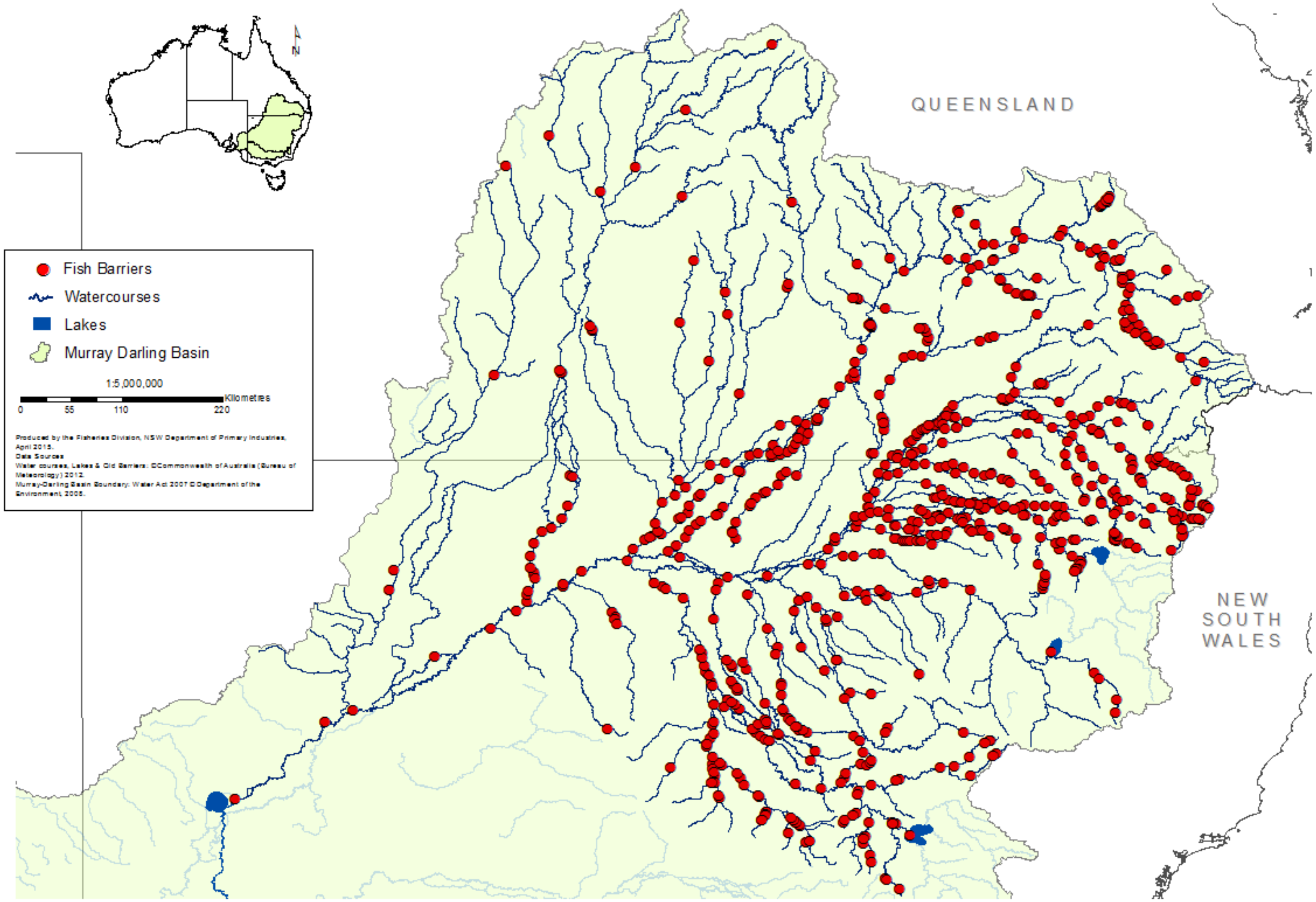
The different hydrological, hydraulic and resource development conditions of the Northern Basin has also resulted in different water management actions when compared to the south. Fewer water storages and more highly variable hydrological connectivity has resulted in the proportion of flows regulated by dams being much lower, with irrigation production primarily relying on the diversion of unregulated flows into privately constructed storages, and as a consequence, there is less opportunity to store held entitlements for directed use.

However, river regulation, including construction of weirs and in-stream infrastructure and offtake to private storages and floodplain structures, has changed the natural hydrograph for many systems in the Northern Basin. Increases in surface water use varies across the Northern Basin, from over 1.5 times the average annual available surface water in the Namoi, to virtually no public storages in the Paroo and Moonie, and very low relative storage in the Warrego and Barwon–Darling, with on-farm storages representing 90% or more of total storage capacity in these systems (CSIRO 2007a-d; CSIRO, 2008a-d).

The infrastructure associated with urban and agricultural development in the Northern Basin, including diversion channels and weirs, is concentrated along the major tributaries, with over 200 weir structures located in the Northern Basin (NSW DPI, 2007; Nichols *et al*. 2012; Figure 5). These structures cause significant modification of the catchment and result in environmental problems such as changes to flow regimes, barriers to fish passage, reduction in water quality, degradation of riparian vegetation, and loss of aquatic habitat.

These structures have varying levels of impacts on native fish within the system, with some structures drowning out more frequently than others to provide suitable fish passage (Cooney, 1994; NSW DPI, 2006a). Tilpa Weir on the Darling River for example is estimated to drown out at flows exceeding 2,400 ML/day at Bourke, providing fish passage approximately 52% of the time, whilst Collarenebri Weir on the Barwon River requires flows in excess of 18,000 ML/day at Collarenebri before drowning out, only providing potential fish passage 4% of the time (NSW DPI, 2006a).

However, the cumulative impact of these weirs along the system impedes natural and managed environmental flows, affecting not only the life histories of native fish but also the condition and hydraulics of upstream and downstream habitats, and seasonal or ephemeral habitats on floodplains and wetlands (Thorncraft and Harris, 2000; Fairfull and Witheridge, 2003; Mallen-Cooper and Zampatti, 2015). The regulation of flows in the Northern Basin has compounded the impact of weirs on river health, and whilst their presence has increased the availability of drought refugia in some areas, these pools are often of poor quality favouring alien fish species.



<u>Figure 5</u>: Instream structures that cause barriers to fish passage in the Northern Murray–Darling Basin.

Water management in the Northern Basin is complex with responsibilities shared between a number of agencies within NSW, Queensland and the Commonwealth. Some of these agencies include NSW Office of Environment and Heritage, NSW Office of Water, NSW Local Land Services, NSW Fisheries, Qld Department of Science, Information, Technology and Innovation, Qld Department of Natural Resources and Mines, Qld Department of Agriculture and Fisheries, MDBA, and Department of Environment (Commonwealth Environment Water Holder).

The increased pressure on water dependent ecosystems in the Northern Basin from river regulation has seen the development of numerous initiatives aimed at maintaining the health of the system whilst accommodating agricultural and urban needs (Thoms *et al*. 2004). One of the major issues in developing water management initiatives that aim to restore river health is the lack of understanding regarding the quantity, timing and quality of water needed to provide ecological benefits (Baumgartner *et al*. 2013). This information is vital to ensure measurable outcomes are achieved within an adaptive framework.

Future arrangements that will guide water management in the Northern Basin includes the MDBAs Basin-wide Watering Strategy (BWS), intended to help environmental water holders, Basin state governments and waterway managers plan and manage environmental watering at a Basin scale and over the longer term (MDBA, 2014a). The BWS includes a number of broad objectives relating to fish outcomes, including:

- Improved distribution of key short and long-lived species across the Basin
- Improved breeding success for short-lived species (every 1–2 years) and long-lived species in at least 8/10 years at 80% of key sites.
- Improved populations of short-lived species (numbers at pre-2007 levels) and long-lived species (with a spread of age classes represented) and Murray cod and Golden Perch (10–15% more mature fish at key sites).
- Improved movement: more native fish using fish passages to be detected in 2019–2023; compared to passage rates detected in 2014–2019 (relevant species to the Northern Basin include Murray Cod, Trout Cod, Golden Perch, Silver Perch and Hyrtl's Tandan).

The BWS identifies a number of 'important environmental assets for fish' across the Basin, including key movement corridors, high biodiversity, sites of other significance, key sites of hydrodynamic diversity, threatened species and dry period/drought refuges. These are detailed in relevant valley chapters within this report, along with specific targets relating to improved distribution for key fish species in the Northern Basin.

The following sections provide summaries of individual valleys for the Barwon–Darling, Condamine–Balonne, Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh, including a general introduction to the valley, barriers to fish passage within the catchment, a summary of BWS objectives and existing flow indicators established by the MDBA, aquatic habitat information, and information on the valley's fish community.

4.2 Barwon–Darling

4.2.1 Introduction

The Barwon–Darling is a large Australian dryland river system with a catchment area of 650,000 km^2 and a main channel length of 3,100 km (Boys and Thoms, 2006). Sixty percent of the catchment has altitudes less than 300 m above sea level, and much of the semi-arid to arid area is covered by floodplains (Boys and Thoms 2006). For the purpose of this project, the system has been defined as the Darling River upstream of Menindee Lakes and the Barwon River to its upstream extent at the Barwon/Macintyre junction, covering approximately 1,500 km of waterway (Figure 6).

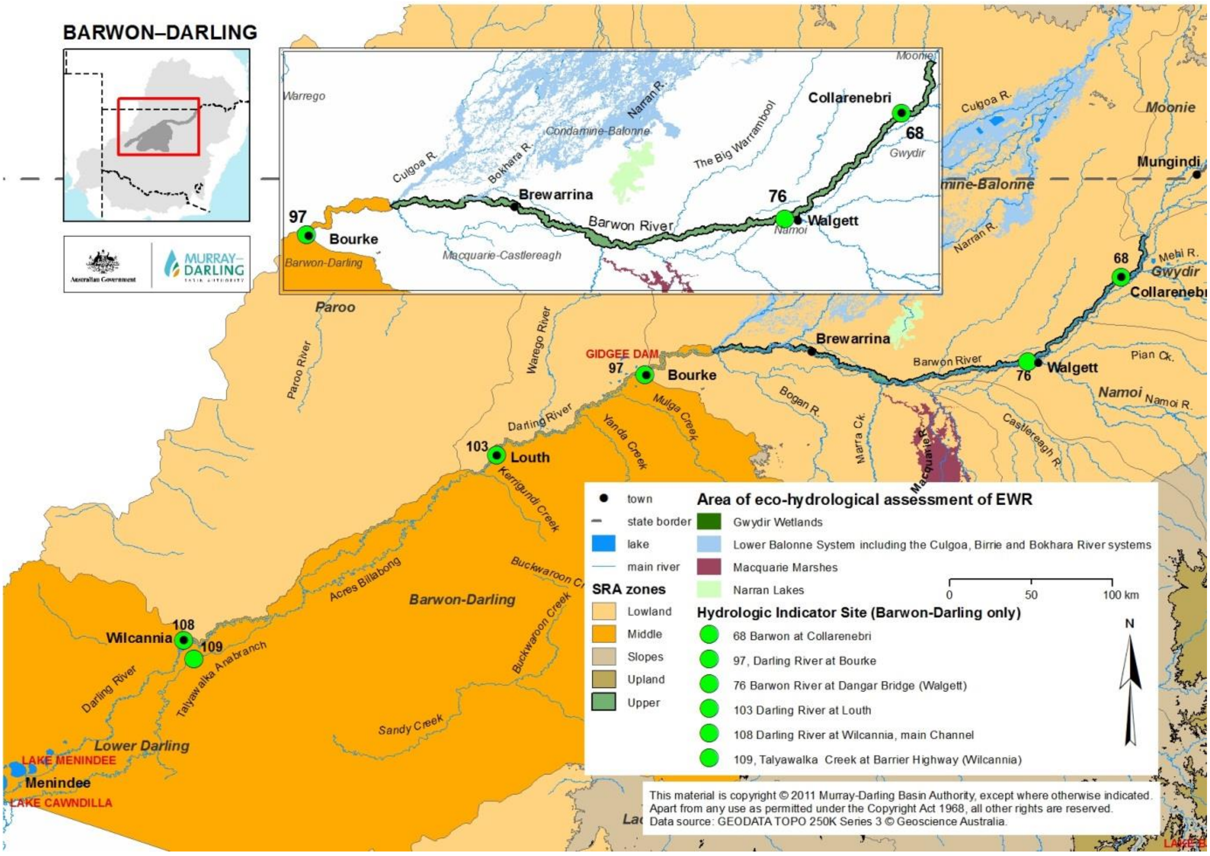


Figure 6: Location and extent of the Barwon–Darling River valley (MDBA, 2012a).

For management purposes the Barwon–Darling system can be divided into three geomorphic zones, including (Thoms, 1996; NSW DPI, 2012c):

- From Mungindi to Walgett the Barwon River has a relatively narrow floodplain with a tightly meandering channel and many in-channel benches. The channel capacity is highly variable, ranging from 4,000 ML/day near Mungindi to 50,000 ML/day upstream of Walgett. River channel capacity increases dramatically downstream of Collarenebri with inflows from the Boomi, Little Weir, Gwydir, Mehi and Moonie rivers. The channel width varies from 40 to 60 m and the depth may be up to 10 m on the channel bends.
- The floodplain widens downstream of Walgett as it flows unrestricted across alluvial plains with few bedrock outcrops to restrict its path. The floodplain is at its widest between Walgett and Bourke. Within this reach the channel becomes less sinuous, but there are many anabranches and effluent channels, which split from and later re-join the main channel. Several large tributaries flow into this reach of the river including the Bokhara, Culgoa, Namoi, Castlereagh, Macquarie and Bogan rivers. The channel capacity increases to more than 80,000 ML/day near Bourke, while the channel width varies from 60 to 80 m and the depth may be up to 20 m.
- Downstream of Bourke the Darling River is strongly influenced by geological controls which determine its course in a southwest direction. The river flows within a deeply incised channel with few channel benches and a narrow floodplain. The channel width is between 60 to 80 m and channel depth up to 25 m. The Darling River enters the Menindee Lakes system at Lake Wetherell, a large artificial storage formed behind the Menindee weir. From here water is diverted into the other main storage lakes of Pamamaroo, Menindee and Cawndilla.

Major tributary valleys of the Barwon–Darling include the Condamine–Balonne, Macintyre, Gwydir, Namoi, Castlereagh and Macquarie Rivers, which enter the system upstream of Bourke; and the Paroo and Warrego Rivers that contribute intermittent flows downstream of Bourke during high rainfall periods (MDBA, 2012a).

The Barwon–Darling valley's population is approximately 50,000 people spread over a vast area, with town centres including Collarenebri, Walgett, Brewarrina, Bourke and Wilcannia (MDBA, 2015a). Agriculture is the region's primary economic activity, with primarily cattle and sheep grazing making up over 94% of all land use (Crabb, 2004; Green and Petrovic 2011a). There is also some dryland cropping and areas of irrigated cropping between Brewarrina and Mungindi. Irrigation activities are focused on cotton, citrus, grapes and vegetables, with around 63,000 ha of land irrigated, including over 57,000 ha for cotton production (CSIRO, 2008a). Irrigation, together with dryland cropping comprises less than 1% of total land use in the catchment (Green and Petrovic 2011a; NSW DPI, 2012b). In 2011 agricultural production contributed $48.2 million to the economy, of which $9.5 million came from irrigated production (MDBA, 2015a). There are around 1,053 local anglers in the catchment and annual expenditure associated with recreational fishing in the Barwon–Darling has been estimated at around $1,994,867 (based on 2012 figures), with an annual consumer surplus of $663,098 (Deloitte Access Economics, 2012; p.63).

The Barwon–Darling is a typical semi-arid Australian river characterised by extreme climatic variability, with low rainfall a feature of the catchment, leading to intermittent flow conditions in many of the river systems. The system's flow regime is characterised by a series of flood events and intervening recessions which can last a few months or occasionally a few years. Despite the semi-arid nature of the river, minor flow events can be expected once or twice a year, and periods of low flow are generally the exception, with the river only stopped flowing 4% of the time (Green and Petrovic, 2011; NSW DPI, 2012b). Major flood peaks exceeding 100,000 ML/day (such as those during the 1950s and 1970s) have occurred every 20 to 30 years, while medium sized floods of up to 50,000 ML/day have occurred once or twice per decade (NSW DPI, 2012b).

Average rainfall in the catchment decreases in a gradient from east to west from around 500 mm in the north near Mungindi to around 200 mm near Broken Hill (Green and Petrovic, 2011; NSW DPI, 2012b). In the north rainfall tends to be summer dominant while southern parts of the catchment receive lower monthly rainfall which is more evenly distributed throughout the year; however, the catchment does receive intense rainfall, which can result in severe and widespread flooding. It is estimated that the system contributes 2.8% of total runoff in the Murray–Darling Basin (CSIRO, 2008). Surface water flows in the system generally increase in volume upstream of Bourke; however, further downstream, flows generally decrease because of the lack of inflows from tributaries and increased rates of evaporation (Thoms *et al*. 2004).

There are over 100 major (greater than 2 m head loss) instream barriers to fish passage located within the Barwon–Darling valley, including weirs, and road crossings, with the majority of these occurring along the main stem Barwon–Darling River upstream of Menindee Lakes to the Macintyre junction (NSW DPI, 2007; Nichols *et al*. 2012; Figure 7). These structures have varying levels of impacts on native fish within the system, with some structures drowning out more frequently than others to provide suitable fish passage; however, the cumulative impact of these weirs along the system impedes natural flow, affecting not only the life histories of native fish but also the condition of upstream and downstream habitats, and seasonal or ephemeral habitats on floodplains and wetlands (Cooney, 1994; Thorncraft and Harris, 2000; Fairfull and Witheridge, 2003; NSW DPI, 2006).

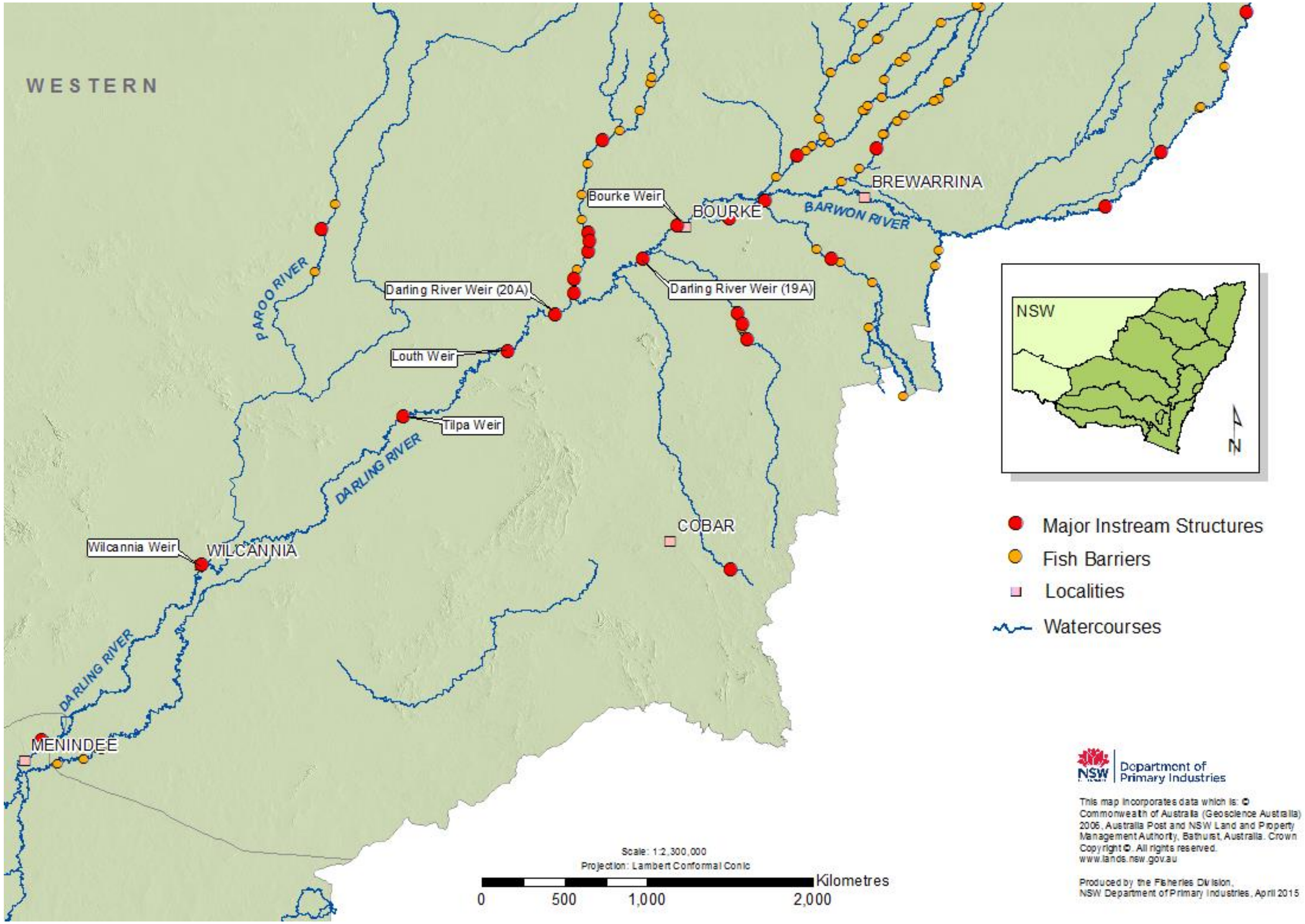


Figure 7: Location of fish passage barriers in the Barwon–Darling valley, highlighting major instream regulating structures.

Within the Barwon–Darling catchment, the BWS identifies the Barwon–Darling river (Menindee to Mungindi) as an important environmental asset on the basis that it provides a key movement corridor, high biodiversity, a key site of hydrodynamic diversity, threatened species and dry period/drought refuge (MDBA, 2014a). The Talyawalka Anabranch is also identified as an important asset as a key movement corridor, key site of hydrodynamic diversity and dry spell/drought refuge (MDBA, 2014a).

In addition, the BWS identifies priorities for increasing distribution of specific native fish species (expansion of existing populations and/or establishment of new populations). Those specific to the Barwon–Darling catchment include:

- Expanding the core range of Silver Perch populations in the Barwon–Darling system; and
- Establishing or improving core range of Southern Purple Spotted Gudgeon by 2–5 additional populations with priority populations including the Barwon–Darling.

The MDBA currently uses nine site-specific flow indicators to define the environmental water requirements of the Barwon–Darling river system. The flow indicators include gauged locations at Wilcannia, Bourke and Louth (Table 8).

The flow indicators for Louth in Table 8 were based on flow thresholds required for inundation of key aquatic habitat known to be an important part of the reproductive cycle for Murray Cod and Golden Perch (MDBA, 2012a; p.18, based on Boys, 2007), with the 10 day flow duration based on the known reproductive requirements of Murray Cod and the mean duration of in-channel flows under modelled without development conditions (MDBA, 2012a; p.20). The flow indicators for nutrient cycling (specified at Bourke) are also relevant for fish outcomes (particularly in terms of maintenance and condition) and were based on flow thresholds required for inundation of in-channel benches between Walgett and Bourke and the mean duration of in-channel flows under modelled without development conditions (Southwell, 2008; MDBA, 2012a). The two events in a year are based on Barwon–Darling system hydrology. The flow indicators at Wilcannia are specified to meet the requirements of the Talyawalka – Teryaweynya Creek system but there is an assumption that the flow indicators will also inundate the wider floodplain of the Barwon–Darling river system. The MDBA is investing in floodplain inundation models that will be able to test this assumption and further analyse the environmental water requirement for floodplain environmental outcomes in the Barwon–Darling river system.

Table 8: Existing site specific flow indicators and associated ecological targets for the Barwon–Darling River upstream of Menindee Lakes (MDBA, 2012a).

Asset	Site-specific ecological targets	Site-specific flow indicators
Floodplain wetlands and vegetation (Talyawalka – Teryaweynya Creek system; flows gauged at Wilcannia on the Darling River)	Provide a flow regime that 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 that supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds. Provide a flow regime that supports recruitment opportunities for a range of native aquatic species. Provide a flow regime that supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain.	30,000 ML/day for a minimum of 21 days between January and December for 20% (high uncertainty) to 25% (low uncertainty) of years. 30,000 ML/day for a minimum of 30 days between January and December for 15% (high uncertainty) to 18% (low uncertainty) of years. A total in-flow volume of 2,350 GL (based on a minimum flow rate of 30,000 ML/day) during January and December for 8% (high uncertainty) to 10% (low uncertainty) of years.
Nutrient cycling (flows gauged at Bourke on the Darling River)	Provide a flow regime that supports recruitment opportunities for a range of native aquatic species. Provide a flow regime that supports key ecosystem functions, particularly those related to longitudinal connectivity.	Minimum of two events of 10,000 ML/day for 5 consecutive days between January and December for 46% (high uncertainty) to 61% (low uncertainty) of years. Minimum of two events of 10,000 ML/day for 17 consecutive days between January and December for 29% (high uncertainty) to 38% (low uncertainty) of years. Minimum of two events of 20,000 ML/day for 5 consecutive days between January and December for 28% (high uncertainty) to 38% (low uncertainty) of years.
Connectivity (flows gauged at Louth on the Darling River)	Provide a flow regime that supports recruitment opportunities for a range of native aquatic species. Provide a flow regime that supports key ecosystem functions, particularly those related to longitudinal connectivity.	Minimum of two events of 5,000 ML/day for 10 consecutive days between January and December for 49% (high uncertainty) to 66% (low uncertainty) of years. Minimum of two events of 10,000 ML/day for 10 consecutive days between January and December for 37% (high uncertainty) to 49% (low uncertainty) of years. Minimum of two events of 14,000 ML/day for 10 consecutive days between January and December for 28% (high uncertainty) to 37% (low uncertainty) of years.

4.2.2 Aquatic habitat of the Barwon–Darling

Habitat features of the Barwon–Darling have been described in NSW DP, 2013a; however it is important to acknowledge that relevant flow related information for key habitat features will be developed as part of the *Fish and Flows in the Northern Basin* project, with details contained herein based on existing information.

In brief, the system includes a diverse range of habitats including deep channels, swamps, floodplains and wetlands as well as niche habitats such as deep pools, riffles, benches, snags, gravel beds, aquatic vegetation and riparian vegetation.

There are many floodplain wetlands in the Barwon–Darling, with a total of 583 wetlands between Mungindi and Menindee, dominated by anabranches in the upper reaches and larger, complex billabongs in the lower sections (Brennan *et al*. 2002). Flood events of up to 50,000 ML/day are considered the most important in connecting these floodplain wetlands with the main channel (i.e. inundation of 90% of wetlands).

The main channel also contains areas of quality in-stream habitat, including deep pools, snags, benches and woody debris. An initial assessment identified 256 benches along two 15 kilometre stretches of the Barwon–Darling River at Walgett and Bourke (Southwell, 2008). Benches can be classes as either low, mid or high based on their position in the channel (Southwell, 2008), with associated inundation thresholds (Table 9).

Table 9: Inundation information for benches identified in the Barwon–Darling at Walgett and Bourke, with flow values measured at Dangar Bridge and Bourke respectively (Southwell, 2008).

Reach	Attributes	Low	Mid	High
Walgett Reach	Flow range (ML/day)	1–2,000	2,000–5,000	5,000–10,000
Walgett Reach	No. of surfaces	67	46	36
Walgett Reach	Surface area (m^2)	18,153	17,250	13,044
Bourke Reach	Flow range (ML/day)	1–5,000	5,000–10,000	10,000–30,000
Bourke Reach	No. of surfaces	38	28	41
Bourke Reach	Surface area (m^2)	10,628	8,066	12,479

Initial habitat mapping between Mungindi and Tilpa also identified over 7,800 pieces of large woody debris of varying levels of complexity and size. This debris is important as habitat for large-bodied native fish species). Thresholds to inundate this habitat vary along the system, ranging from 0 to 106,469 ML/day at Mogil Mogil (Boys, 2007).

Complementing this existing information, detailed habitat mapping is being undertaken as part of the *Fish and Flows in the Northern Basin* project along the Barwon–Darling between Wilcannia and Walgett. Mapping will include the identification of Large Woody Debris, fish barriers, pump sites, stock access points, river access points, tributaries and gullies, riparian woody weeds and aquatic vegetation, refuge habitat, in-channel benches and erosion, with commence-to-inundate heights to be calculated for instream habitat features including large woody debris, benches and channel connectivity. The methodology used to identify benches is limited to be benches that could be observed from the boat, and as a result not all high level benches will have been identified. The analysis during Stage 3 of the *Fish and Flows in the Northern Basin* project will need to acknowledge this limitation when presenting the results of the benches inundated by different flow bands.

As part of the MDBA's Northern Basin Review, mapping and modelling of waterhole persistence and refugia in the Lower Balonne and Barwon–Darling is also being undertaken. This project intends to fill knowledge gaps about the persistence times of refuge waterholes and the relationship between flow and sediment infilling. Selected waterholes in the Barwon–Darling are under review, but include weir pools at Presbury Weir, Barwon Nature Reserve, Collewaroy, Summerville, Jandra (Weir 19A), Hells Gate, Akuna, Weir 20A, Winbar, Nangara Bend, Trevallyn, Wilga and Ellendale (natural pool) (Queensland DSITI and NSW Office of Water, 2015). These waterholes have depth loggers installed to measure water level decline over an extended dry period. This decline will be used to calibrate the waterhole persistence models. The waterhole models can then be used to test the maximum persistence of the individual waterholes and model the persistence of the network of waterholes through the modelling of a flow regime (i.e. model a time series of actual or modelled flow data). The project also includes additional spatial LANDSAT analysis to identify additional Northern Basin waterholes (and their persistence during past no-flow spells) across the Queensland MDB and the Barwon–Darling catchment. This project is likely to produce extra habitat information for the Barwon–Darling.

In recognition of how important a healthy Barwon–Darling River is to the local communities and native fish populations of the Basin, the system has been recognised as a High Conservation Value Aquatic Ecosystem and a demonstration reach has been established between Brewarrina and Bourke (NSW DPI, 2011). Demonstration reaches are large sections of river where multiple, community-driven, activities are implemented to improve in-stream and riparian habitats (Barrett and Ansell, 2005). Demonstration reaches provide an opportunity to showcase the benefit of river rehabilitation activities, empowering local communities to improve river health and achieving significant changes on the ground (Barrett and Ansell, 2005).

Since the establishment of the Brewarrina to Bourke demonstration reach a significant amount of on-ground work has been completed along the reach, including the installation of over 400 pieces of large woody debris; over 8,500 native trees planted; over 100km of weed management undertaken; erosion controlled at 3 priority sites, and; nine off-stream watering points installed (NSW DPI, 2011). Additional mapping of woody debris was undertaken along reach, identifying 7,295 pieces of large wood habitat; however it was estimated that only 10% this habitat was available to native fish for 90% of the time (Boys *et al*. 2013). In addition to this, complementary works, including strategic riparian fencing and the reintroduction of 525 pieces of large woody debris, have also been completed on the Barwon–Darling River at a 60 km reach near Wilcannia. Extensive community engagement has also been undertaken as part of these activities, and a monitoring and evaluation plan has been developed focussing on trends in fish assemblages across the reach (NSW DPI, 2011; Boys *et al*. 2013).

4.2.3 Fishes of the Barwon–Darling

The extensive range of aquatic habitat in the Barwon–Darling River supports a diverse assemblage of aquatic species. A total of 19 fish species inhabit the Barwon–Darling system, including 15 native fish species (Gehrke and Harris, 2004; Table 10). This list was compiled by reviewing current species distributions from the NSW DPI Freshwater Fish Research Database (NSW DPI FFRD) (records collected between 1994 and 2011; NSW DPI, 2012b) as well as Australian Museum records (as cited in Morris *et al*. 2001). The NSW DPI Freshwater Fish Research Database was also analysed to determine fish community health (NSW DPI, 2015; Figure 8).

Table 10: Fishes of the Barwon–Darling valley and associated Northern Basin functional group

(Threatened Species indicated by an asterisk/shaded green and alien species indicated by a hash/shaded red).

Functional group	Species	Zones	Valley comments
Flow Dependent Specialists	Golden Perch	Upper, middle and lower	Appears most common in Zone 3 (Brewarrina – Bourke) of the Barwon–Darling (Boys and Thoms, 2006; p.18). Research on spawning requirements at Menindee Lakes suggests lower spawning temperature (<18.8 °C) than previously recorded and spawning over an extended period (autumn, winter and spring) (Ebner *et al.* 2009; p.575). This is distinct from Southern Basin populations, which generally spawn in spring and early summer (Ebner *et al*. 2009; p.576).
*Flow Dependent Specialists	Silver Perch	Upper, middle and lower	Conservation advice notes that 'no Silver Perch have been sampled in the mid-Darling Rivers since 2002 (Australian Government Department of Environment, 2013; p.12). The species is noted of being 'particular concern' in the Barwon–Darling (encountered at two sites in the upper Barwon (Boys, 2007), and on the Darling River at Bourke and Tilpa) (Boys and Thoms, 2006; p.18; NSW DPI, unpublished data).
Flow Dependent Specialists	Hyrtl's Tandan	Upper, middle	NSW DPI FFRD records species in the Darling River (Bourke, Brewarinna and Louth).
Flow Dependent Specialists	Spangled Perch	Upper, middle and lower	Occurs in northern and western portions of the Murray–Darling Basin (essentially north of Condobolin).
*Inchannel Specialists	Murray Cod (2A)	Upper, middle and lower	National recovery plan identifies 'Border rivers (Barwon and Macintyre) and all major tributaries in NSW' as an important population (National Murray Cod Recovery Team 2010, p.9). Strongly associated with large wood in the Barwon–Darling system (Boys *et al*. 2005). Key asset sites include the Barwon River (Brewarrina and Tilpa) (NSW DPI, unpublished data).
*Inchannel Specialists	Freshwater Catfish (2B)	Upper, middle and lower	Collected on less than 1% of sampling occasions in the Darling (Rourke and Gilligan, 2010; p.7). Primarily recorded in the upper Darling (Rourke and Gilligan, 2010; p.8). Also recorded at Bourke to Tilpa reach (Boys and Thoms, 2006; p.18).
*Inchannel Specialists	Purple Spotted Gudgeon (2B)	Upper, middle and lower	Historical distribution includes the Darling River (NSW DPI, 2013b; p.2).
*Floodplain Specialists	Olive Perchlet	Upper, middle and lower	NSW DPI FFRD records species in the Barwon River (Collymongle Falls) and Darling River (Wilga, Weilmoringle Rd and near Bourke). Western population has significantly declined in recent years (NSW DPI, 2013b; p.1).
Floodplain Specialists	Rendahl's Tandan	Upper	Listed as expected in the Upper Darling system in SRA 2 fish community (Davies *et al*. 2012).
#Floodplain Specialists	Gambusia	Upper, middle and lower	Third most abundant alien species identified in Darling catchment (Davies *et al*. 2012).
Generalists	Australian Smelt	Upper, middle and lower	Common throughout Barwon–Darling system.
Generalists	Bony Bream	Upper, middle and lower	Most numerous species recorded for Darling in SRA 2 (Davies *et al*. 2012; p.223).

Functional group	Species	Zones	Valley comments
Generalists	Carp Gudgeon	Upper, middle and lower	Primarily found in lower Darling in SRA 2, also upper Darling in low numbers (Davies *et al*. 2012; p.223).
Generalists	Flat-Headed Gudgeon	Middle and lower	Not recorded in SRA 2 data (Davies *et al*. 2012; p.223).
Generalists	Unspecked Hardyhead	Upper, middle and lower	Not recorded in SRA 2 data (Davies *et al*. 2012; p.223).
Generalists	Murray–Darling Rainbowfish	Upper, middle and lower	Recorded in all three zones in SRA 2 data (primarily upper zone) (Davies *et al*. 2012; p.223).
#Generalists (alien)	Carp	Upper, middle and lower	Most abundant alien species in the Darling catchment (Davies *et al*. 2012). Hotspots identified in the Barwon upstream of Bourke and Darling between Tilpa and Burtundy (Gehrig and Thwaites, 2013).
#Generalists (alien)	Goldfish	Upper, middle and lower	Second most abundant alien species identified in Darling catchment (Davies *et al*. 2012).
#Generalists (alien)	Redfin Perch	Middle and lower	Included as expected species in previous report on recruitment in the Barwon–Darling (NSW DPI, 2013b).

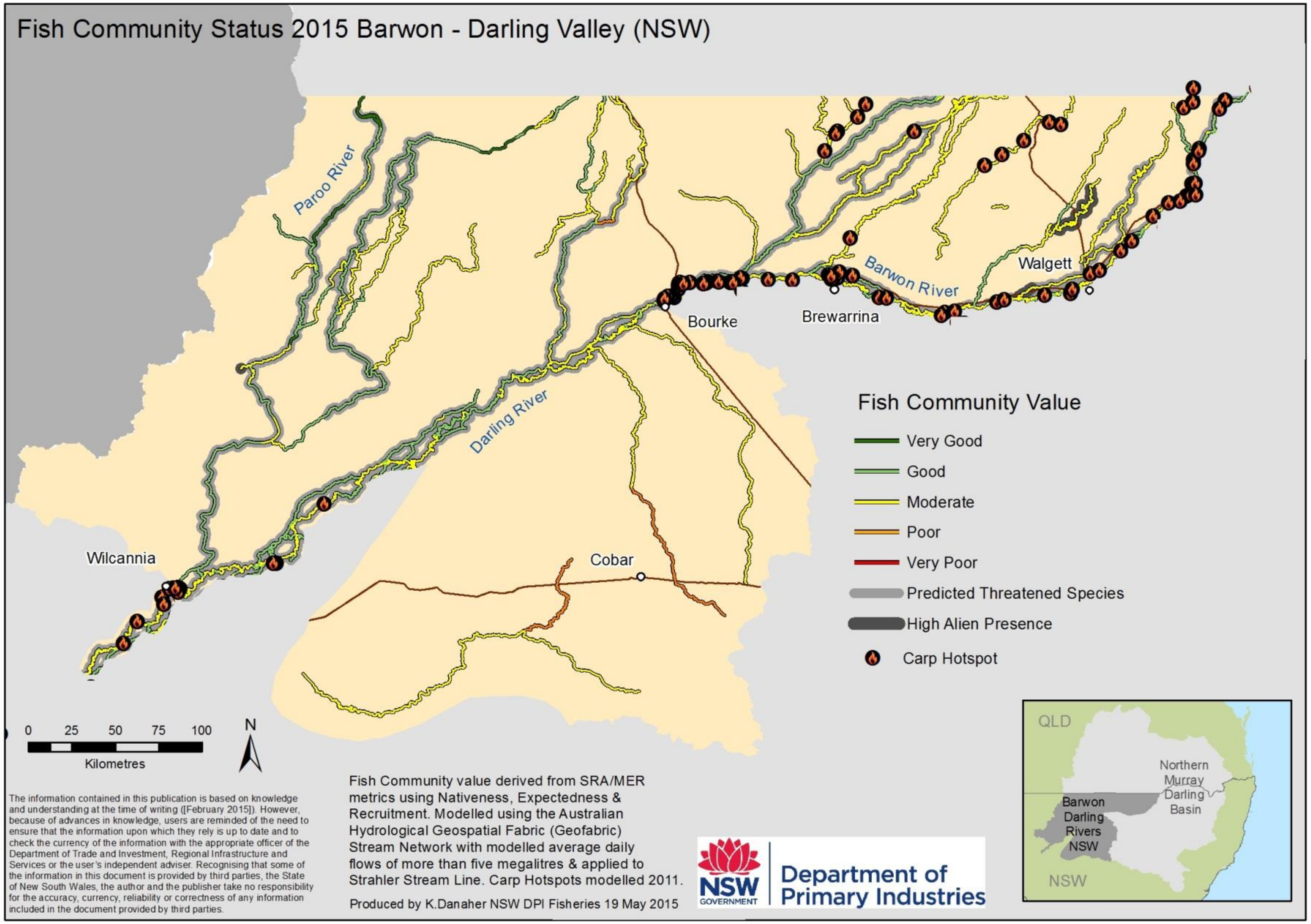


Figure 8: Fish Community Status for the Barwon–Darling valley, highlighting condition of fish communities and Carp hotspots.

Overall, the fish community of the Barwon–Darling Valley is in moderate health, with minimal reaches below poor condition and some parts of the valley, mainly western systems, possessing fish communities in good to very good condition (Figure 8). The valley also contains threatened species distributions, with the predicted range of threatened species covering the length of the Barwon–Darling and Paroo systems, as well as reaches of other major waterways (Figure 8). Many factors have contributed to the deterioration of native fish in the Barwon–Darling valley including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and alien fish species (NSW DPI, 2007); however whilst the majority of the fish community of the valley is in a moderate condition, this provides a strong platform for fish recovery if management actions are developed and implemented appropriately.

Five of the native fish species recorded in the Barwon–Darling valley are listed as threatened in NSW waters (Table 10). Purple Spotted Gudgeon, Freshwater Catfish of the Murray–Darling Basin, and the western population of Olive Perchlet are listed as Endangered under the FM Act 1994, whilst Silver Perch and Murray Cod are listed as Vulnerable under the FM Act 1994 and EPBC Act 1999, respectively. All of these species have an expected distribution in the Barwon–Darling River and associated tributaries, with historical records indicating their presence throughout the area (NSW DPI, 2007; Table 9; Figure 8). In addition to these threatened native fish species, the threatened river snail species *Notopala sublineata* is also listed as an Endangered species in NSW under the FM Act 1994. This species also has an expected distribution in the Barwon–Darling River, and was once widespread in the Murray–Darling Basin; however similar threats to those affecting native fish populations have also resulted in a decrease in the presence of this aquatic species (NSW DPI, 2005).

The Barwon–Darling valley also possesses four alien species that have been introduced into the system from outside their normal range: Carp, Goldfish, Gambusia and Redfin Perch (Table 9). The second report of the SRA found that alien fish found in the Darling Valley river system contributed 35% of the total fish biomass, and represented 16% of all fish recorded in the upper and middle zones of the valley (Davies *et al*. 2012). The most common alien fish captured in the Darling Valley river system was Carp, which represented 10% of all fish recorded in the upper and middle zones of the valley (Davies *et al*. 2012). NSW DPI fish community status mapping identifies a number of areas with a 'high alien presence', including tributaries near Walgett and the Barwon River between Walgett and Brewarrina (Figure 8). Additional separate analyses to examine Carp recruitment across the Basin complements the 'high alien presence' information, identifying a number of areas within the Barwon–Darling, including the mainstem Barwon upstream of Bourke and some tributaries as Carp hotspots (Figure 8). Differences between NSW Fish Community Status mapping of 'high alien presence' and Carp hotspot mapping may be accounted for by different methodologies used by the two projects and the presence of other alien species in the NSW Fish Community Status results. The identification of alien species hotspots also aligns with the identification of Carp hotspots in the Barwon and lower reaches of tributary valleys, and the Darling between Tilpa and Burtundy and including Menindee (Gehrig and Thwaites, 2013; p.19).

4.3 Condamine–Balonne

4.3.1 Introduction

The Condamine–Balonne region is largely located in southern Queensland, spanning the high country in the east to the wide alluvial western plains of the lower Balonne catchment, and containing distinct tablelands, slopes and plains landforms (Figure 9). Nearly two-thirds of the region is comparatively flat, rising in the Great Dividing Range near Warwick and bounded to the west by the Warrego region and to the south by the Border Rivers, Moonie and Barwon–Darling regions.

The Condamine–Balonne has been divided into five distinct geomorphic zones:

- Uplands
- Upper floodplain
- Lower floodplain
- Alluvial fan
- Maranoa valley (McCosker, 1996).

Others have divided the catchment into the upper Condamine (upstream of Loudon); Lower Condamine and upper Balonne (Chinchilla to St George) and Lower Balonne (downstream of St George (Queensland DNR, 2000).

The population of the Condamine–Balonne is approximately 180,000, and includes the major population centre of Toowoomba (approximately 131,258 people), as well as other towns including Dalby, Roma, Chinchilla, Miles and St George (MDBA, undated). The region is one of the most intensively farmed landscapes in eastern Australia, supporting grazing and dryland crops, with more than 112,000 ha irrigated for cotton, grapes, fruit and nuts (CSIRO, 2008b). Coal deposits are leading to an expansion of the mining and energy sectors, both of which have significant water demands. Central Condamine and lower Balonne towns such as St George and Dirranbandi are service towns for farming that are dependent on agriculture. Further upstream, towns such as Roma, which also has an agricultural presence, are expanding due to an increase in the servicing of other industries such as mining and coal seam gas. Significant dryland farming expansion has occurred in the Balonne; however, the region is dependent on water supply to support its agriculture activities and water availability is a contributing factor to the continuity and success of business and the community in these central Condamine and lower Balonne towns (MDBA, undated).

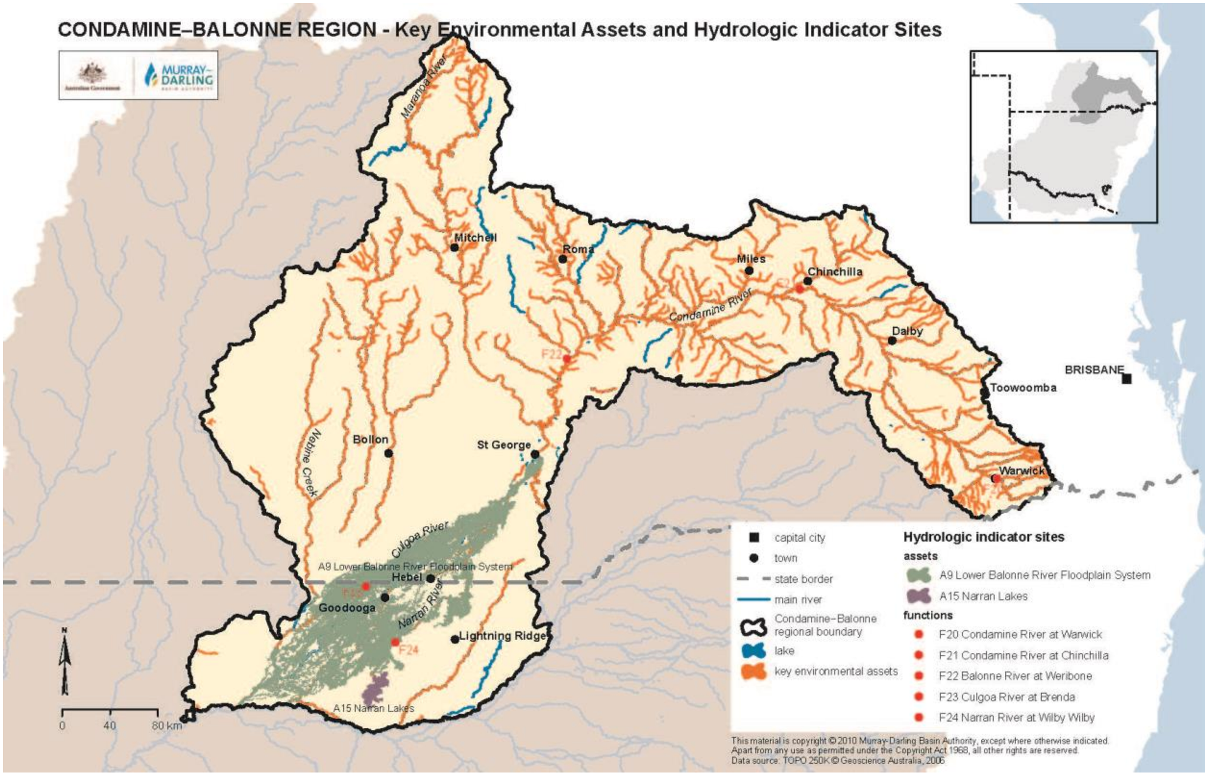


Figure 9: Location and extent of the Condamine–Balonne valley (MDBA, 2012b).

The Condamine–Balonne catchment covers 150,101 km^2 or 14.4% of the Murray–Darling Basin area. Major tributaries include the Condamine, Balonne and Maranoa Rivers, Nebine Creek in the west, which flows into the Culgoa River in northern NSW. The catchment flow discharges either to the

Barwon River (via the Culgoa and Bokhara rivers) or to the terminal lakes and wetlands of the Narran River (Commonwealth Environmental Water Office, undated).

The Lower Balonne is a complex floodplain channel system that is heavily dissected by well-defined channels of various sizes. During flood events these channels carry a significant proportion of the overland flow (Thoms *et al*. 2002). The Balonne River enters the floodplain downstream of Beardmore Dam, flowing through St George and over Jack Taylor Weir. It then travels more than 70 km before splitting into the Culgoa and Balonne Minor Rivers at the so-called 'first bifurcation'. Downstream, the Balonne Minor River subdivides further to form four identifiable streams, the Narran, Bokhara, Ballandool and Birrie Rivers.

The hydraulics of the Lower Balonne resembles that of a delta, with flows of up to 30,000 ML/day at St. George dispersing into many small flood channels (Thoms *et al*. 2002). At higher flows, water spreads out over the floodplain, and a significant portion does not return to the river as a result of evaporation and infiltration into the soil. Consequently, under without-development conditions, the flow crossing the Queensland/NSW border is lower than the flow recorded at St George. The median annual flow at St George is 1,300 GL, but flows are highly variable. The maximum annual recorded flow of 8,000 GL occurred in 1954–55, but extended periods of no-flow occur during droughts. Based on recorded flows, the record period of no-flow exceeds 600 consecutive days (NSW Western Catchment Management Authority 2006).

Floodwaters received in the Balonne River result from rainfall in the northern part of the Condamine–Balonne catchment and occur mainly in summer and autumn (NSW National Parks and Wildlife Service 2003). Flood frequency is highly variable, occurring anywhere between several times a year to once every five years (Sheldon *et al*. 2000). The depth of the floodwater varies from a few centimetres to 10 m and inundation of the floodplain can last for up to four months, during which large amounts of sediment are trapped or deposited onto the floodplain (Smith *et al*. 2006). The main river channels in the Lower Balonne system are very unstable and small changes to the flow can result in significant changes in channel morphology (Smith *et al*. 2006). Sediment movement has increased with an increase in management infrastructure in the upper catchment (Cullen *et al* 2003).

A range of instream barriers to fish movement exist in both the Condamine and Balonne systems, with structures in lower reaches potentially creating greater disturbance for fish populations due to the presence of migratory fish species in the lowland areas (Thorncraft and Harris, 2000; Piltz, 2005; Cox, 2011). Major structures in the valley include Talgai Weir (6.3 m high), Loudon Weir (5.3 m high, with functional fishway), and Chinchilla Weir (10.9 metres high).

Note: due to difficulties in gaining access to information on fish barriers in Queensland systems, this has not been included for the Condamine–Balonne for the purposes of Stage 2 of the Project.

To address current knowledge gaps, the Queensland Department of Natural Resources and Mines (DNRM) are currently compiling a barriers database for use in modelling migratory and flow-spawning fish in the Queensland Murray–Darling Basin (Queensland DNRM 2015, pers comm). With assistance from the Queensland Department of Science, Information Technology and Innovation, this database will be used to calculate drown-out values for specific barriers (Queensland DNRM 2015, pers comm). Information from this review could potentially be used by MDBA and other agencies for the purpose of informing revised EWRs for fish in the Condamine–Balonne in the future.

A number of important environmental assets for fish have been identified in the Condamine–Balonne catchment as part of the BWS process, including:

- The Culgoa junction to St George (including lateral connectivity to the floodplain): key movement corridor, site of high biodiversity, supporting threatened species and as a dry period/drought refuge.

- The Condamine River – Surat to Oakey Creek including lower Oakey Creek: key movement corridor, high biodiversity, key site of hydrodynamic diversity, threatened species and dry period/drought refuges.
- Floodplain lagoons between Condamine and Surat: key movement corridor, high biodiversity, site of other significance, threatened species and dry period/drought refuge.
- Condamine headwaters and Spring Creek upstream of Killarney: key site of hydrodynamic diversity, threatened species and dry period/drought refuge.
- Charley's Creek and tributaries (upstream from Chinchilla): high biodiversity, site of other significance, key site of hydrodynamic diversity, threatened species and dry period/drought refuge (MDBA, 2014a).

In addition, the BWS identifies priorities for increasing distribution of specific native fish species through the expansion of existing populations and/or establishment of new populations. Those specific to the Condamine–Balonne catchment include:

- Silver Perch: improve core range (candidate sites include the Condamine Rivers (including Oakey Creek).
- Freshwater Catfish: Expand core range of at least 3-5 existing populations (candidate sites include the Condamine catchments).
- Olive Perchlet: expand the range (or core range) of at least 3 existing populations (candidate sites include the middle Condamine River) and establish or improve the core range of 2-4 additional populations (candidate sites include Gowrie Creek and Oakey Creek (Condamine tributaries).
- Southern Purple-Spotted Gudgeon: Expand the range (or core range) of at least three existing populations (priority populations include the Condamine) and establish or improve the core range of 2-5 additional populations (priority catchments include Condamine in Oakey Creek).
- River Blackfish: Expand the range of at least two current populations (candidate sites include tributaries of the Condamine).

There are currently ten flow indicators used to inform the MDBA Basin Plan in the Lower Balonne River Floodplain and Narran Lakes, measured on the Culgoa River at Brenda (Lower Balonne) and the Narran River at Wilby Wilby (Narran Lakes) (Table 11).

<u>Table 11</u>: Existing site specific flow indicators and associated ecological targets for the Condamine–Balonne (MDBA, 2012b).

Asset	Site-specific ecological targets	Site-specific flow indicators
Lower Balonne floodplain (flows gauged at Culgoa River at Brenda)	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 the habitat requirements of waterbirds Provide a flow regime which supports a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	1,200 ML/day for a minimum of 7 days (preferably summer/autumn but timing not constrained) with a max period of 1.8 years (low uncertainty) to 2.3 years (high uncertainty) between events. 12,000 ML/day for a minimum of 11 days (preferably summer/autumn but timing not constrained) with an average period of 3 years (low uncertainty) to 4 years (high uncertainty) between events. 18,500 ML/day for a minimum of 9 days (preferably summer/autumn but timing not constrained) with an average period of 4 years (low uncertainty) to 5 years (high uncertainty) between events. 26,500 ML/day for a minimum of 7 days (preferably summer/autumn but timing not constrained) with an average period of 7 years (low uncertainty) to 10 years (high uncertainty) between events. 38,500 ML/day for a minimum of 6 days (preferably summer/autumn but timing not constrained) with an average period of 20 years.
Narran Lakes (flows gauged at Wilby Wilby)	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 the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates). Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	25,000 ML/day for a maximum of 2 months (preferably summer/autumn but timing not constrained) with an average period of 1 years (low uncertainty) to 1.1 years (high uncertainty) between events. 50,000 ML/day for a maximum of 3 months (preferably summer/autumn but timing not constrained) with an average period of 1 years (low uncertainty) to 1.33 years (high uncertainty) between events. 250,000 ML/day for a maximum of 6 months (preferably summer/autumn but timing not constrained) with an average period of 8 years (low uncertainty) to 10 years (high uncertainty) between events. 100,000 ML/day for a maximum of 12 months (preferably summer/autumn but timing not constrained) with a maximum period of 6 years (low uncertainty) to 8 years (high uncertainty) between events. 50,000 ML/day for a maximum of 3 months (preferably summer/autumn but timing not constrained) with a maximum period of 7 years (low uncertainty) to 10 years (high uncertainty) between events.

The in-channel flow indicator for the Culgoa River at Brenda (1,200 ML/day for seven days, with a maximum period between events of 1.8 years (low uncertainty) to 2.3 years (high uncertainty)) was developed to maintain important waterhole refugia in the Lower Balonne. Development of the indicator drew on earlier work from the Moonie River that provided an indication of how long the waterholes can hold water, and a hydrologic assessment to determine what type of flow would be needed to connect waterholes along the entire length of the Culgoa River, which would also benefit fish passage through the Lower Balonne (MDBA, 2012b; pp.20, 25-26; Webb, 2009; QLD DERM, 2010). It is assumed that the other flow indicators for the Lower Balonne (the four overbank indicators) will provide a range of ecosystem functions such as the long term-persistence of fish assemblages (MDBA, 2012b).

Flow indicators for Narran Lakes designed to achieve ecological targets for native vegetation and water birds were assumed to also benefit native fish and other aquatic biota, including provision of cues for spawning, migration and access to food resources (MDBA, 2012b). However, these flow indicators did not consider the needs of individual species or provide detailed conceptual models for fish-flow relationships in the Narran system.

4.3.2 Aquatic habitat of the Condamine–Balonne

While there has not been comprehensive mapping of habitat features in the upper Condamine catchment, work in the Condamine headwaters near Killarney described a range of upland habitat types, including 'true' headwaters (small streams running through a series of pool and riffle habitats along an undulating plateau); gorge environments (a series of pools and rapids), and; slopes environments in Killarney (to Spring Creek-Condamine junction), characterised by slower flowing water in a deeply incised channel through floodplain flats (Butcher and Henderson, 2008). Assessment of riparian condition in these areas suggests it was mixed, with better condition in headwaters followed by gorge environments. Instream habitat complexity was also limited, restricted by absence of woody debris and deep scouring in some pools, particularly in channel bends (Butcher and Henderson, 2008).

Fish habitat mapping has also been undertaken as part of a distribution study on River Blackfish at a number of sites in the Upper Condamine, including Spring Creek and several sites on the Condamine River itself (Balcombe *et al*. 2011). Mapping parameters included stream width, depth, velocity, mud and sand levels, substrates (gravel, cobble, rock or bedrock), macrophyte presence, leaf litter, vegetation (overhanging, submerged, emergent and root masses), undercut banks, large woody debris and small woody debris. The study found that sites where River Blackfish were most abundant ('Butchers Playground', 'Water Supply Road Crossing' and 'Inter-Daggs') had high levels of in-stream structural habitat, made up of a combination of rock, bedrock and wood (Balcombe *et al*. 2011). Sites with high abundance of Blackfish were also shallower than those with lower numbers (Balcombe *et al*. 2011). The Condamine River in this region also tends to have a less complex physical bed structure, apart from a short section (a few km) of forested stream around Double Crossing (Balcombe *et al*. 2011). For the two most downstream and the most upstream Condamine River sites, in-stream structural habitat was largely confined to the presence of wood as the substrate was largely comprised of gravel and finer sediments (Balcombe *et al*. 2011).

Other habitat mapping efforts in the upper Condamine region includes work informing selection of the Dewfish demonstration reach near Dalby and incorporating parts of Myall Creek, Oakey Creek and the Condamine River. The Demonstration Reach falls within the transportation functional process zone (FPZ) of the Condamine Catchment (Thoms and Parsons 2003; SMEC 2008). This FPZ stretches from around Canal Creek, some 45 km north-west of Warwick, to below the confluence of the Condamine River and Dogwood Creek (Balonne River). Within the FPZ, the river channel is active, containing mobile sediments such as silt and sand slugs, overlaying a more stable clay-based substrate. The channel is deeply incised into the surrounding flood plain within a highly modified riparian corridor. Tributary streams and gullies are marked by large deposits of silt where they join the main channel. Submerged vegetation is rare or absent in the main channel due primarily to the high levels of turbidity. Instream mesohabitats include pools, riffles, snags, fallen trees, and smooth banks (Norris *et al*. 2011; p. 4).

The Dewfish Demonstration Reach is comprised of four sections spread over three separate water bodies including Myall Creek from Dalby to the confluence with the Condamine River; The Condamine River between Myall and Oakey Creeks; The Condamine River upstream of the in-flow of Oakey Creek to St Ruths Reserve, near Newtons-Stephens Rd; and Oakey Creek from its confluence with the Condamine River upstream to the St Ruths-Jondaryan Road crossing. The Myall Creek section is characterised as a 'highly modified ephemeral stream', moving downstream through a series of pools and increasing lengths of dry channel before it meets the Condamine River about 3 km downstream of the Loudoun Bridge . The riparian border is highly modified by adjacent land use for urban and agricultural purposes (Norris *et al*. 2011, p. 4). The Condamine River section of the Demonstration Reach runs for approximately 10 km between Myall and Oakey Creeks. It contains long stretches of dry channel, interspersed with semi-permanent waterholes including the Loudoun Weir pool. The channel is deeply incised and the riparian corridor, while often modified, does create a buffer between the river and the adjacent agricultural land use, as well as providing a source for snags (Norris *et al*. 2011, p.5). The Oakey Creek water holes are a series of narrow pools, some extending over a kilometre in length bounded by a highly variable riparian border. In the lower section this border is highly modified by the adjacent agricultural land use. Further upstream the riparian border is better established and functionally more efficient, providing dense thickets of overhanging branches, and a source for the numerous large woody debris in the channel. However, there are areas in both sections of Oakey Creek where unrestricted stock and human access has led to severe bank instability and instream infilling of waterholes (Norris *et al*. 2011, p. 6).

Existing and proposed rehabilitation activities in the Dewfish demonstration reach include:

- Re-opening of the Loudon Weir fishway near Dalby (opening up around 150 km of waterway upstream of the weir, improving connectivity and increased native fish numbers at all intervention sites, including Golden Perch, Hyrtl's Tandan and Dwarf Flat-headed Gudgeon) (Condamine Alliance, undated).
- Re-snagging and introduction of large woody debris on Oakey Creek
- Fencing of riparian vegetation and provision of off-stream watering.
- Re-instatement of small rock ramp fishways and 'drown out ponds' below several minor road crossing barriers.
- Installation of the Edward St Fishway.
- Removal of illegal and obsolete barriers (crossings).
- Investigation of mitigation infrastructure on irrigation pumps.
- Lunkers, logs/rock-ramp and riparian rehabilitation to stabilise banks at key recreation sites, including in Myall Creek near Dalby above the Edward St Weir.
- Installation of storm water retention facilities and swales to reduce intensity of storm water runoff and remove pollutants including rubbish.
- Willow removal
- Integrated Carp control programs at three intervention sites (Norris *et al.* 2011).
- Stocking of Murray Cod and Golden Perch along Oakey Creek (Norris *et al*. 2011).
- Installing or replanting of small and juvenile fish habitat.
- Installation of trial breeding structures for cod.
- Management of illegal fishing (Norris *et al*. 2011; Condamine Catchment Natural Resource Management Corporation Limited, 2012).

As part of the MDBA's Northern Basin Review, mapping and modelling of waterhole persistence and refugia in the Lower Balonne and Barwon–Darling is also being undertaken on behalf of the MDBA. This project intends to fill knowledge gaps about the persistence times of refuge waterholes and the relationship between flow and sediment infilling in the Northern Basin. Selected waterholes in the Lower Balonne included 15 pools in the Culgoa River (Gurrawarra, Warraweena, Caringle, Westmunda (Grogan's Hole), Lilyfield, Weirmoringle, Innisfail, Culgoa NP, Brenda, Brenda Weirpool, Ingie, Cubbie, Woolerbilla GS) and 15 pools in the Narran River (Angledool, Narrandool, Golden Plains, Bomali, Bil Bil, Belvedere, Bangate (Sorrento Hole), Narran Park, Narran Plains, Killarney, Amaroo, Booligah, Clyde, Glenogie and 'GS422206A' (Queensland DSITI and NSW Office of Water, 2015). These waterholes have depth loggers installed to measure water level decline over an extended dry period, which will be used to calibrate the waterhole persistence models. The waterhole models can then be used to test the maximum persistence of the individual waterholes and model the persistence of the network of waterholes through the modelling of a flow time series (i.e. model a time series of actual or modelled flow data). The project also includes additional spatial LANDSAT analysis to identify additional Northern Basin waterholes (and their persistence during past no-flow spells) across the Queensland MDB and the Barwon–Darling catchment. This project is likely to produce extra habitat information for the Condamine–Balonne.

In addition to work being undertaken under the Northern Basin Review, Queensland DNRM is also conducting several 'Waterholes as Refugia' projects in the middle and upper Condamine, including bathymetry and sediment profiling in the middle Condamine. Fifteen loggers have been installed in waterholes between St George and Chinchilla, with another 15 loggers currently being installed between Chinchilla and Warwick (QLD DRNM, 2015, pers. comm.). These projects may also produce relevant information on habitat features in the Condamine–Balonne. However, as these focus on the middle and upland Condamine, information may be less relevant for the purpose of developing revised EWRs in the Northern Basin.

4.3.3 Fishes of the Condamine–Balonne

The extensive range of aquatic habitat in the Condamine–Balonne supports a diverse assemblage of aquatic species. A total of 23 fish species inhabit the Condamine–Balonne system, including 19 native fish species (Table 12).

Table 12: Fishes of the Condamine–Balonne and associated Northern Basin functional group

(Threatened Species shaded green and indicated by an asterisk; alien species are shaded red and indicated by a hash).

Functional group	Species	Zones	Valley comments
Flow Dependent Specialists	Golden Perch	Slopes and lowland	Research in the Condamine and Border Rivers suggests Golden Perch are more likely to move downstream and decreased movement in winter (Hutchison *et al*. 2008). Also more likely to move on natural flows, potentially associated with lunar phase and olfactory cues.
*Flow Dependent Specialists	Silver Perch	Slopes and lowland	No Silver Perch have been sampled by NSW Fisheries in the...Culgoa-Narran...since 2002 (Australian Government Department of Environment, 2013; p.12). Recorded in Condamine River at Warwick (2011); Sunnyside (1998); and in the Lower Balonne (Culgoa River, Lower Plains, Whyenbah Balonne Minor, Donegri Creek). Silver Perch have been recorded in the Narran river (in low numbers) at sites downstream of Narran Park Weir (Rolls and Wilson, 2010; p.826). Silver Perch were also recorded in the Narran ecosystem during the 2004 flood (less than 1% of fish caught) (Thoms *et al*. 2007; p.47).
Flow Dependent Specialists	Hyrtl's Tandan	Slopes and lowland	Not recorded upstream of Warwick. Recorded in the Condamine at Warwick (2010); Rangers Bridge; Springvale Bridge; Barwon River at Surat (2007); St George Reserve Balonne (2013 SRA 3); Woolshed Dam Mungallala Creek (SRA 2); Thundaree, Horse Ck (2010 SRA 2); and off-channel lagoons in the Lower Balonne (Clyde Lagoon, Police Lagoon). Also recorded in Narran River and Lakes (Rolls and Wilson, 2010). Studies in the Lower Balonne and elsewhere (Benson, 2005; Balcombe and Arthington 2009; Rolls and Wilson, 2010; Woods *et al*. 2012; p.85) suggests that species is an 'obligate flood spawner when flood events correspond with ideal water temperature in the summer season, but will not spawn during cold periods (Woods *et al*. 2012; p.85). Research in the Condamine and Border Rivers also suggests adult fish migrate upstream (possibly to spawn), with juveniles moving downstream (Hutchison *et al*. 2008; p.90).
Flow Dependent Specialists	Spangled Perch	Slopes and lowland	Third most abundant native species in SRA 2 for Condamine (Davies *et al*. 2012; p. 187). Research in Condamine and Border Rivers suggests species moves in response to natural, rather than artificial flows (Hutchison *et al*. 2008; p. 63). Movement both upstream and downstream was observed, with significant downstream movements during spring and on falling flows. Some substrate preferences were also observed (sandy substrates used for foraging behaviour). Species also appears to actively migrate to off-channel lagoons on connecting flows.
*Inchannel Specialists	Murray Cod (2A)	Slopes and lowland	Not recorded in Butcher and Henderson, 2008. Recorded in low numbers in lowland zone only (SRA 2). Oral history accounts suggest the species may not have been abundant in Narran system (Salac *et al*. 2012a; p.6), but was commonly caught in the Culgoa-Balonne (Salec *et al*. 2012a; p.12). Not present in some fish surveys for the Narran system (Rolls and Wilson, 2010), but were recorded in earlier surveys (Thoms *et al*. 2007; p.47).
*Inchannel Specialists	Freshwater Catfish (2B)	Slopes and lowland	Collected on less than 1% of sampling occasions in the Darling (Rourke and Gilligan, 2010; p.7). Primarily recorded in the upper Darling (Rourke and Gilligan, 2010; p.8).
Inchannel Specialists	River Blackfish (2B)	Slopes	Species recorded in upland habitats (upstream of Killarney) with recruitment occurring in cobble habitat in deeper pools (Butcher and Henderson, 2008). Species also recorded upstream of Warwick (Balcombe *et al*. 2011), in the mid-Condamine (SRA 1) and Lower Balonne. Not recorded in sampling from Narran Lakes ecosystem (Thoms *et al*. 2007; Rolls and Wilson, 2010).

Functional group	Species	Zones	Valley comments
*Inchannel Specialists	Purple Spotted Gudgeon (2B)	Slopes and lowland	Not recorded in SRA 2 (Davies *et al*. 2012; p.187) or Balcombe *et al,* 2011. Recorded at 'Elbow Valley' (tributary above Killarney) in 1997 and also anecdotally in upper Condamine (Butcher and Henderson, 2008).
*Floodplain Specialists	Olive Perchlet	Slopes and lowland	Recorded in low numbers in slopes zone for SRA 2 (Davies *et al*. 2012). The Australian Musuem records the species at the south end of Lake Narran (Australian Museum, 1999) and on the Narran River near Angledool (Australian Museum, 1975). Research in Condamine and Border rivers suggests some evidence of migration in riverine habitats (adult fish in an upstream direction). Species is strongly associated with lagoon habitats, particularly for recruitment (entry to off-channel habitats potentially related to olfactory cues) (Hutchison *et al*, 2008). Not strictly a wetland species as can breed in the river channel if suitable macrophyte or emergent vegetation is present (Hutchison, 2015; *pers. comm*.).
Floodplain Specialists	Rendahl's Tandan	Slopes and lowland	Expected but not recorded in SRA 2 data (Davies *et al*. 2012; p.187). Recorded in upstream reaches of Dogwood and Charley's Creeks in Condamine catchment). Also recorded from Balonne near St George (Clyde Lagoon, Lower Plains Lagoon, Beardie Lagoon 2008, Chinaman's Creek and Walla Lagoon, Donegri Creek (Narran River) near Dirranbandi and Culgoa River near Balendool. The species has been recorded in low oxygen, high temperature rivers (23-38°C), migrating to lowland lagoons to breed during wet events, possibly to spawn (Lintermans, 2007; Cox, 2011; Hutchison, 2015; *pers. comm.).*
Floodplain Specialists	Darling River Hardyhead	Slopes and lowland	Recorded in SRA1. Not recorded in Lintermans (2007), Butcher and Henderson (2008), or SRA 2.
#Floodplain Specialists	Gambusia	Slopes and lowland	Second most abundant alien species in the Condamine–Balonne catchment (Davies *et al*. 2012).
Generalists	Bony Bream	Slopes and lowland	Meso-movement study in Condamine suggests species is probably not mobile, but may undertake lateral movement into lagoon environments (Hutchison *et al*. 2008).
Generalists	Carp Gudgeon	Slopes and lowland	Abundant in SRA 2 data for both zones (Davies *et al*. 2012). Research in the Condamine and Border rivers suggests species shows some migration (both upstream and downstream, up to 10 km in some cases. There was greater downstream movement on falling flows and peak movements occurring in spring (Hutchison *et al*, 2008; p.44).
Generalists	Flat-Headed Gudgeon	Slopes	Expected but not recorded in SRA 2 data (Davies *et al*. 2012; p.187).
Generalists	Dwarf Flat-Headed Gudgeon	Slopes	Expected but not recorded in SRA 2 data (Davies *et al*. 2012; p.187). Hutchison *et al.* (2008) records species from mid-Condamine (riverine habitats only). Species shows some evidence of downstream movement on falling flows; and potentially upstream movement of up to 11 km by adults (Hutchison *et al*. 2008; p.88).
Generalists	Mountain Galaxias	Slopes	Species reliant on streams with overhanging vegetation, cobble bottom and some flow (Henderson and Butcher, 2008).
Generalists	Unspecked Hardyhead	Slopes and lowland	Recorded in slopes zone only for SRA 2 data (Davies *et al*. 2012; p. 187).
Generalists	Murray–Darling Rainbowfish	Slopes and lowland	Research in the Condamine and Border Rivers suggests species is relatively rare in the mid Condamine (potentially due to lack of backwater macrophytes to complete spawning and recruitment). Strong evidence of recruitment in the late spring and autumn.

Functional group	Species	Zones	Valley comments
			Appears more likely to move on artificial releases rather than natural flows (Hutchison *et al*. 2008). Movement in the Condamine appears more likely on falling or no flows (Hutchison *et al*. 2008).
#Generalists (alien)	Carp	Slopes and lowland	Most abundant alien species in the Condamine–Balonne catchment (primarily lowland zone) (Davies *et al*. 2012).
#Generalists (alien)	Goldfish	Slopes and lowland	Second most abundant alien species in the Condamine–Balonne catchment (Davies *et al*. 2012).
#Generalists (alien)	Redfin Perch	Montane, uplands	Recorded in SRA 1. Not recorded in SRA 2, Lintermans, (2007) or Butcher and Henderson (2008).

The Sustainable Rivers Audit found that the fish community in the Condamine–Balonne was in moderate condition overall, with the slopes community being in moderate condition and the lowland community in poor condition (Davies *et al*. 2012). The fish community was characterised by a poor score for expected native species, a good score for nativeness and a moderate score for native fish recruitment. The slopes zone lacked 50% of predicted native species and the valley had reduced native species richness. Alien species contributed 43% of the biomass in samples. Native fish recruitment was moderate in both the Slopes and Lowland zones and in the valley overall (Davies *et al*. 2012).

With the exception of Golden Perch, there were few large-bodied native fish caught. Bony Herring and Carp Gudgeons were most abundant native species, particularly in the slopes zone, with Spangled Perch also being numerous, particularly in the Lowland Zone. Purple Spotted Gudgeon and Rendahl's Tandan were expected to occur but were not detected (Davies *et al*. 2012).

A number of listed vulnerable or threatened species occur in the catchment, including Silver Perch (expansion of core range in the Condamine, including Oakey Creek is a BWS priority); Murray Cod; Freshwater Catfish; Olive Perchlet; Southern Purple-Spotted Gudgeon and River Blackfish (Table 12). While no listed Queensland threatened species occur in the catchment, connectivity between Queensland and NSW portions of the Condamine–Balonne and with the Barwon–Darling is critical for the wellbeing and improvement of threatened NSW fish populations.

In addition to listed native species, a total of four alien fish species are recorded from the Condamine–Balonne catchment. Carp is the most dominant alien species, particularly in the lowland zone (Davies *et al*. 2012). Gambusia and Goldfish are also present in smaller numbers. Redfin Perch has also been recorded during SRA 1 sampling, but appears rare in the catchment (Butcher and Henderson, 2008). Carp hotspots have also been identified for the distributaries of the lower Condamine–Balonne river (Gehrig and Thwaites, 2013; p.19).

(Note: due to difficulties to gaining access to fish community mapping data this has not been included for the Condamine–Balonne for the purposes of Stage 2 of the Project).

4.4 Border Rivers

4.4.1 Introduction

The Border Rivers region incorporates systems both in NSW and Queensland, covering 45,675 km^2 or 4.4% of the total Murray–Darling Basin, with the NSW portion of the catchment covering approximately 24,500 km^2 (Australian Government Environmental Water Office, undated). The major tributaries of the Border Rivers valley are the Macintyre and Dumaresq Rivers, which ultimately flow into the Barwon River upstream of Mungindi. The Macintyre River's main tributary is the Severn River, whilst the principal tributaries of the Dumaresq River are the Beardy River and Ottley's Creek (Figure 10).

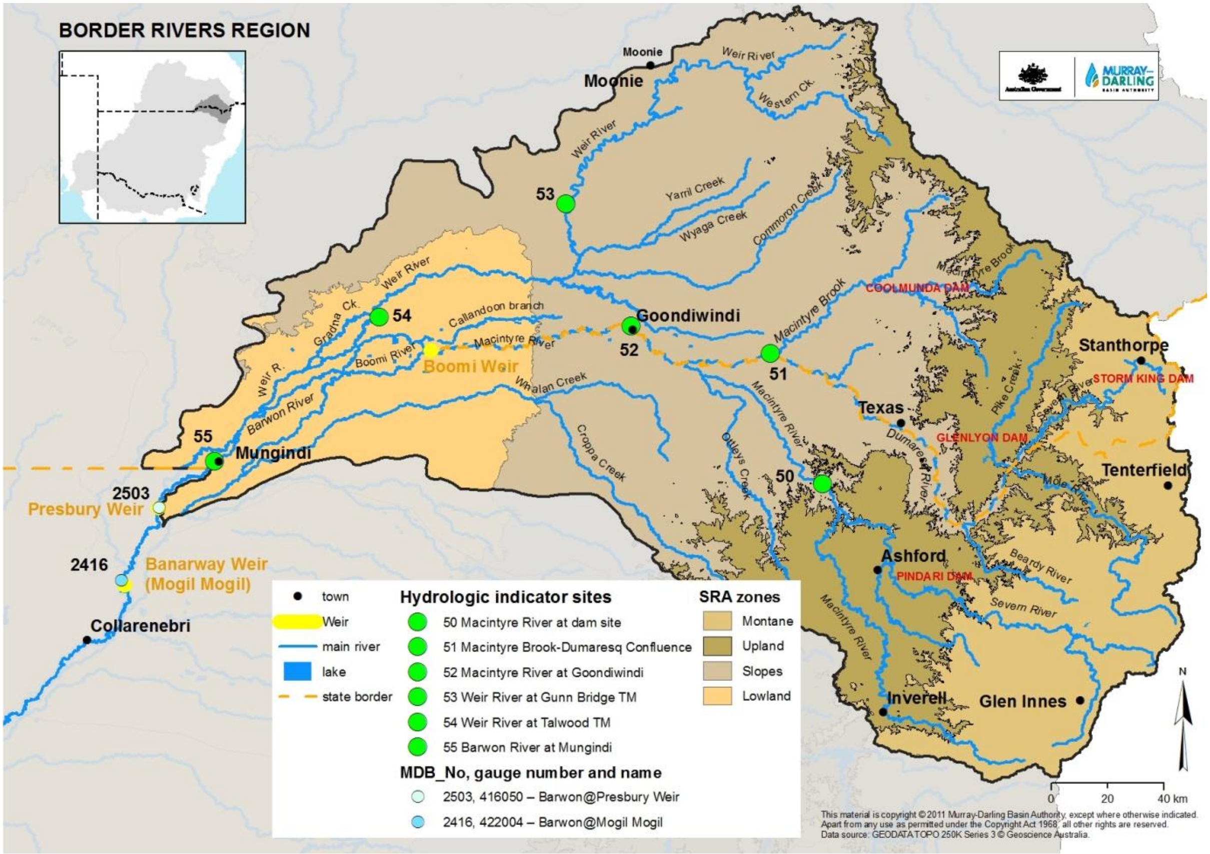


Figure 10: Location and extent of the Border Rivers valley (MDBA, 2012d)

The eastern half of the Border Rivers comprises the ranges and foothills of the Great Dividing Range with elevations from 1,500 m to 500 m in the lower foothills (NSW DPI, 2012d). The south western region of the catchment comprises flat alluvial plains which are drained by a series of intermittent watercourses, the principal ones being Croppa Creek, Whalan Creek and Gil Gil Creek. The elevation across these plains ranges from around 400 m in the eastern extent to just 150 m at Mungindi (NSW DPI, 2012d).

Below Goondiwindi, effluent creeks and anabranches break off the Macintyre River channel and form a meandering complex of billabongs and wetlands across an extensive floodplain. These breakouts include Callandoon and Dingo creeks in Queensland, and Whalan Creek and Boomi River in NSW. Hydrological connectivity of this floodplain area relies on overbank flows. Intermittent connection of anabranches with the rivers stimulates nutrient and carbon cycling (Australian Government Commonwealth Environmental Water Office, 2014).

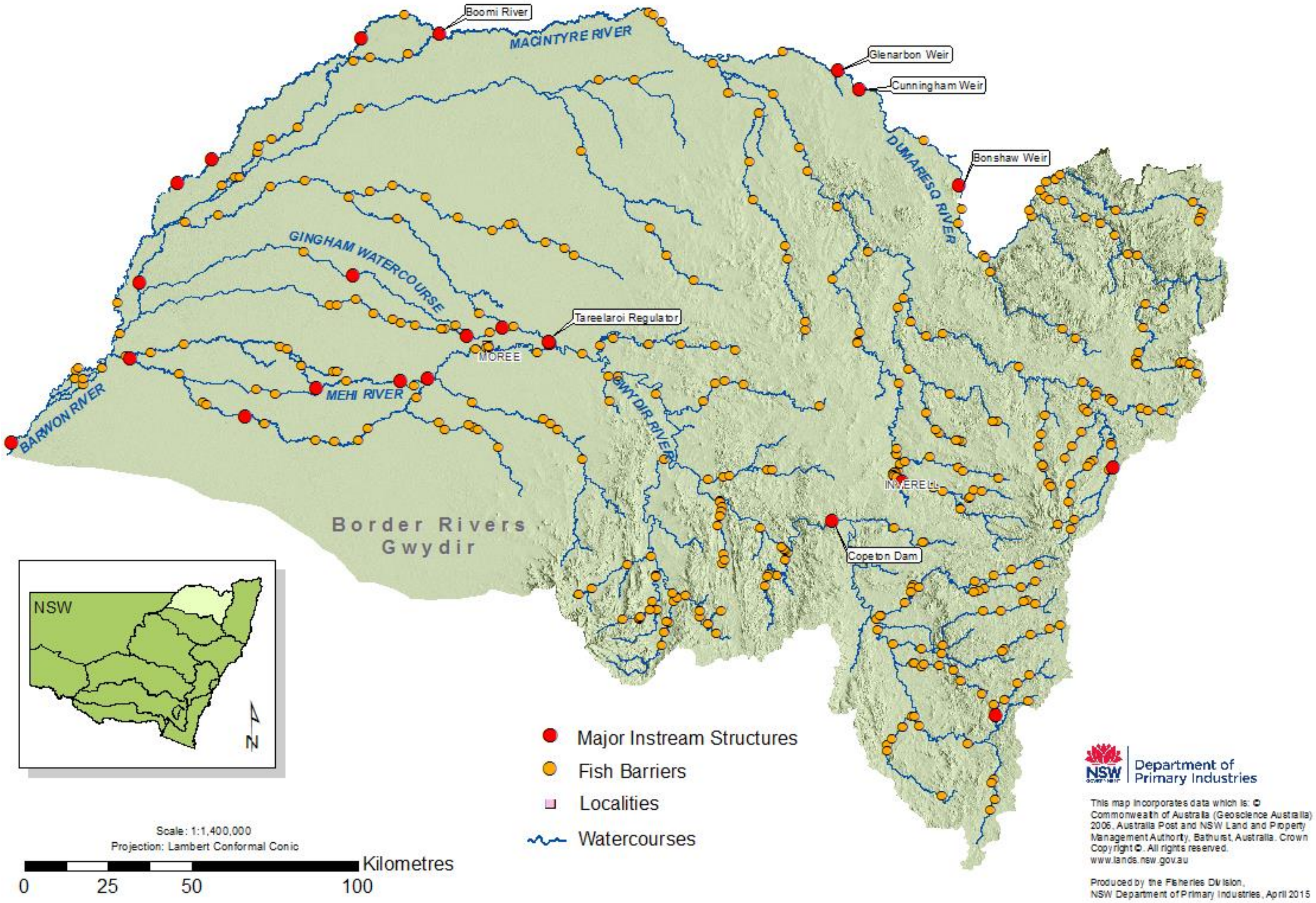
There are many wetlands, billabongs and flood runners associated with the main rivers of the catchment and their tributaries. Boobera Lagoon and the Morella Watercourse are permanent remnants of the previous course of the Macintyre River, fed by flood water from the river approximately once every 10 years (Arthington, 1995). The waterway complex extends some 10.3 km from a point about 13.5 km west of Boggabilla, and in some areas is 150m wide (Arthington, 1995). Other wetlands in this system include Telephone/Malgarai, Rainbow and Maynes Lagoons and Whalan Creek.

This entire wetland complex is recognised as one of very few permanent standing water bodies in the Murray–Darling Basin and is an important recreational area that also supplies irrigation water to local cotton and oilseed farmers (Arthington, 1995). The lagoon wetland system is also highly regarded in Aboriginal culture with many lagoons having significance. Boobera Lagoon is regarded as the home of the Rainbow Serpent by the Boggabilla and Toomelah communities. Many wetlands have multiple-use values, including wildlife habitat, grazing, cropping, stock watering and recreation (NSW Department of Water Resources, 1995). However, as a result of the development of intensive irrigation many of the wetlands now receive less water and are contracting in size (Johnson, 1999).

Collectively, public storages providing regulated supplies in the Border Rivers catchment have a capacity of 635 GL, comprising Pindari Dam on the Severn River in NSW (312 GL), Glenlyon Dam on Pike Creek in Queensland (254 GL) and Coolmunda Dam on Macintyre Brook in Queensland (69 GL), with volumes of private on-farm storages comparable to public storages (Australian Government Commonwealth Environmental Water Office, 2014).

The Border Rivers has a population of over 50,000 people, concentrated in the larger towns of Glen Innes, Inverell, Tenterfield, Stanthorpe, Inglewood, Mungindi and Goondiwindi (MDBA, 2014c). With low salinity, fertile soil and a suitable climate, the Border Rivers region generates hundreds of millions of dollars from agriculture each year; therefore, towns in the region provide numerous jobs for local people servicing agriculture industries. Farming includes wine and table grapes, stone and pome fruit (such as apples), citrus, herbs, vegetables, nuts, pumpkins, melons, potatoes and corn, peanuts, lucerne, winter cereals such as wheat and barley, edible beans, native buds and foliage, crops for feedlots, sheep, cattle, pigs, chickens and cotton, whilst dryland grazing is predominant in the west of the catchment (MDBA, 2014c).

There are over 390 barriers to fish passage in the Border Rivers/Gwydir catchment, including weirs, regulators and road crossings, with major structures in the Border Rivers, including Boggabilla Weir, Boomi Weir and Goondiwindi Weir within the Border Rivers demonstration reach and also Glenarbon Weir, Cunningham Weir and Bonshaw Weir on the Dumaresq River on the border of NSW and Queensland (Queensland Murray–Darling Committee, 2008; Berghuis *et al*. 2013; Figure 11).



<u>Figure 11</u>: Location of fish passage barriers in the Border Rivers and Gwydir valleys (mapped as part of the same catchment in NSW), highlighting major instream regulating structures.

The BWS has identified important environmental assets for fish in the Border Rivers catchment, including:

- Macintyre River – floodplain lagoons between Goondiwindi and Boomi: key movement corridor, high biodiversity, site of other significance, threatened species and dry period/drought refuge.
- Macintyre River – Mungindi to Severn in NSW: key movement corridor, high biodiversity, key site of hydrodynamic diversity, threatened species and dry period/drought refuge.
- Severn River within Sundown National Park: high biodiversity, key site of hydrodynamic diversity, threatened species and dry period/drought refuge.

In addition, the BWS identifies priorities for increasing distribution of specific native fish species (expansion of existing populations and/or establishment of new populations). Those specific to the Border Rivers catchment include:

- Freshwater Catfish: Expand core range of 3-5 existing populations (candidate sites include the Border Rivers).
- Olive Perchlet; Expand range (or core range) of at least 3 existing populations (candidate sites include the Border Rivers).
- Purple-Spotted Gudgeon: Expand the range (or core range) of at least 3 existing populations (priority catchments include Border Rivers/Gwydir) and establish or improve core range of 2-5 additional populations (priority catchments include Border Rivers/Gwydir).
- River Blackfish: Expand the range of at least 2 current populations (candidate sites include upland systems of the Border Rivers) and establish 1-3 additional populations.

There are currently three site-specific flow indicators used to inform the MDBA Basin Plan in the Lower Border Rivers (inchannel flow) measured at Mungindi on the Barwon River (MDBA, 2012d; Table 13).

<u>Table 13</u>: Existing site specific flow indicators and associated ecological targets for the Lower Border Rivers (inchannel flows) (MDBA, 2012d).

Asset	Site-specific ecological targets	Site-specific flow indicators
Lower Border Rivers in-channel flows (flows gauged on the Barwon River at Mungindi)	Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon	4,000 ML/day for a minimum of 5 days between October and December with an event required 32% of years (low uncertainty) to 24% of years (high uncertainty). 4,000 ML/day for a minimum of 5 days between October and March with an event required 59% of years (low uncertainty) to 45% of years (high uncertainty). 4,000 ML/day for a minimum of 11 days (minimum 2 events/year) with an event required 36% of years (low uncertainty) to 27% of years (high uncertainty).

The flow indicators are focused on in-channel flows for the Lower Border Rivers, including:

- Inundation required for key habitat such as:
    - anabranches (Thoms *et al*. 2005; Reid, 2006; CSIRO, 2007; MDBA, 2012d).
    - large woody debris such as snags and fallen timber (Queensland DNR and NSW DLWC, 1999; Boys, 2007; MDBA, 2012d).

- Nutrient cycling, including inundation of benches and other in-channel environments (McGinness *et al*. 2002; Thoms *et al*. 2005; MDBA, 2012d).
- Needs of native fish, including Murray Cod (through inundation of key aquatic habitat) and Golden Perch (through inundation of key habitat and flow variability in spring and summer) (MDBA, 2012d).

4.4.2 Aquatic habitat of the Border Rivers

The Border Rivers region has been classified into:

- Upper foothills and sediment source zone (400-600 m ASL): between Stanthorpe, Inverell, Texas and Wallangara (including parts of Macintyre Brook, Dumaresq River, Macintyre and Severn River). Aquatic habitat in these zones are predominantly pool and riffle habitats with semi-permanent flowing clear water and submerged aquatic vegetation (Butcher, 2007).
- Lower foothills/sediment zone (150-400 m ASL) between the upper foothills zone and Toobeah on the Macintyre River. This region is characterised by a network of pools, intermittently connected during floods. Sides of pools are often clay or mud, with bottoms covered with sand or silt. Areas of bedrock and rubble are common. Waters are quite turbid and submerged aquatic vegetation is patchy (Butcher, 2007).

The floodplain between Goondiwindi and Mungindi contains a large number of anabranches and billabongs (CSIRO, 2007c). Downstream from Goondiwindi small effluent creeks such as Boomi, Callandoon, Dingo and Whalan Creeks break off from the main channel and meander across the region forming a complex floodplain of billabongs and wetlands that rely on overbank flows (Kingsford, 1999). When flooded, these areas are known to provide large amounts of dissolved organic carbon to the riverine ecosystem which is essential to aquatic ecosystem functioning (CSIRO, 2007c). The anabranches and billabongs of the Macintyre River floodplain are important geomorphological assets.

Habitat diversity is an important determinant for community diversity, and channel habitat diversity for the entire Border Rivers catchment is rated low to very low (NSW DNRW, 2002). However, a small percentage of the stream length in the Macintyre River and Severn River sub-catchment (2%) and in the Dumaresq River sub-catchment (4%) was observed to have high channel habitat diversity. Pools were observed to be the most common habitat type recorded throughout the catchment, followed by runs (NSW Department of Natural Resources and Water, 2002; Australian Wetlands Pty Ltd, 2009).

Existing research on habitat in the Border Rivers includes mapping of 69 anabranch channels on the Macintyre River between Goondiwindi and Boomi (Thoms *et al*. 2005; MDBA, 2012d; p.11); and commence to flow thresholds for anabranches in the floodplain between Goondiwindi and Mungindi (Reid, 2006). Boys (2007) also mapped the location of 7,812 large wood pieces across 12 study reaches located between Mungindi and Tilpa and estimated their commence-to-inundate height. In the study reach downstream of Mungindi (between Presbury Weir and Collarenebri), Boys (2007) identified 1,873 large wood pieces and reported that these became progressively inundated at flows up to 20,000 ML/d (gauged at Mogil Mogil) (MDBA, 2012, p.12). Limited habitat information appears to have been produced for the Border Rivers region since the MDBA released its EWR report.

The Border Rivers Demonstration Reach comprises approximately 335 kilometre of river between Mungindi and Glenlyon, with three phases focusing on stretches between Glenlyon and Texas (Phase 1), Texas to Goondiwindi Weir (Phase 2) and Goondiwindi Weir (Phase 3) (Australian Wetlands, 2009). On-ground activities haven't been undertaken as yet; however key rehabilitation and maintenance aspirations under the Reach include:

- Investigation of options to address cold water pollution at Glenlyon Dam.
- Investigation and implementation of fish passage options at Boggabilla Weir, Cunningham Weir, Texas Town Weir, Glenarbon Weir, Bonshaw and Boomi Weirs.
- Study to investigate extent of large woody debris throughout the demonstration reach, identify areas requiring re-snagging and other habitat enhancement.

- Wetland rehabilitation.
- A sedimentation and sand-mining study.
- Riparian fencing and rehabilitation and identification of sediment sources.
- Willow identification study and removal (whole reach).
- Implementation of a Carp cage at Boggabilla and pest fish control week.
- Increased efficiency program for on-farm water delivery systems and actions to reduce fish diversions into off-takes.
- Development of a catchment-scale and area-wide approach to stocking (Australian Wetlands Pty Ltd, 2009; p.43).

NSW DPI has also identified a number of important assets for native fish in the Border Rivers catchment, including:

- Deepwater Creek (Purple Spotted Gudgeon population)
- Dumaresq and Barwon Rivers (Mingoola to Goondiwindi, including stretch between Bengalla and Yellowbank Reserves, and Bonshaw) (High biodiversity, including Freshwater Catfish, Olive Perchlet and Purple-spotted Gudgeons).
- Lower Macintyre River at Booberoi Lagoon property (40 km downstream of Goondiwindi) (Low lying lagoons that support breeding sites for Purple Spotted Gudgeons, and also includes Freshwater Catfish, Olive Perchlet and Murray Cod)
- Macintyre River above Macintyre Falls near Ashford (Carp free catchment, abundant Catfish and Murray Cod)
- Severn River (Strahbogie to Pindari Dam) (Near natural habitat that includes Murray Cod, Silver Perch and Freshwater Catfish, and is Carp free).
- Severn-Macintyre River (High biodiversity, including Olive Perchlet and Purple Spotted Gudgeons)
- Tenterfield Creek (Murray Cod and Purple Spotted Gudgeons).

4.4.3 Fishes of the Border Rivers

The extensive range of aquatic habitat in the Border Rivers valley supports a diverse assemblage of aquatic species. A total of 20 fish species inhabit the waterways of the valley, including 16 native fish species (Gehrke and Harris, 2004; Table 14). This list was compiled by reviewing current species distributions from the NSW DPI Freshwater Fish Research Database (records collected between 1994 and 2011; NSW DPI, 2012b) as well as Australian Museum records (as cited in Morris *et al*. 2001). The NSW DPI Freshwater Fish Research Database was analysed to determine fish community health (NSW DPI, 2015; Figure 12).

Table 14: Fishes of the Border Rivers valley and associated Northern Basin functional group

(Threatened Species shaded green and indicated by an asterisk; alien species shaded red and indicated by a hash).

Functional group	Species	Zones	Valley comments
Flow Dependent Specialists	Golden Perch	Upland, slopes and lowland	Identified as 'widely distributed' within the Macintyre-Dumaresq River system, but more common in the Macintyre than Dumaresq River (potentially due to Queensland stocking programs) (Butcher, 2007; p. 21). Research on 'meso-movement' of fish species in the Border Rivers catchment suggests juvenile golden perch may be more mobile on natural flows than on artificial flow releases (with odours in runoff potentially triggering migration) (Hutchison *et al*. 2008; p.xi).
*Flow Dependent Specialists	Silver Perch	Upland, slopes and lowland	NSW DPI FRRD records species in Severn, Macintyre, Barwon and Boomi Rivers. The species has a relatively wide distribution in the Border Rivers catchment (partly due to local stocking programs) but rare abundance (Butcher, 2007; p.12). Potential knowledge gaps for the species in the Border Rivers catchment includes need for improved information on distribution (Butcher, 2007; p.35). Part of meso-scale movement study, but only one individual recorded (Macintyre zone) (Hutchison *et al*. 2008; p.17). Key asset sites include Severn River (Strathbogie to Pindari Dam).
*Flow Dependent Specialists	Spangled Perch	Upland, slopes and lowland	Widely distributed within the Macintyre-Dumaresq River system, but is more abundant in the Macintyre than the Dumaresq River (Butcher, 2007; p.18).
*Inchannel Specialists	Murray Cod (2A)	Upland, slopes and lowland	Recorded in all zones (including montane) in SRA 2 data (Davies *et al*. 2012; p.46). National Recovery Plan identifies 'Border rivers (Barwon and Macintyre) including all major tributaries in NSW' as important population based on 'population size/integrity etc, regional importance and quality fish community' (National Murray Cod Recovery Team, 2010; p.9). The Queensland Border rivers population are also identified as important populations (based on 'regional important representative upland population) and some evidence that there was once a genetically distinct population in the Macintyre and Beardy Rivers'. Widely distributed and reasonably common within the Border Rivers region, but difficult to tell if this is a result of natural populations, or the stocking programs (Butcher, 2007; p.19). Key asset sites include Lower Macintyre River at Booberoi Lagoon; Macintyre River above Macintyre Falls near Ashford; Severn River (Strathbogie to Pindari Dam); and Tenterfield Creek.
*Inchannel Specialists	Freshwater Catfish (2B)	Montane, upland, slopes and lowland	Recorded in SRA 2 data (montane, upland and slopes zones) (Davies *et al*. 2012; p.46). Detected for around 45% of sampling occasions in the Border Rivers (Rourke and Gilligan, 2010; p. 7). The only inland waterways that still support substantial populations are those upstream of dams or waterfalls that Carp have not invaded (Rouke and Gilligan, 2010; p.7). Some research also suggests that the species does not utilise artificial storages (Lutton, 2009). Noted as 'widely distributed throughout the Macintyre and Dumaresq Rivers and common in the Macintyre and abundant in the Dumaresq' (Butcher, 2007; p.28). Moderate remnant populations in the Border Rivers catchment upstream of Goondiwindi (Fisheries Scientific Committee, 2008; p.1). Key asset sites include Dumaresq and Barwon Rivers (Mingoola to Goondiwindi, including stretch between Bengalla and Yellowbank Reserves, and Bonshaw; Lower Macintyre River at Booberoi Lagoon; Macintyre River above Macintyre Falls near Ashford, and; Severn River (Strathbogie to Pindari Dam).

Functional group	Species	Zones	Valley comments
Inchannel Specialists	River Blackfish (2B)	Montane and upland	Remnant populations noted in 'uplands zones of the Condamine and Border Rivers of Queensland and NSW, including upper reaches of the Dumaresq River and Macintyre (Moffatt and Voller, 2002; Butcher, 2007; p.15). Potential knowledge gaps for the species in the Border Rivers catchment includes information on reproductive cues and larval habitat (Butcher, 2007; p.35). SRA1 data records species at upper Severn River (Bald Creek).
*Inchannel Specialists	Purple Spotted Gudgeon (2B)	Montane, upland, slopes and lowland	Recorded (low numbers) in slopes zone for SRA 2 data (Davies *et al*. 2012; p. 46). Noted as 'locally abundant' in the Border Rivers catchment (Lintermans, 2007; p.101), primarily in areas above 240 m sea level on the Dumaresq River (Butcher, 2007; p. 8, 23). A research project on fish species present at Tenterfield Creek (focusing on the Purple Spotted Gudgeon) suggests the species is 'relatively abundant' (primarily at Log Hut Creek) (Lewis and Gowns, 2012; p.5, 6). Further work on fish habitat availability and suitability in Tenterfield Creek is also being conducted in a collaborative project between the NSW Office of Water and the University of New England (Lewis and Gowns, 2012; p.6; Birch *et al*. 2013). Key asset sites include Deepwater Creek, Dumaresq and Barwon Rivers (Mingoola to Goondiwindi, including stretch between Bengalla and Yellowbank Reserves, and Bonshaw, Lower Macintyre River at Booberoi Lagoon property, Severn-Macintyre River and Tenterfield Creek.
*Floodplain Specialists	Olive Perchlet	Upland, slopes and lowland	Recorded in low numbers in upland zone for SRA 2 data (Davies *et al*. 2012; p.46). NSW DPI FFRD records species at Severn River, Little Oaky Creek, Mole River, Pike Creek, Dumaresq River, Tenterfield Creek, Boomi River, Macintyre River, Barwon River and Little River Weir. Described as 'locally abundant' in the Border Rivers catchment (Lintermans, 2007; p.71). Has been recorded in the Dumaresq and Macintyre Rivers (Morris *et al*, 2001), but is quite rare in both distribution and abundance for these systems (Butcher, 2007: p.10). Work on 'meso-scale' movements of fish in the Border Rivers catchment (Macintyre River), particularly suggests access to lagoon habitats is particularly important for the species' survival (need to assist serial connection of lagoon habitats during the reproductive season) (Hutchison *et al*. 2008; pp.73-76). Lateral movement may be associated with chemicals liberated from rewetted lagoon sediments (Hutchison *et al*. 2008; p.95). Key asset sites include Dumaresq and Barwon Rivers (Mingoola to Goondiwindi, including stretch between Bengalla and Yellowbank Reserves, and Bonshaw; Lower Macintyre River at Booberoi Lagoon property; and Severn-Macintyre River.
Floodplain Specialists	Darling River Hardyhead	Montane, upland and slopes	Species is 'patchily distributed (Lintermans, 2007; p.58). Relatively abundant in Macintyre-Dumaresq systems, but with a restricted distribution (upper foothill waters) (Butcher, 2007; p.9, 13). Potential knowledge gaps for the species in the Border Rivers catchment include physiological tolerances, migration, reproductive cues, spawning, larval and juvenile habitats and diet (Butcher, 2007; p.35).
#Floodplain Specialists	Gambusia	Montane, upland, slopes and lowland	Recorded in SRA 2 (montane, upland, slopes and lowland zones). Most abundant alien species recorded in Border Rivers catchment for SRA 2 (primarily montane zone) (Davies *et al*. 2012; p.146). Widely distributed throughout the Macintyre and Dumaresq Rivers but are far more abundant in the Dumaresq River than the Macintyre (Butcher, 2007).

Functional group	Species	Zones	Valley comments
Generalists	Australian Smelt	Montane, upland, slopes and lowland.	Widely distributed and relatively common in the Macintyre and Dumaresq Rivers (Butcher, 2007; p.27). Potential knowledge gaps for the species in the Border Rivers catchment include information on reproductive cues and juvenile habitat (Butcher, 2007; p.35). Research on 'meso-scale movements' of fish in the Condamine and Border Rivers catchments suggests this species is probably not mobile (Hutchison *et al*. 2008; p.93).
Generalists	Bony Bream	Upland, slopes and lowland	Widely distributed in the lowland and lower foothills zones of both the Macintyre and Dumaresq Rivers, but is much more abundant in the Macintyre River (Butcher, 2007; p.24). Potential knowledge gaps for the species in the Border Rivers catchment include information on larval and juvenile habitat (Butcher, 2007; p.35). Research on 'meso-movement' of fish species in the Border Rivers catchment suggests juveniles may be more mobile on natural flows than on artificial flow releases (with odours in runoff potentially triggering migration) (Hutchison e*t al*. 2008; p.xi).
Generalists	Carp Gudgeon	Montane, upland, slopes and lowland.	Hypseleotris spp. are one of the most widely distributed and abundant species within the Macintyre-Dumaresq River system. They have also been widely translocated (Butcher, 2007; p.17). Potential knowledge gaps in the Border Rivers catchment for the 'Carp Gudgeon complex' include physiological tolerances within the system and information on migration and larval habitat (Butcher, 2007; p.35). Research on 'meso-scale' movements of this species in the Border Rivers suggests sub-adults and juveniles are more mobile on natural flows than regulated events. On falling flows, species also tends to migrate downstream. Peak movement occurred in spring (Hutchison *et al*. 2008; p.xi).
Generalists	Flat-Headed Gudgeon	Slopes	Only been found in the lower foothill waters of the Macintyre River and appears to be quite rare in the Border Rivers region of the Murray–Darling Basin (Butcher, 2007).
Generalists	Mountain Galaxias	Montane, upland and slopes.	Recorded in low numbers in upland zone for SRA 2 data (Davies *et al*. 2012). Usually restricted to upper foothill waters (greater than 600 m ASL) in the Macintyre-Dumaresq River system (Butcher, 2007; p.8). Quite rare in the Macintyre River system, being restricted to waters higher than 400 m. The species is much more common in the upper regions of the Dumaresq River system (Butcher, 2007; p.16). Potential knowledge gaps for the species in the Border Rivers catchment include improved distribution data, physiological tolerances and reproductive cues (Butcher, 2007; p.35).
Generalists	Unspecked Hardyhead	Upland, slopes and lowland	Has a wide distribution within the Border Rivers region and has a relatively low, but not rare, level of abundance (Butcher, 2007; pp.13-14). Potential knowledge gaps for the species in the Border Rivers catchment includes distribution data (currently patchy) and need for improved knowledge of reproductive cues and spawning, larval and juvenile habitat (Butcher, 2007; p.35).
Generalists	Murray–Darling Rainbowfish	Upland, slopes and lowland	Widely distributed in the lowland and lower foothills zones of both the Macintyre and Dumaresq Rivers, but is much more abundant in the Macintyre River (Butcher, 2007; p.24). Potential knowledge gaps for the species in the Border Rivers catchment include information on larval and juvenile habitat (Butcher, 2007; p.35). Research on 'meso-movement' of fish species in the Border Rivers catchment suggests juveniles may be more mobile on natural flows than on artificial flow releases (with odours in runoff potentially triggering migration) (Hutchison *et al*. 2008; p.xi).

Functional group	Species	Zones	Valley comments
#Generalists (alien)	Carp	Upland, slopes and lowland	Recorded in SRA 2 (upland, slopes and lowland zones, more in lowland zone) (Davies *et al*. 2012; p.146). More common in Dumaresq River than Macintyre system (Butcher, 2007). Several Carp-free catchments have been identified in the Border Rivers, including Severn River (Strathbogie to Pindari Dam) and Macintyre River above Macintyre Falls near Ashford.
#Generalists (alien)	Goldfish	Montane, upland, slopes and lowland	Recorded in SRA 2 (montane, upland, slopes and lowland zones) (Davies *et al*. 2012; p.146). Widely distributed in both the Macintyre and Dumaresq Rivers and common in both river systems (Davies *et al*. 2012).
#Generalists (alien)	Redfin Perch	Montane zone	Recorded in SRA 2 (montane zone only) (Davies *et al*. 2012; p.146). Found in head waters of the Dumaresq (Beardy River) and the Macintyre Rivers (NSW Severn River), usually higher than 700 m ASL, but have also been recorded from upper foothill waters as low as 240 metres ASL (Figure 22) during colder months of the year (Butcher, 2007).

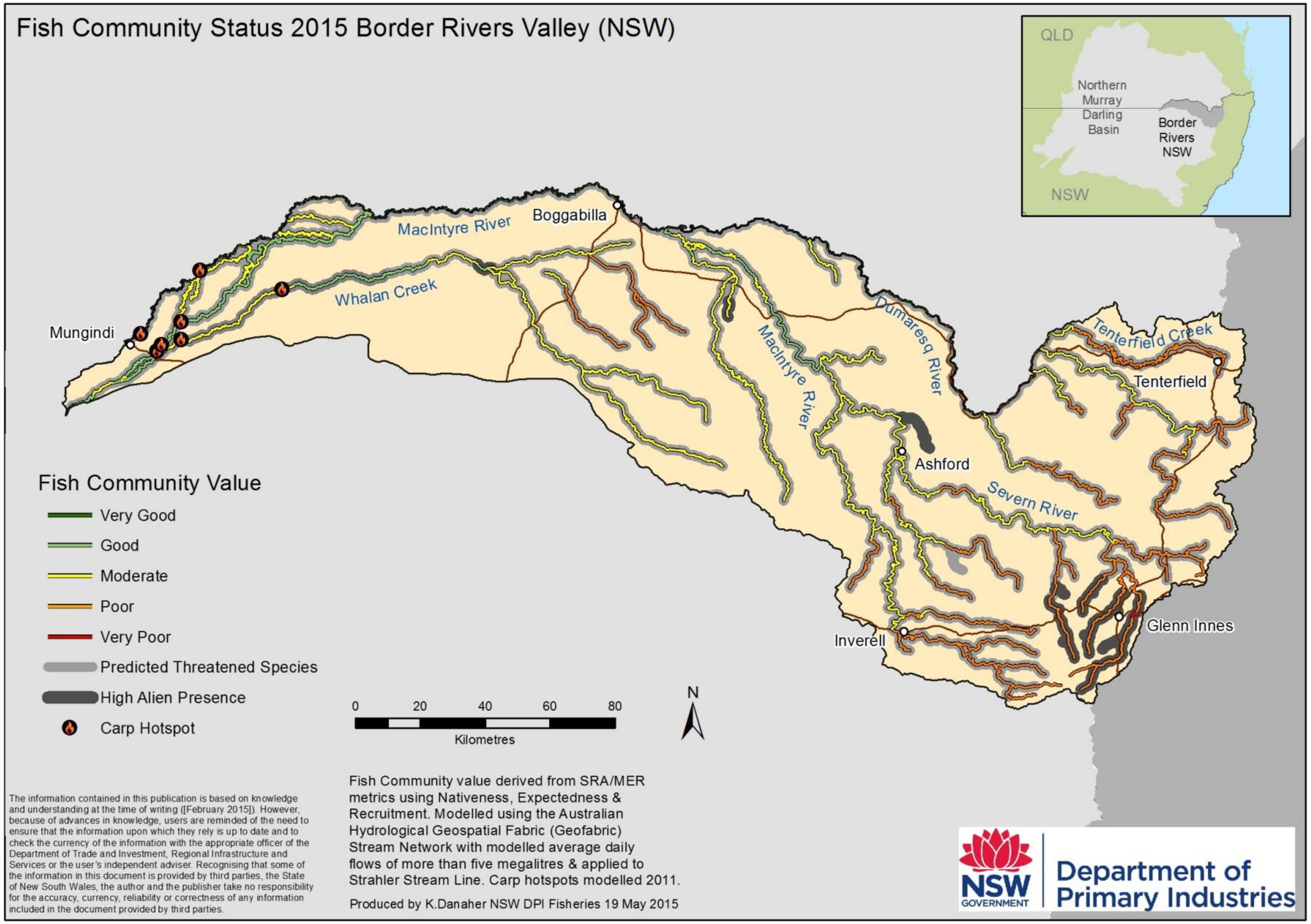


Figure 12: Fish Community Status for the Border Rivers valley, highlighting condition of fish communities and Carp hotspots.

Overall, the fish community of the Border Rivers valley is in moderate health, with minimal lowland reaches below poor condition and some part of the valley possessing fish communities in good to very good condition (Figure 12). The valley also contains threatened species distributions, with the predicted range of these species covering the majority of major waterways in the valley (Figure 12). Many factors have contributed to the deterioration of native fish in the Border Rivers, including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and alien fish species (NSW DPI, 2007); however whilst the majority of the fish community of the valley is in a moderate condition, this provides a strong platform for fish recovery if management actions are developed and implemented appropriately.

Native fish species in the Border Rivers are dominated by Gudgeons (primarily in montane zone) and Bony Herring, with numbers of Golden Perch, Murray Cod, Spangled Perch, Australian Smelt, Murray–Darling Rainbowfish and Darling River Hardyhead also present (Butcher, 2007; Davies *et al*. 2012). The Border Rivers supports populations of a number of listed threatened and vulnerable species, including Freshwater Catfish, Silver Perch, Murray Cod, Olive Perchlet and Purple-Spotted Gudgeon, whilst at least four native fish species (Flat-Headed Gudgeon, River Blackfish, Olive Perchlet and Silver Perch) are relatively rare in the Border Rivers region (Butcher, 2007; Table 14).

Four alien species also occur in the Border Rivers, including Gambusia, Carp, Goldfish and Redfin Perch (Butcher, 2007). Carp is present in the majority of Murray–Darling Basin slopes and lowland rivers and creeks, and some upland streams as well. They are widely distributed in the Macintyre and Dumaresq River systems but are more common in the Macintyre than the Dumaresq River (Butcher, 2007). Gambusia are widely distributed throughout the Macintyre and Dumaresq Rivers but are far more abundant in the Dumaresq River than the Macintyre (Butcher, 2007). Goldfish is also widely distributed and common in both the Macintyre and Dumaresq Rivers, while Redfin Perch has a restricted distribution in headwaters of the Dumaresq and Macintyre Rivers and upper foothill waters during colder months, accounting for the very poor fish community status and high alien presence in these systems (Butcher, 2007; Figure 12). 'High alien presence' is also indicated for some parts of the Severn River near Ashford and lowland areas around Glen Innes, whilst a small section of Whalan Creek also appears to be an alien species 'hotspot' (Figure 12). NSW DPI Carp recruitment hotspot modelling also identifies a small number of hotspots in the upper Barwon River near Mungindi, as well as lowland parts of Whalan Creek (Figure 12). Differences between NSW Fish Community Status mapping of 'high alien presence' and Carp hotspot mapping may be accounted for by different methodologies used by the two projects and the presence of other alien species in the NSW Fish Community Status results.

4.5 Gwydir

4.5.1 Introduction

The Gwydir valley is in north-eastern NSW and is based around the Gwydir River and Ramsar-listed Gwydir wetlands (Figure 13). The catchment is bordered to the north by the Border Rivers, to the south by the Namoi River valley, to the east by the Great Dividing Range, and to the west by the Barwon River.

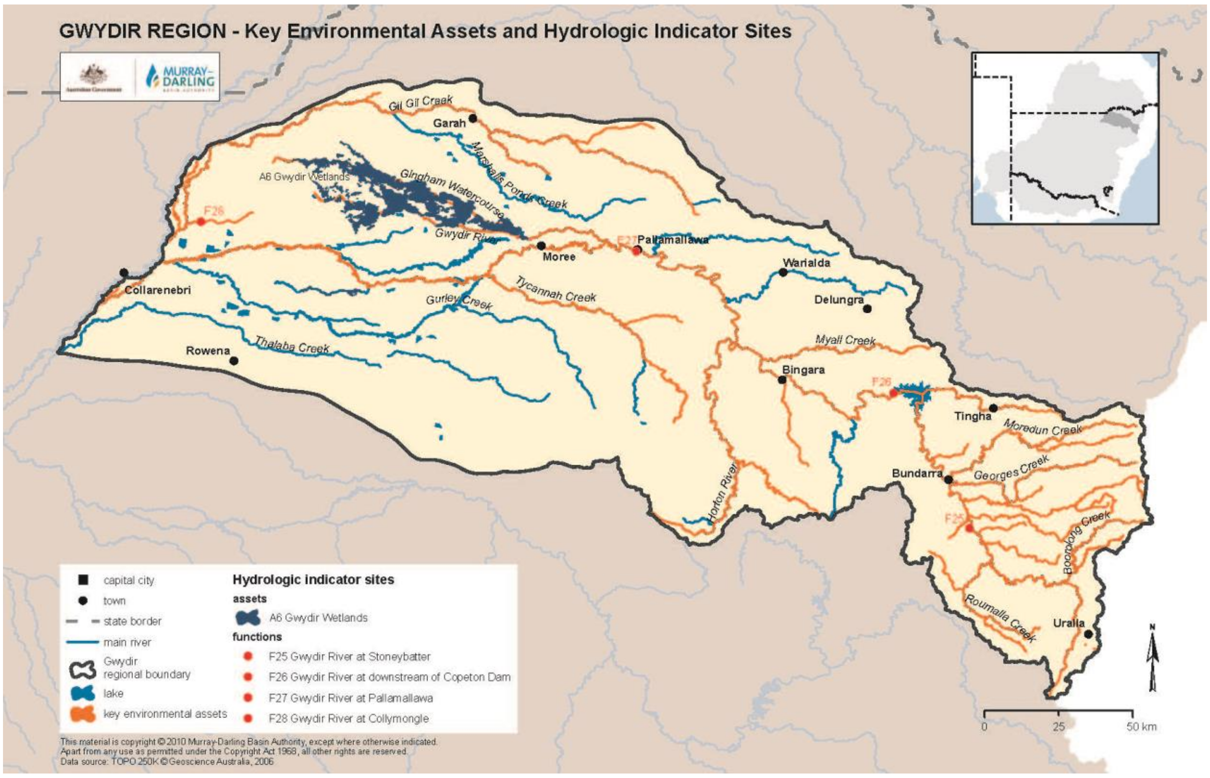


Figure 13: Location and extent of the Gwydir Valley (MDBA, 2012e).

The Gwydir catchment covers 28,998 km^2, which represents 2.78% of the total area of the Murray–Darling Basin (Australian Government Commonwealth Environmental Water Office, undated). Upstream of Pallamallawa, the Gwydir is predominantly a gravel bed stream characteristic of the higher relief catchment that it drains. Downstream of this, the river breaks into a number of distributary channels, which flow out through a flat landscape. Upstream of Moree the Mehi River breaks from the main Gwydir channel to the south at Tareelaroi Weir where it then flows through Moree and on through the south west of the catchment (Southwell *et al*. 2015). Several other creeks break from the Mehi, namely Moomin Creek and further downstream Mallowa Creek, which contains significant wetland areas (Southwell *et al*. 2015).

Downstream of Tareelaroi Weir, Carole Creek breaks from the Gwydir to the north, with the Gwydir River flowing through what is known as "the Raft" downstream of the junction, which is a 15 km long accumulation of woody debris and silt that largely obscures the main channel and heavily influences inundation patterns in this part of the catchment (NSW DECCW, 2011; Southwell *et al*. 2015). Around this area the Gingham watercourse splits from the Lower Gwydir River, with both these watercourses taking the form of a series of wetlands, waterholes and paleo-channels rather than well-defined single channels, and as such support a range of habitats consistent with wetland systems (Pietsch, 2006 in Gawne *et al*. 2013; Southwell *et al*. 2015).

The population of the Gwydir Catchment is approximately 26,500, with Moree being the largest town with a population of 8,083 in 2006 (CSIRO, 2007d). The main industry in the region is agriculture, with a steady movement from grazing to cropping over the last 40 years, whilst irrigated cotton is the most financially significant sector worth $200 million per year (NSW DECCW, 2011; MDBA, 2013).

Lucerne and pasture are grown on the narrow alluvial floodplains of the upper Gwydir River and its tributaries, and broad acre crops are grown on the western plains. Irrigated crops were grown on 90,000 ha on the western plains of the region in the year 2000, of which cotton accounted for 85,000 ha (95%) of the irrigated area (Carr and Kelly, 2010); however the total area of irrigated farming fluctuates each year in response to water availability (NSW DECCW, 2011; MDBA, 2013).

Dryland cropping activities in the region are dominated by wheat combined with chickpeas, sorghum and cereal crops. After cotton, wheat is the second highest-value broad-acre crop in the Gwydir region and is a vital driver for the regional economy. Grazing enterprises are also an important primary industry in the Gwydir region, although its prominence has diminished in recent years, particularly sheep.

The Kamilaroi people are the traditional owners of the Gwydir catchment. The Gwydir region contains many cultural sites and values that are important to the local Aboriginal community, including cultural modifications such as Coolamon scars to living trees that are flood-dependent species (NSW DECCW, 2011; MDBA, 2012e).

Major water resources in the Gwydir region include the Gwydir River, alluvial aquifers, wetlands and water storages. Water storages include private farm dams and public infrastructure, including Copeton Dam. The mean annual rainfall for the region is 644 mm ranging from around 850 mm in the east and central south to 500 mm in the west (CSIRO, 2007). Rainfall is generally higher in the summer months. The region's average annual rainfall has remained relatively consistent over the past 50 years (CSIRO, 2007).

The BWS identifies priorities for increasing distribution of specific native fish species (expansion of existing populations and/or establishment of new populations). Those specific to the Gwydir catchment include:

- Freshwater Catfish: Expand core range of at least 3-5 existing populations (candidate sites include the Gwydir).
- Southern Purple-Spotted Gudgeon: Expand the range (or core range) of at least three existing populations (priority populations include the Border Rivers/Gwydir) and establish or improve the core range of 2-5 additional populations (priority catchments include Border Rivers/Gwydir).
- River Blackfish: Expand the range of at least two current populations (candidate sites include the Gwydir).

There are currently nine flow indicators used to inform the MDBA Basin Plan in the Gwydir catchment, seven for the Lower Gwydir/Gingham Channel management unit and two for the Mallowa management unit (Table 15).

Table 15: Existing site specific flow indicators and associated ecological targets for the Gwydir Valley (MDBA, 2012e).

Site	Site-specific ecological targets	Site-specific flow indicators
Lower Gwydir/Gingham Channel (flows gauged on the Gwydir River at Yarraman Bridge)	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 the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	45 GL total volume over maximum of 60 days between October and March with an event required 90% of years (low uncertainty) to 80% of years (high uncertainty). 60 GL total volume over maximum of 60 days between October and March with an event required 70% of years (low uncertainty) to 60% of years (high uncertainty). 80 GL total volume over maximum of 60 days between October and March with an event required 50% of years (low uncertainty) to 40% of years (high uncertainty). 150 GL total volume over maximum of 60 days between October and March with an event required 30% of years (low uncertainty) to 20% of years (high uncertainty). 250 GL total volume over maximum of 60 days between October and March with an event required 12% of year.
Lower Gwydir/Gingham Channel (flows gauged on the Gwydir River at Yarraman Bridge)	Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates)	150 ML/day for 45 days October to January with an event required 85% of years. 1,000 ML/day for 2 days October to January with an event required 85% of years.
Mallowa Creek (flows gauged on Mallowa Creek at Mallowa Creek Regulator)	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 key ecosystem functions, particularly those related to longitudinal connectivity	5.4 GL total volume over 120 days between Feb/March and Aug/Sept with an event required 95% of years. 4.5 GL total volume over 92 days between November and January with an event required 50% of years (low uncertainty) to 40% of years (high uncertainty).

Two flow indicators for the Lower Gwydir/Gingham Channel were focused on in-channel migration and recruitment of native fish through the provision of in-channel flows, based on work by Wilson *et al*. (2009) and Spencer *et al*. (2010). This suggested that native fish in the Gwydir generally spawn during spring and early summer, associated with increased flow and temperature; and that higher base flows may be linked to improved recruitment opportunities. Subsequent analysis of gauged flow data by MDBA supported an elevated base flow of 150 ML/d or more for a period of 45 days or greater, in combination with a short-duration fresh of at least 1,000 ML/day over two days (MDBA, 2012e).

4.5.2 Aquatic habitat of the Gwydir

Below Pallamallawa, the Gwydir River system begins to form a broad floodplain that extends all the way to the Barwon River. In-channel flows are carried across the floodplain by the Gwydir River and its three main effluent systems: Mehi River, Moomin Creek and Carole Creek (NSW DECCW, 2011). In addition to the larger, well defined channels, a significant proportion of flow is carried through a series of depressions such as the Gingham and Lower Gwydir Watercourses (NSW DECCW, 2011).

A significant feature of the Gwydir system is the Raft, which was formed in the early 1900s by a build-up of silt and large woody debris upstream of Brageen Crossing (Pietsch, 2006). The head of the Raft has stabilised about 20 km west of Moree, where it partly dams the Gwydir River, creating the Gwydir Pool (Pietsch, 2006). The blocking effect of the Raft has increased the proportion of flows entering the Gingham Watercourse; however this redistribution of flow was in part addressed by the construction of the Tyreel regulator which allowed water to be redirected back into the Lower Gwydir River (Pietsch, 2006).

The Gwydir wetlands cover an area of over 1,000 km^2 on the lower Gwydir floodplain west of Moree. The most extensive wetland areas are located along the Gingham and Lower Gwydir watercourses, where flat overland grades result in extensive shallow flooding over large areas, with water flowing through a series of natural and constructed channels and swamps (Green *et al*. 2011).

Detailed habitat mapping has been undertaken for 100 km of the downstream portion of the Horton River to its confluence with the Gwydir (NSW DPI, 2013b). Mapping identified that large woody debris occurred at a relatively low level throughout the study area, with a total of 484 pieces located that had an average load which increased in a downstream direction (NSW DPI, 2013b). In addition, 71 drought refugia sites were identified, but only three were greater than three metres in depth, with greater refuge habitat availability in upstream reaches. Four man-made barriers to fish passage, including three road crossings and one weir/road crossing were also identified, along with four natural barriers (NSW DPI, 2013b).

NSW Fisheries has identified key asset sites for fish within the Gwydir catchment, including:

- the Gwydir River above Copeton Dam (identified as a Carp-free catchment, but does contain a population of Redfin Perch)
- Halls Creek (supporting populations of Purple Spotted Gudgeon, Darling River Hardyhead and Freshwater Catfish)
- Horton and Gwydir Rivers (High biodiversity, including Purple Spotted Gudgeon, Silver Perch, Murray Cod and Freshwater Catfish).

There are over 390 barriers to fish passage identified in the Border Rivers/Gwydir catchment, including weirs, regulators, and road crossings (NSW Fisheries and NSW Department of Land and Water Conservation, 2002; Wilson *et al*. 2009; Figure 11). These structures have varying levels of impacts on native fish within the system, with some structures drowning out more frequently than others to provide suitable fish passage; however, the cumulative impact of these weirs along the system impedes natural flow, affecting not only the life histories of native fish but also the condition of upstream and downstream habitats, and seasonal or ephemeral habitats on floodplains and wetlands (Cooney, 1994; Thorncraft and Harris, 2000; Fairfull and Witheridge, 2003; NSW DPI, 2006).

4.5.3 Fishes of the Gwydir

The Gwydir catchment fish community includes 15 native species recorded or expected to occur, and up to five alien species, two of which primarily occur in upland regions and are therefore not considered as part of functional groupings (Table 16). This list was compiled by reviewing current species distributions from the NSW DPI FFRD (records collected between 1994 and 2011; NSW DPI, 2012b) as well as Australian Museum records (as cited in Morris *et al*. 2001). The NSW DPI FFRD was also analysed to determine fish community health (NSW DPI, 2015; Figure 14).

Table 16: Fishes of the Gwydir valley and associated Northern Basin functional group

(Threatened Species shaded green and indicated by an asterisk; alien species shaded red and indicated by a hash).

Functional group	Species	Zones	Valley comments
Flow Dependent Specialists	Golden Perch	Uplands, slopes, lowlands	Recorded by Lintermans (2007); SRA 2; Wilson *et al*. (2009) and Southwell *et al*. (2015).
*Flow Dependent Specialists	Silver Perch	Upper, middle and lower	Not recorded in Wilson *et al*. 2009; SRA 2; Southwell *et al*. 2015). NSW FRD records species in Gwydir River near Bingara and Mehi River (mid-1990s). NSW key asset sites include Horton and Gwydir Rivers.
Flow Dependent Specialists	Spangled Perch	Uplands, slopes, lowlands	Recorded by Lintermans (2007); SRA 2; Wilson *et al*. (2009) and Southwell *et al*. (2015).
*Inchannel Specialists	Murray Cod (2A)	Slopes and lowland	Species appears more common in the Mehi River compared to Gingham Watercourse, Carole Creek or Gwydir River (Southwell *et al*. 2015). Gwydir population (downstream of Copeton Dam) identified as an 'important population' (National Murray Cod Recovery Team, 2010). NSW key asset sites include Horton and Gwydir Rivers.
*Inchannel Specialists	Freshwater Catfish (2B)	Slopes and lowland	Recorded in Lintermans (2007); SRA 2 (all zones except lowlands); Wilson *et* al. (2009); Southwell *et al*. (2015). NSW key asset sites for species include Halls Creek and Horton and Gwydir Rivers.
Inchannel Specialists	River Blackfish (2B)	Montane, uplands	Not recorded in Wilson *et al*. (2009); Southwell *et al*. (2015). NSW FFRD primarily records species at Laura Creek (upstream of Hudson's Crossing).
*Inchannel Specialists	Purple Spotted Gudgeon (2B)	Montane, uplands, slopes, lowlands	Not recorded in SRA 2; Wilson *et al.* (2009); Southwell *et al.* (2015). NSW key asset sites include Halls Creek and Horton and Gwydir Rivers (Horton to Moree).
*Floodplain Specialists	Olive Perchlet	Upland, slopes and lowland (expected)	Not recorded in Lintermans (2007); SRA 2; Wilson *et al.* (2009). Species were detected in Boyanga and Gingham waterholes in 2013-14 (potentially due to large overland flows from Northern catchments) (Southwell *et al*. 2015).
Floodplain Specialists	Darling River Hardyhead	Montane, uplands and slopes	Not recorded in SRA 2; Wilson *et al.* (2009). NSW FFRD species in Halls Creek (2003).
#Floodplain Specialists	Gambusia	Montane, uplands, slopes, lowlands.	Most abundant alien species in the Gwydir catchment (less in lowland zone) (Davies *et al*. 2012; p.300). Recorded in Lintermans (2007); SRA 2 (all zones); Wilson *et al.* (2009); Southwell *et al.* (2015).
Generalists	Australian Smelt	Uplands, slopes, lowlands	Lintermans (2007); SRA 2; Wilson *et al.* (2009); Southwell *et al*. (2015).
Generalists	Bony Bream	Slopes, lowlands	Most abundant native species in lower Gwydir (Wilson *et al*. 2009). Appears to spawn in response to flow events early in the season in lower Gwydir (Southwell *et al*. 2015).
Generalists	Carp Gudgeon	Montane, uplands, slopes and lowlands	Recorded in Lintermans (2007); SRA 2 (all zones – second most abundant native fish species); Wilson *et al*. (2009); Southwell *et al*. (2015). Species appears to be in low abundance and to show little recruitment response to flow in the Lower Gwydir catchment (Southwell *et al*. 2015).

Functional group	Species	Zones	Valley comments
Generalists	Mountain Galaxias	Montane, uplands	Recorded in Lintermans (2007); SRA 2 (montane only). Not recorded in Wilson *et al*. (2009); Southwell *et al.* (2015).
Generalists	Unspecked Hardyhead	Upland, slopes and lowlands	Recorded in slopes zone only for SRA 2 data (Davies *et al*. 2012; p. 187). Least abundant species detected in CEWO LTIM monitoring for Lower Gwydir (Southwell *et al*. 2015).
Generalists	Murray–Darling Rainbowfish	Uplands, slopes, lowlands	Recorded in Lintermans (2007); SRA2 (slopes zone only); Wilson *et al*. (2009); Southwell *et al*. (2015).
#Generalists (alien)	Carp	Uplands, slopes, lowlands	Recorded in Lintermans (2007); SRA 2; Wilson *et al.* (2009); Southwell *et al.* (2015). Third most abundant alien species in the Gwydir catchment (dominant in lowland zone) (Davies *et al.* 2012; p.300). Spawning appears triggered by flows early in the season in the Lower Gwydir (Oct-Nov) (Southwell *et al.* 2015). Gwydir wetlands is identified as a hotspot for Carp.
#Generalists (alien)	Goldfish	Montane, uplands, slopes, lowlands	Recorded in Lintermans (2007); SRA 2 (all zones); Wilson *et al*. (2009); Southwell *et al.* (2015). Fourth most abundant alien species in Gwydir catchment (Davies *et al*. 2012; p.300).
#Generalists (alien)	Redfin Perch	Montane, uplands	Recorded in Lintermans (2007); SRA 2. Not recorded in Wilson *et al.* (2009) or Southwell *et al*. (2015). Third most abundant alien species in Gwydir catchment (primarily montane zone) (Davies *et al*. 2012; p.300). Identified in NSW key assets as occurring upstream of Copeton Dam.

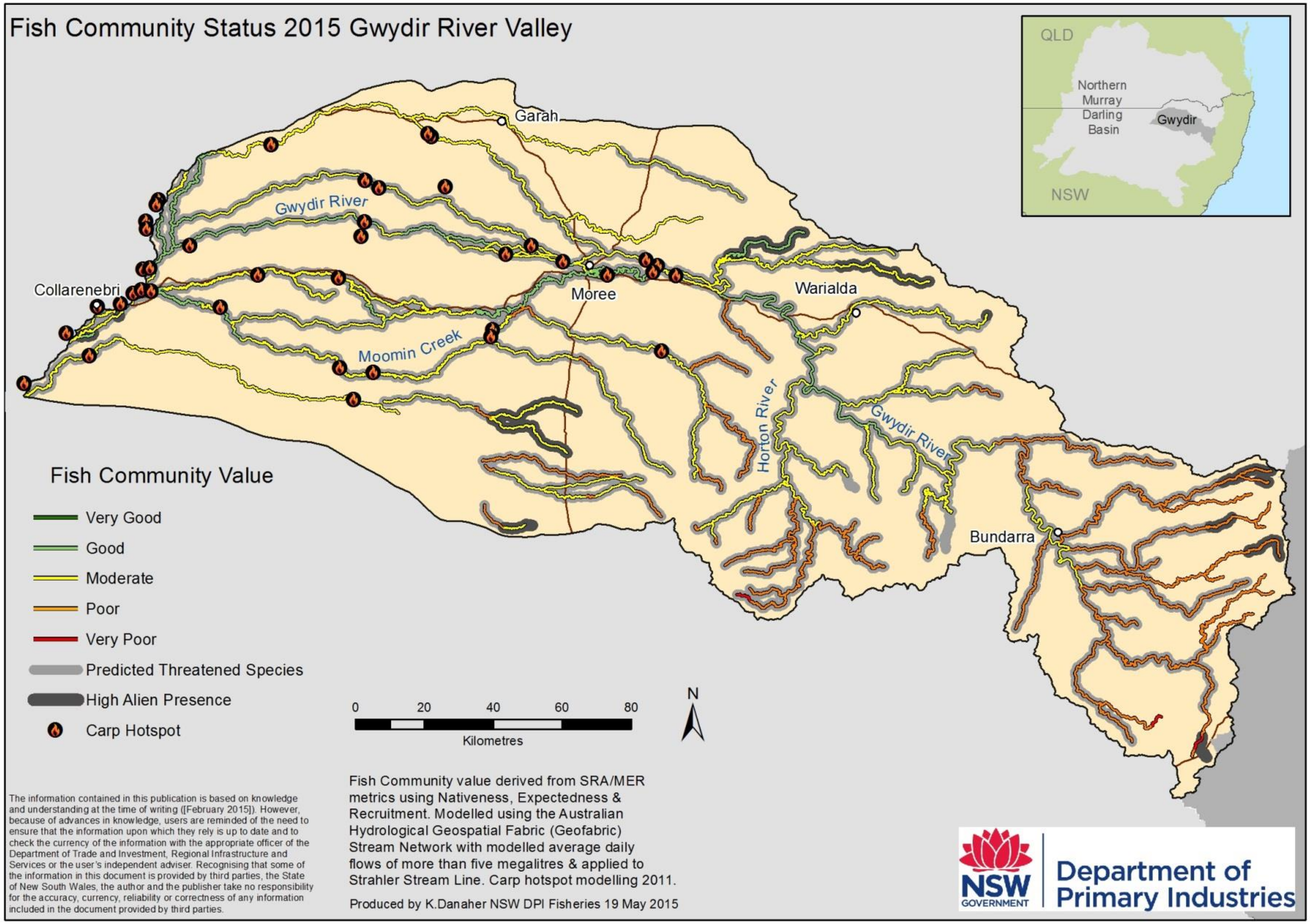


Figure 14: Fish Community Status for the Gwydir valley, highlighting condition of fish communities and Carp hotspots.

Overall, the fish community of the Gwydir Valley is in moderate health, with minimal lowland reaches below poor condition and some parts of the valley, mainly on the Gwydir and Mehi systems, possessing fish communities in good condition (Figure 14). The valley also contains threatened species distributions, with the predicted range of threatened species covering significant reaches of the Gwydir and Mehi, as well as upland systems (Figure 14). The Gwydir supports a number of listed threatened and vulnerable species, including Purple Spotted Gudgeon, Silver Perch, Murray Cod and Freshwater Catfish, with the endangered Olive Perchlet also recently detected in Boyanga and Gingham waterholes in 2013-14, potentially due to large overland flows from Northern catchments (Southwell *et al*. 2015; Table 16).

Many factors have contributed to the deterioration of native fish in the Gwydir valley including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and alien fish species (NSW DPI, 2007); however whilst the majority of the fish community of the valley is in a moderate condition, this provides a strong platform for fish recovery if management actions are developed and implemented appropriately.

Alien species recorded or expected in the Gwydir catchment include Carp, Gambusia, Goldfish and Redfin Perch (Table 16). Rainbow Trout and Brown Trout have been recorded in some upland areas of the catchment, but have not been considered as part of functional groupings for the *Fish and Flows in the Northern Basin*, due to the restriction to upland systems. Gambusia were the most abundant alien species recorded in SRA 2 data, with high Carp numbers also recorded particularly in the Lowland zone (Davies *et al*. 2012). Redfin Perch was also present in high numbers in the montane zone and also upland zone (Davies *et al*. 2012; p.300). This dominance of alien species in some locations of the Gwydir valley is reflected in the Fish Community Status analysis, with ‘high alien presence’ found in upland tributaries (largely due to the influence of Redfin Perch) and some lowland tributaries of the Gwydir and the Thalaba Creek system (Figure 14). Carp recruitment analysis also identifies hotspots in a number of areas in the Gwydir catchment, including lowland tributaries of the Gwydir and in the wetland complex, as well as the mainstem Gwydir around Moree (Figure 14). Differences between ‘high alien presence’ mapping and the Carp hotspot population analysis may be accounted for by the different methodologies and the presence of other alien species not included in the Carp population modelling.

4.6 Namoi

4.6.1 Introduction

Located in north-western NSW, the Namoi catchment borders the Gwydir and Castlereagh catchments and is bounded by the Great Dividing Range in the east, the Liverpool Ranges and Warrumbungle Ranges in the south, and the Nandewar Ranges and Mount Kaputar to the north (Figure 15). The Namoi catchment area is approximately 42,000 km^2 from the Great Dividing Range near Tamworth, to the Barwon River near Walgett. It is over 350 km long, stretching from Bendemeer in the east to Walgett on the western boundary. The Peel River has a catchment area of around 4,700 km^2 and contributes an average annual volume of approximately 280,000 ML to the Namoi River (Green *et al*. 2011a). Elevations range from over 1,500 m to the south and east, to just 100 m on the alluvial floodplain of the lower catchment west of Narrabri (Green *et al*. 2011a).

The Namoi catchment supports a diversity of landscapes ranging from the Liverpool and Kaputar ranges, through the rolling hills of the sedimentary slopes, to the open floodplains of the Liverpool Plains and Darling Riverine Plains in the western part of the catchment. The relatively young volcanic geology of the region and extensive alluvial floodplains derived from these materials results in very productive heavy black and grey clays that are sought after for farming and irrigation. However, the impact of these activities resulted in more than 10% of the Namoi catchment being moderately to severely eroded by the early 1990s (Namoi CMA, 2006). The extent of erosion is now improving in some areas due to reduced tillage farming practices (Green *et al*. 2011a).

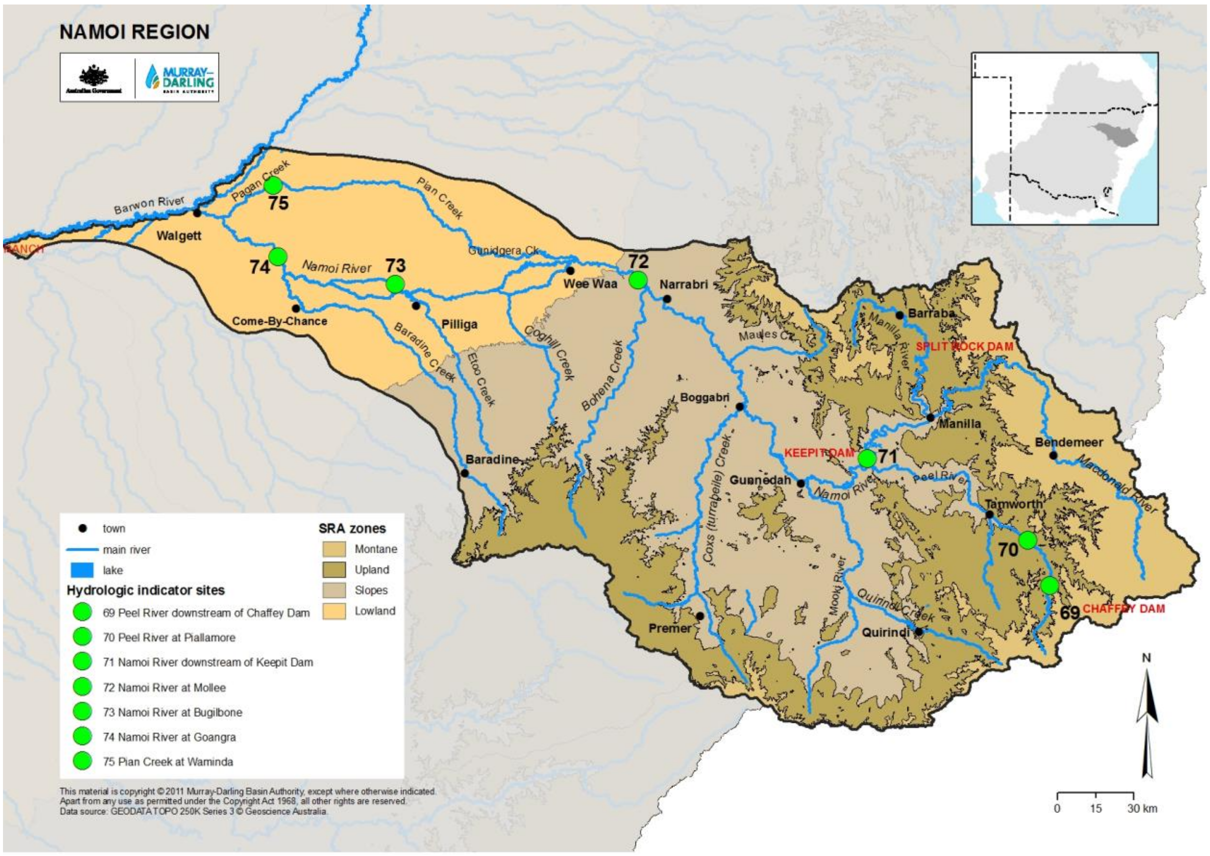


Figure 15: Location and extent of the Namoi valley (MDBA, 2012f).

While the Namoi catchment does not contain any extensive wetland complexes, a feature of the river downstream of Narrabri is the many small lagoons, wetlands, and anabranches, as well as extensive areas of floodplain woodlands and high level flood runners that occur on the lower Namoi floodplain (Green and Dunkerley, 1992; Eco Logical Australia, 2008; Green *et al*. 2011a). The catchment also contains a number of significant wetlands that are independent of the river system, with the largest of these being Lake Goran, a large internal drainage basin south of Gunnedah that covers more than 60 km^2 (Green *et al*. 2011a).

The Namoi is characterised by major tributaries of the Namoi River including Coxs Creek and the Mooki, Peel, Manilla, and Macdonald Rivers, which join the Namoi upstream of Boggabri, with Pian, Narrabri, Baradine and Bohena Creeks joining below Boggabri (Figure 30). Major tributaries of the Peel River are Goonoo Goonoo Creek, Cockburn River, and Dungowan Creek. Stream flows in the Namoi catchment are regulated by Keepit Dam on the Namoi River, Split Rock Dam on the Manilla River and Chaffey Dam on the Peel River (Figure 30). The regulated section of the Peel River has historically been managed as a separate allocation scheme to the Namoi regulated river, and operationally the management of Chaffey Dam is independent of the other storages on the Namoi (Green *et al*. 2011).

Prior to European settlement in the mid-1800s the Namoi and Peel catchments were occupied by the Kamilaroi people (Green *et al*. 2011a). Today, approximately 100,000 people live within the Namoi catchment, mostly along the Namoi River and its tributaries between Tamworth and Narrabri. Tamworth, located on the Peel River, is the largest urban centre in the catchment with a population of nearly 33,500 people living in town (Green *et al*. 2011a). Gunnedah, on the Namoi River, has a population of 7,500 people, and Narrabri, also on the Namoi, has a population of 6,100 people Green *et al*. 2011a). A number of smaller towns throughout the catchment, such as Barraba, Manilla, Quirindi, Walgett, Wee Waa and Werris Creek, support between 1,000 and 3,000 people (Green *et al*. 2011a).

The annual regional output is over $1 billion, with dryland and irrigated agricultural production representing approximately half this amount (Green *et al*. 2011a). Major industries include cotton, livestock production, grain and hay, poultry, horticulture and forestry. The region's local councils also depend on the Namoi and Peel Rivers to meet the urban water requirements of many of the region's urban centres with the most notable being the major urban centre of Tamworth whose water supply is provided from the Peel River (Green *et al*. 2011a).

There are over 496 instream structures in the Namoi catchment, of which 57 are considered likely to pose a significant barrier to fish passage with a head loss greater than 2 m, including the major regulating structures of the system (NSW DPI, 2006b; Figure 16). Keepit Dam has been identified as causing relatively large and pervasive cold water pollution, as it impounds deep storages and releases large volumes of cold hypo limnetic water during spring and summer (Preece, 2004). The largest discharges occur between September and February, with a median monthly discharge of 2,000 ML/day in January (Preece, 2004; p. 20). Estimates of likely impacts vary from 180 km of river downstream (Whittington and Hillman, 1998) through to 300 km (Lugg, 1999). Regardless of the spatial extent that cold water pollution affects, it is important to acknowledge the influence that this impact can have on native aquatic biota downstream of Keepit Dam and consider this during the development of water management actions.

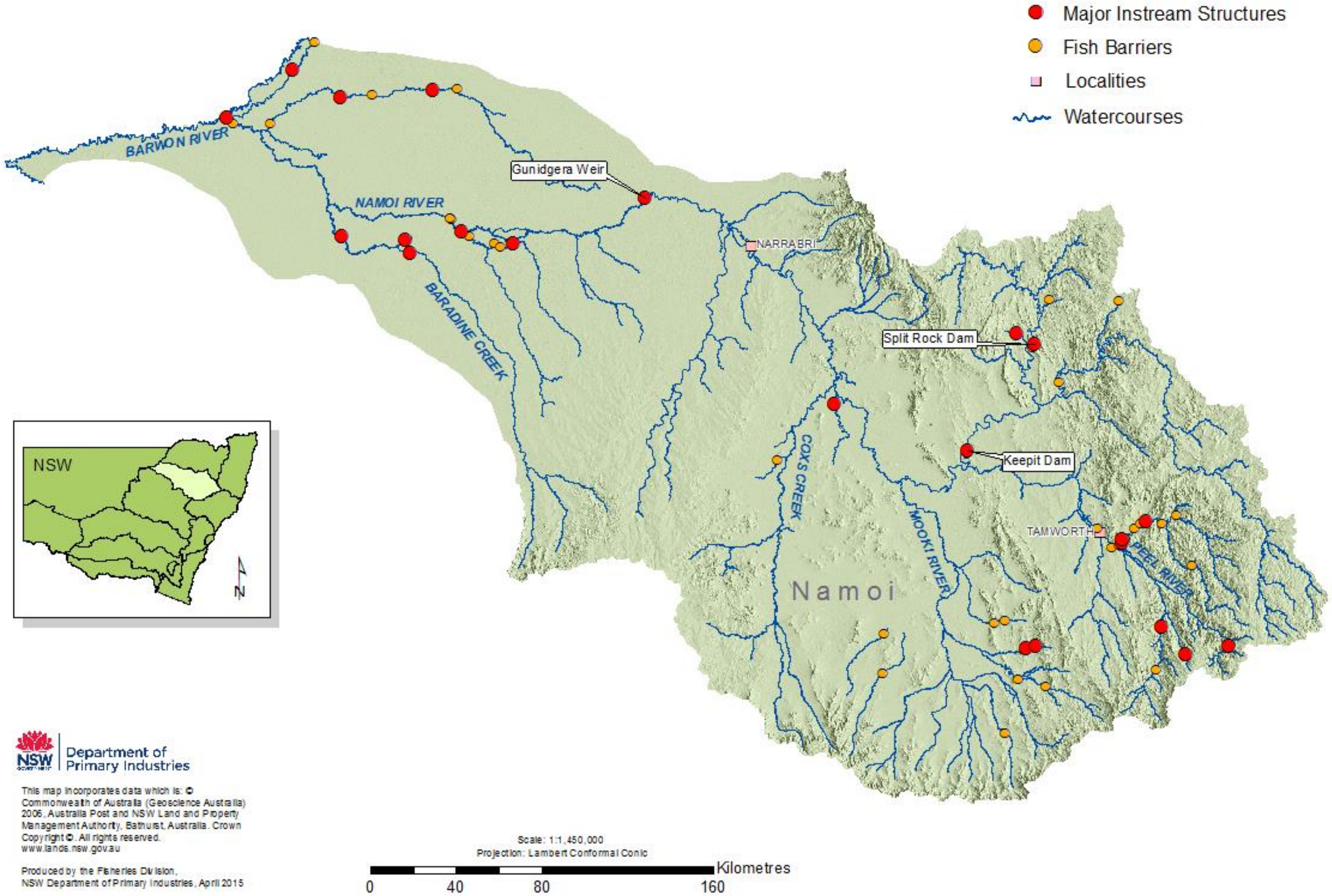


Figure 16: Location of significant fish passage barriers in the Namoi valley, highlighting major instream regulating structures.

The BWS identifies a number of important asset sites for native fish in the Namoi catchment, including:

- Namoi River (Gunnedah to Walgett): 'key movement corridor', 'high biodiversity', 'site of other significance', 'key site of hydrodynamic diversity', 'threatened species' and 'dry period/drought refuge'.
- Peel River downstream of Chaffey Dam: 'high biodiversity', 'key site of hydrodynamic diversity', 'threatened species' and 'dry period/drought refuge'.
- Namoi River upstream of Keepit Dam: 'high biodiversity', 'key site of hydrodynamic diversity' and 'threatened species'.

In addition, the BWS identifies priorities for increasing distribution of specific native fish species (expansion of existing populations and/or establishment of new populations). Those specific to the Namoi catchment include:

- Silver Perch: expand the core range of at least 2 existing populations (candidate sites include populations in the Namoi).
- Freshwater Catfish: expand the core range of at least 3-5 existing populations (candidate sites include the Namoi).
- Olive Perchlet (additional populations): establish or improve the core range of 2-4 additional populations (candidate sites include the Namoi).
- Southern Purple-Spotted Gudgeon (additional populations): Establish or improve the core range of 2-5 additional populations (priority catchments include the Gwydir).
- River Blackfish (range extension): expand the range of at least two current populations (candidate sites include upland systems of the Namoi).

The MDBA's environmental water requirements for the Lower Namoi River currently include three site-specific flow indicators, measured in the Namoi River upstream of Bugilbone. Indicators are focused on environmental outcomes for in-channel flows for the Lower Namoi, defined as being downstream of Wee Waa (Table 17).

Table 17: Existing site-specific flow indicators and associated ecological targets for the lower Namoi valley (MDBA, 2012f).

Asset	Site-specific ecological targets	Site-specific flow indicators
Lower Namoi River downstream of Wee Waa (flows gauged on the Namoi River upstream Bugilbone)	Provide a flow regime which ensures the current extent of native vegetation of the anabranch 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, invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon	4,000 ML/day for 45 days total (with a 7 day minimum), timing not constrained but preferably clustered in late spring/summer as well as winter, with an event required 25% of years (low uncertainty) to 22% of years (high uncertainty). 1,800 ML/day for 60 days total (with a 6 day minimum), timing not constrained but preferably clustered in late spring/summer as well as winter, with an event required 39% of years (low uncertainty) to 29% of years (high uncertainty). 500 ML/day for 75 days total (with a 25 day minimum) timing not constrained but preferably clustered in late spring/summer as well as winter, with an event required 55% of years (low uncertainty) to 41% of years (high uncertainty).

The proposed inundation frequencies for vegetation communities of the anabranches and effluent channels have been informed by the requirements of the dominant water dependent species, focussing largely on the vegetation communities on the Lower Namoi (MDBA 2012f). It is anticipated that native fish would receive some benefit from the proposed flow regimes, especially through the increase in duration of the in-channel flow events and through the maintenance of healthy river pools and low level bars.

4.6.2 Aquatic habitat in the Namoi

The freshwater environment of the Namoi catchment is comprised of an extensive range of aquatic habitats including swamps, floodplains, wetlands, streams and rivers. Within these broad habitat types, niche habitats such as pools and riffles, gravel beds, snags, aquatic vegetation and riparian vegetation are present, diversifying the habitat available to aquatic species in the Namoi catchment.

The river downstream of Keepit Dam (the lower Namoi) has been described in four geomorphic zones by Thoms *et al.* (1999). Immediately downstream of Keepit and the Peel River tributary confluence is a mobile zone linking into a meander zone to just upstream of Boggabri. From Boggabri to Wee Waa is an anabranching zone, while Pian Creek and Namoi River downstream is primarily a distributary zone.

There are three major tributaries, including the Manilla River (with Split Rock Dam), the Macdonald River and Halls Creek, as well as numerous smaller creeks. The rivers rise at elevations over 1000 m, falling to 400 m where the Upper Namoi and Manilla Rivers meet near Manilla (Figure 15). In these reaches the water flows within well-defined channels and the river only has a limited floodplain (Green *et al*. 2011a).

The Peel River catchment covers about 11% of the Namoi catchment. The Peel River joins the Namoi River a short distance downstream of Keepit Dam. The river starts in the Great Dividing Range south of Tamworth and includes the major catchments of the Upper Peel River (including Chaffey Dam), Cockburn River, and Goonoo Goonoo Creek (Figure 15). The upper reaches of the Peel River flow through narrow valleys to the Cockburn River junction with the river broadening into wide alluvial floodplains below Tamworth. Carroll Gap is considered the end of the regulated Peel system, with around 40% of the annual discharge in the Peel River at Carroll Gap delivered by the Cockburn River, while Goonoo Goonoo and Dungowan Creeks both contribute approximately 10% (Green *et al*. 2011a).

Downstream of Keepit Dam the Namoi River continues within a confined channel until Gunnedah when the floodplain begins to broaden. A number of small lagoons are found upstream of Gunnedah, and between Gunnedah and Narrabri the floodplain includes a number of long, narrow lagoons that represent prior channels of the Namoi River. Upstream of Narrabri the river channel splits in two with the northern channel (Narrabri Creek) carrying most of the flow and rejoining the Namoi River at Mollee Weir. Major tributaries connecting to the Namoi River include the Mooki and Coxs Rivers, and Maules Creek.

The Mooki River flows north-west from near Quirindi in the Liverpool Ranges and enters the Namoi River upstream of Gunnedah. The Mooki River catchment covers about 9% of the total Namoi catchment area (Green *et al*. 2011a). At the head of the Mooki catchment is Lake Goran, a large internal drainage basin, which forms the largest natural water body in the Namoi catchment when it is full. The Coxs River flows north-west from Tambar Springs in the Warrumbungle Ranges and enters the Namoi River upstream of Boggabri. The Coxs River catchment covers about 9% of the total Namoi catchment area (Green *et al*. 2011a). On the northern side of the river just upstream of Narrabri is the Maules Creek catchment that represents about 1% of the Namoi catchment area (Green *et al*. 2011a).

The Lower Narrabri is considered to be the start of the true riverine zone of the Namoi catchment due to the increased frequency of lagoons, the low gradient of the channel and the development of several anabranches and effluent channels. There are large numbers of lagoons in this reach, although most are small and require overbank flooding for inundation (Green and Dunkerley, 1992; Foster, 1999; Green *et al*. 2011a; MDBA 2012f; Table 18).

Table 18: Commence-to-flow thresholds for lower anabranches and benches in the Lower Namoi (Foster, 1999; MDBA, 2012f).

Reach	Key gauge	Description of in channel feature	Estimated discharge required to inundate bench (ML/d)
Downstream of Duncan's Junction	Namoi River Upstream of Duncan's Junction (419082)	Bench	1,740
Downstream of Duncan's Junction	Namoi River Upstream of Duncan's Junction (419082)	Turragulla Anabranch linkage	3,230
Downstream of Duncan's Junction	Namoi River Upstream of Duncan's Junction (419082)	Anabranch/Floodrunner	3,300
Bugilbone	Namoi River at Bugilbone (419021)	Benches	1,780
Bugilbone	Namoi River at Bugilbone (419021)	Benches	3,921
Bugilbone	Namoi River at Bugilbone (419021)	Benches	3,724
Bugilbone	Namoi River at Bugilbone (419021)	Anabranch/Floodrunner	4,496
Goangara	Namoi River at Goangara (419026)	Benches	1,865
Goangara	Namoi River at Goangara (419026)	Benches	6,277
Goangara	Namoi River at Goangara (419026)	Benches	13,766
Downstream of Goangara	Namoi River at Goangara (419026)	Bench	2,148

Analysis by Lambert and Short (2004) of channel cross-sections in the Lower Namoi also indicates the presence of benches at a stage height of between 3 and 4 m, bars located at a stage height of 1 and 2 m, and low flow channels at around 1 m (MDBA, 2012f).

Eco Logical Australia (2008) mapped a total of 2,766 wetlands in the valley totalling 46,398 ha. Of these, 1,829 were identified as natural wetlands and 937 were artificial wetlands (dams, weir pools and other storages) (Eco Logical Australia, 2008). Notable Namoi wetlands include Barbers Lagoon and Gulligal Lagoon (Barmah Water Resources, 2012).

In recognition of the habitat values and native fish community status in the Namoi catchment, the aquatic ecological community of the natural drainage of the lowland Darling catchment, which includes the Namoi catchment, is listed as an Endangered Ecological Community under the *FM Act* 1994. This includes all native fish and aquatic invertebrates that occur within the natural rivers and their associated tributaries downstream of the major dams in the Namoi catchment, recognising the rarity, vulnerability and habitat importance of the region (NSW DPI, 2005a).

To support the environmental values of the valley, the Namoi Demonstration Reach was established in 2007, focussing aquatic habitat rehabilitation activities along 150 km of the Namoi River and tributaries between Gunnedah and Narrabri. A significant amount of on-ground activities have been completed within the demonstration, and include:

- Introducing 300 snags at priority sites
- Replanting 5,700 aquatic plants at priority sites
- Planting of more than 9,000 native trees and shrubs
- Completing 33.5 km of woody weed management
- Completing 33.5 km of riparian fencing
- Installing 20 off-stream watering points
- Constructing eight in-stream and gully erosion protection works.
- three years of condition based monitoring along the demonstration reach to improve understanding of fish communities in the project area,
- engaging with over 3,000 people in the local region through workshops, field days, fishing events and education days,
- collaborating with 30 stakeholder groups, including all levels of government, community groups, Indigenous communities, landholders, businesses and schools to achieve onground outcomes.

In addition to these activities, NSW DPI has also undertaken initial habitat mapping along the demonstration reach, identifying the spatial distribution of snags, presence of aquatic vegetation, location and extent of riparian weeds and location and depth of deep pools to guide the development of management plans and actions. Analysis of this information is still to occur for the majority of the reach; however review of habitat information has been completed for a 13 km section of the Namoi River on the Whitehaven Vickery South site halfway between Boggabri and Gunnedah (NSW DPI, 2013b). Along this reach, 278 snags were identified, at an average of 34 snags/km and dominated by relatively simple snags; 14 pools were recorded, with an average depth of 4.3 m and range of between 3.5 m to 6.7 m, and; around 30% of the reach was covered by aquatic vegetation, comprising three species (phragmites, juncus and vetiver) (NSW DPI, 2013b). Inundation values were not recorded for this data; however this information may be able to be calculated based flow information at the time of data collection, with further analysis required.

4.6.3 Fishes of the Namoi

The extensive range of aquatic habitat supports a diverse assemblage of species, including 18 freshwater finfish species (Table 19). Three of these species are introduced, competing with 15 native fish species, found within the catchment. This list was compiled by reviewing current species distributions from the NSW DPI FFRD (records collected between 1994 and 2011; NSW DPI, 2012) as well as Australian Museum records (as cited in Morris *et al*. 2001). The NSW DPI FFRD was analysed to determine fish community health (NSW DPI, 2015; Figure 17).

Table 19: Fishes of the Namoi valley and associated Northern Basin functional group

(Threatened Species shaded green and indicated by an asterisk; alien species shaded red and indicated by a hash).

Functional group	Species	Zones	Valley comments
Flow Dependent Specialists	Golden Perch	Uplands, slopes, lowlands	Recorded in SRA 2 (Davies *et al*. 2012; p.236). More common in slopes and lowland areas.
*Flow Dependent Specialists	Silver Perch	Uplands, slopes, lowlands	Not recorded in SRA 2 data (Davies *et al*. 2012; p.236). Silver Perch populations in the Namoi...catchments are...largely only in stocked impoundments, with only small numbers or individuals collected from a small number of sites in the lower reaches (Australian Government Department of Environment, 2013; p.12). NSW key asset sites include Namoi River between Gunnedah and Wee Waa and Upper Namoi River (above Keepit Dam to Warrabah National Park).
Flow Dependent Specialists	Spangled Perch	Uplands, slopes, lowlands	Recorded in slopes and lowland zones for SRA 2 (Davies *et al*. 2012; p.236).
*Inchannel Specialists	Murray Cod (2A)	Upland, slopes and lowland	Recorded in all four zones (including montane zone) for SRA 2 (Davies *et al*. 2012; p.236). National Murray Cod Recovery Plan identifies priority area as: Namoi River from Peel River junction downstream to Wee Waa, including most major tributaries except upper Mooki River (National Murray Cod Recovery Team, 2010; p.9). NSW Key asset areas include Namoi River between Gunnedah and Wee Waa; Peel River between Chaffey Dam and Tamworth; and Upper Namoi.
*Inchannel Specialists	Freshwater Catfish (2B)	Montane, uplands, slopes, lowlands	Recorded in upland and slopes zones (low numbers) for SRA 2 (Davies *et al*. 2012; p.236). NSW key asset areas include Namoi River between Gunnedah and Wee Waa; Peel River between Chaffey Dam and Tamworth; and Upper Namoi River.
Inchannel Specialists	River Blackfish (2B)	Montane, uplands	Recorded in montane zone for SRA 2 (Davies *et al*. 2012; p.236). NSW FFRD records species in McDonald and Peel Rivers.
*Inchannel Specialists	Purple Spotted Gudgeon (2B)	Montane, uplands, slopes, lowlands expected	Not recorded in SRA 2 (Davies *et al*. 2012; p.236). NSW key asset sites include Gulligal Lagoon (stocked population). Upper drainage lines in the Great Dividing Range (unregulated creeks) and unregulated creeks in the New England Tablelands within the Namoi catchment identified as priority drought refuge sites (McNeil *et al*. 2013; p.93).
*Floodplain Specialists	Olive Perchlet	Slopes, lowland expected	Not recorded in SRA 2 (Davies *et al*. 2012; p.236). Identified as part of historical distribution (NSW DPI, 2013, p.2).
Floodplain Specialists	Darling River Hardyhead	Montane, uplands and slopes expected	Not recorded in SRA 2 (Davies *et al*. 2012; p.236). Identified as 'patchily distributed' in the Basin, and 'known from the Condamine, Peel, Namoi, Macintyre and Cockburn rivers and Boiling Down and Warialda Creeks. SRA1 records identify the species at three sites in the Namoi catchment (Lintermans, 2007; pp.58-59).
#Floodplain Specialists	Gambusia	Uplands, slopes, lowlands	Most abundant alien species in the Namoi catchment (primarily upland zone) (Davies *et al*. 2012; p.300).

Functional group	Species	Zones	Valley comments
Generalists	Australian Smelt	Uplands, slopes, lowlands	Recorded in SRA 2 (upland zone only) (Davies *et al*. 2012).
Generalists	Bony Bream	Uplands, slopes, lowlands	Most abundant native species in SRA 2 data (Davies *et al*. 2012; p.236).
Generalists	Carp Gudgeon	Uplands, slopes, lowlands	Recorded in SRA 2 data (Davies *et al*. 2012; p.236). Second most abundant native species.
Generalists	Mountain Galaxias	Montane, uplands	Recorded in montane and upland zones in SRA 2 data (Davies *et al*. 2012; p.236).
Generalists	Unspecked Hardyhead	Upland, slopes, lowlands	Recorded in slopes zone only for SRA 2 data (Davies *et al*. 2012; p. 236).
Generalists	Murray–Darling Rainbowfish	Uplands, slopes, lowlands	Recorded in SRA 2 data (slopes and lowland) (Davies *et al*. 2012; p.236).
#Generalists (alien)	Carp	Uplands, slopes, lowlands	Second most abundant alien species in the Namoi catchment (more dominant in slopes and lowland areas (Davies *et al*. 2012; p.236). Namoi wetlands and tributaries are identified as a hotspot for Carp.
#Generalists (alien)	Goldfish	Uplands, slopes, lowlands	Third most abundant alien species in Gwydir catchment (primarily upland zone) (Davies *et al*. 2012; p.300).

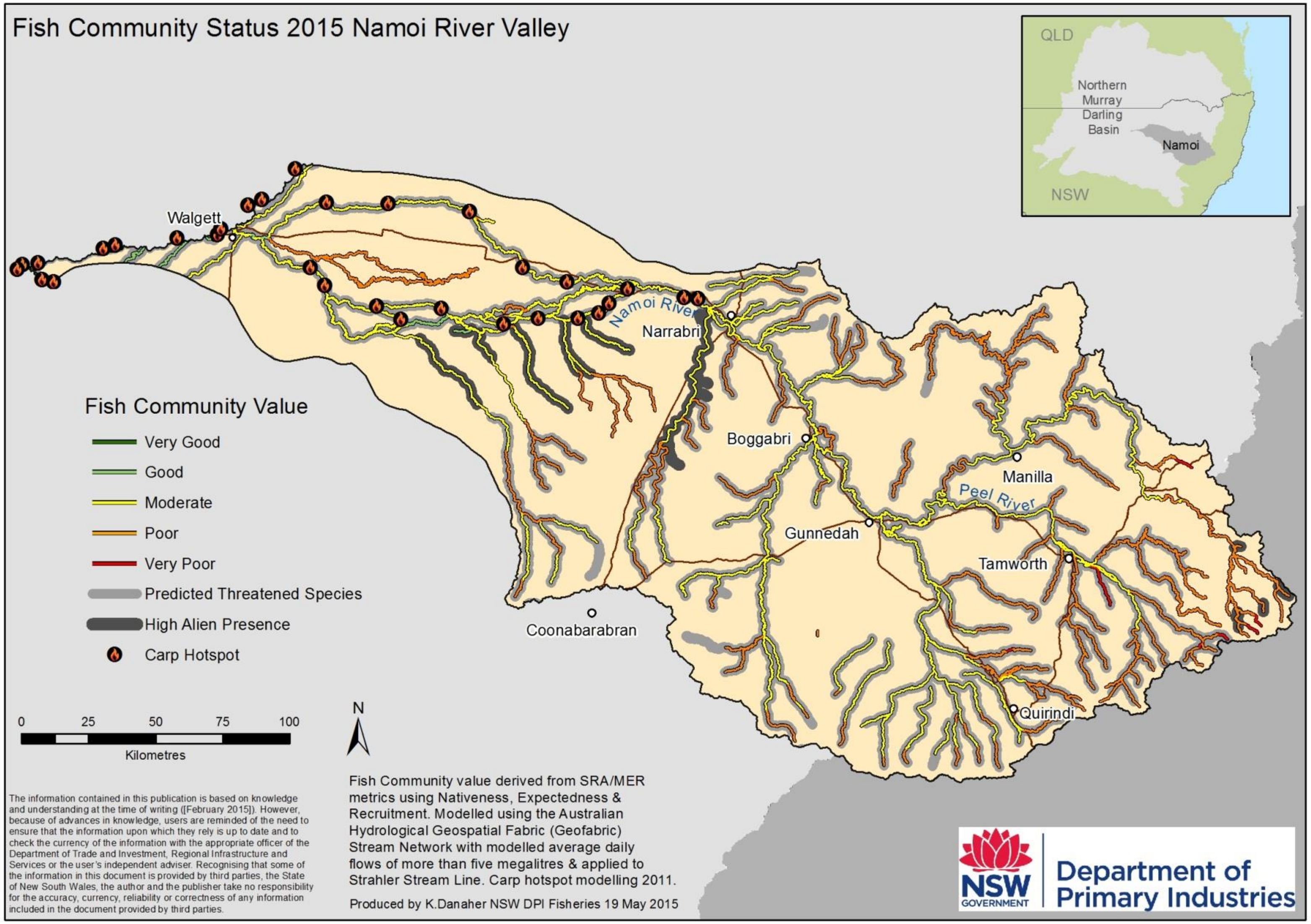


Figure 17: Fish Community Status for the Namoi valley, highlighting condition of fish communities and Carp hotspots.

Overall, the fish community of the Namoi Valley is in moderate health, with minimal reaches below poor condition (mainly restricted to upland tributaries) and some parts of the valley, mainly lowland systems, possessing fish communities in good condition (Figure 17). The valley also contains threatened species distributions, with the predicted range of threatened species covering the majority of major systems in the valley (Figure 17). Five of the species recorded in the Namoi valley are listed as threatened in NSW waters (Table 19), driving the predicted threatened species distribution across the Namoi.

Purple Spotted Gudgeon, Freshwater Catfish of the Murray–Darling Basin, and the western population of Olive Perchlet are listed as Endangered under the FM Act 1994, whilst Silver Perch and Murray Cod are listed as Vulnerable under the FM Act 1994 and EPBC Act 1999, respectively. All of these species have an expected distribution in the Namoi River and associated tributaries, with historical records indicating their presence throughout the area (NSW DPI, 2007; Table 18; Figure 17). In addition to these threatened native fish species, the threatened river snail species *Notopala sublineata* is also listed as an Endangered species in NSW under the FM Act 1994. This species also has an expected distribution in the Namoi River, and was once widespread in the Murray–Darling Basin; however similar threats to those affecting native fish populations have also resulted in a decrease in the presence of this aquatic species (NSW DPI, 2005).

Many factors have contributed to the deterioration of native fish in the Namoi valley including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and alien fish species (NSW DPI, 2007). The majority of the fish community of the valley is in a moderate condition, and this provides a strong platform for fish recovery if management actions are developed and implemented appropriately.

Alien species recorded or expected in the Namoi catchment include Carp, Gambusia, and Goldfish (Table 19). Rainbow Trout have also been recorded in some upland areas of the catchment, but have not been considered as part of functional groupings for the Fish and Flows in the Northern Basin, due to the restriction to upland systems. Gambusia were the most abundant alien species recorded in SRA 2 data, with high Carp numbers also recorded particularly in the Lowland zone (Davies *et al*. 2012). This dominance of alien species in some locations of the Namoi valley has been identified, with known Carp hotspots located in the wetlands and lowland systems of the Namoi River, reflected by the 'high alien presence' found in lowland tributaries downstream of Narrabri, including Bohena, Brigalow and Coghill Creeks (Gehrig and Thwaites, 2013; Figure 17). Carp recruitment hotspot modelling undertaken by NSW DPI also identifies 'point data' for Carp hotspots in the wetlands and lowland systems of the Namoi River downstream of Narrabri (Figure 17). Differences between the 'high alien presence' fish community mapping and Carp hotspot point data may be accounted for by methodological differences and the presence of other alien species in the Fish Community Status information.

4.7 Macquarie–Castlereagh

4.7.1 Introduction

The Macquarie–Castlereagh catchment in central western NSW extends inland from the Great Dividing Range to west of Nyngan and the Bogan River, and is bordered by the Barwon River in the north and encompasses Bathurst in the south (Figure 18). The catchment comprises three distinct river networks: the Macquarie, the Castlereagh and the Bogan, all of which flow generally north-west across central NSW to meet the Barwon River (MDBA, undated).

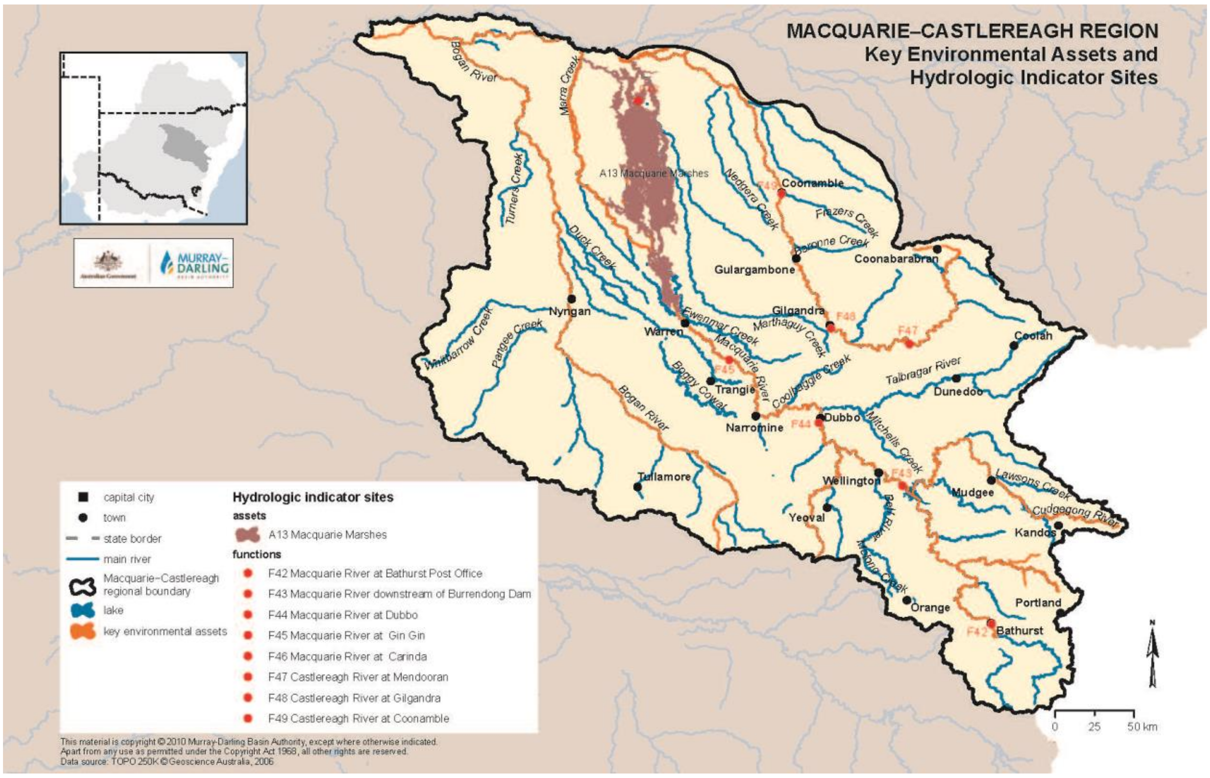


Figure 18: Location and extent of the Macquarie–Castlereagh valley (MDBA, 2012g).

The Macquarie–Castlereagh catchment covers 91,985 km^2 (or 8.8% of the Murray–Darling Basin) and contains two major storages, Windamere Dam (capacity 368 GL) on the Cudgegong River and Burrendong Dam (capacity 1,188 GL) on the Macquarie (Australian Government Commonwealth Environmental Water Office, undated). The catchment's topography ranges from steep terrain in the east (the headwaters of the major rivers) to flat plains in the west. The climate is transitional, with rainfall increasingly variable from east to west. Cotton is the main irrigated crop, followed by oilseeds, cereals, citrus, grapes and stone fruit. Irrigated and dryland livestock grazing is important to the region's economy (MDBA, undated). There were around 77,500 ha of irrigated cropping in 2000 of which is located within the middle and lower reaches of the region, with irrigated cotton accounting for 52,400 ha or over 68% of the irrigated area (CSIRO, 2008c). The Macquarie–Castlereagh area has a population of around 180,000, with its main towns including Orange (the largest, with a population of about 32,000), Dubbo, Wellington, Mudgee and Bathurst (CSIRO, 2008c).

The Macquarie–Castlereagh catchment supports a diverse range of ecosystems, including the Macquarie Marshes and the Castlereagh Wetlands. The Macquarie Marshes Nature Reserve and the privately owned Wilgara Wetland and Mole Marsh are Ramsar listed sites, which support large numbers of waterbirds, up to 500,000 when flooded, as well as native fish populations (MDBA, 2012g). The wetlands were previously one of the biggest bird-breeding sites in Australia; however the Marshes have shrunk by 40% as a result of river regulation and the use of water for irrigation (MDBA, 2012g).

The climate of the lower Macquarie is hot and semi-arid, with summer-dominant rainfall averaging about 400 mm per year and evaporation of about 2,000 mm per year (MDBA, 2012g). The mean annual rainfall for the Macquarie–Castlereagh is 544 mm varying from about 850 mm in the east to 350 mm in the west. Rainfall varies considerably between years but summer is typically the wettest season in the north of the region while winter is typically the wettest season in the south, with the region's average annual rainfall remaining relatively constant over the past 50 years (CSIRO, 2008c).

The Macquarie–Castlereagh region contributes about 8.4 % of the total runoff in the Murray–Darling Basin (CSIRO, 2008c). Mean annual modelled runoff over the region for 1895 to 2006 is 35 mm and is reasonably uniform throughout the year, whilst the mean annual modelled runoff over the ten-year period between 1997 and 2006 was 33 mm (CSIRO, 2008c). The upper Macquarie catchment has winter-dominant rainfall of between 600 mm and 1,000 mm per year and evaporation of about 1,300 mm per year (CSIRO, 2008c).

Most of the river flow comes from rainfall in the catchments upstream of Narromine, but annual flows in the Macquarie River are extremely variable. Recorded flows at Dubbo range from 2% to 900% of average flow since records were first kept in 1898 (NSW DWE 1991; MDBA, 2012g).

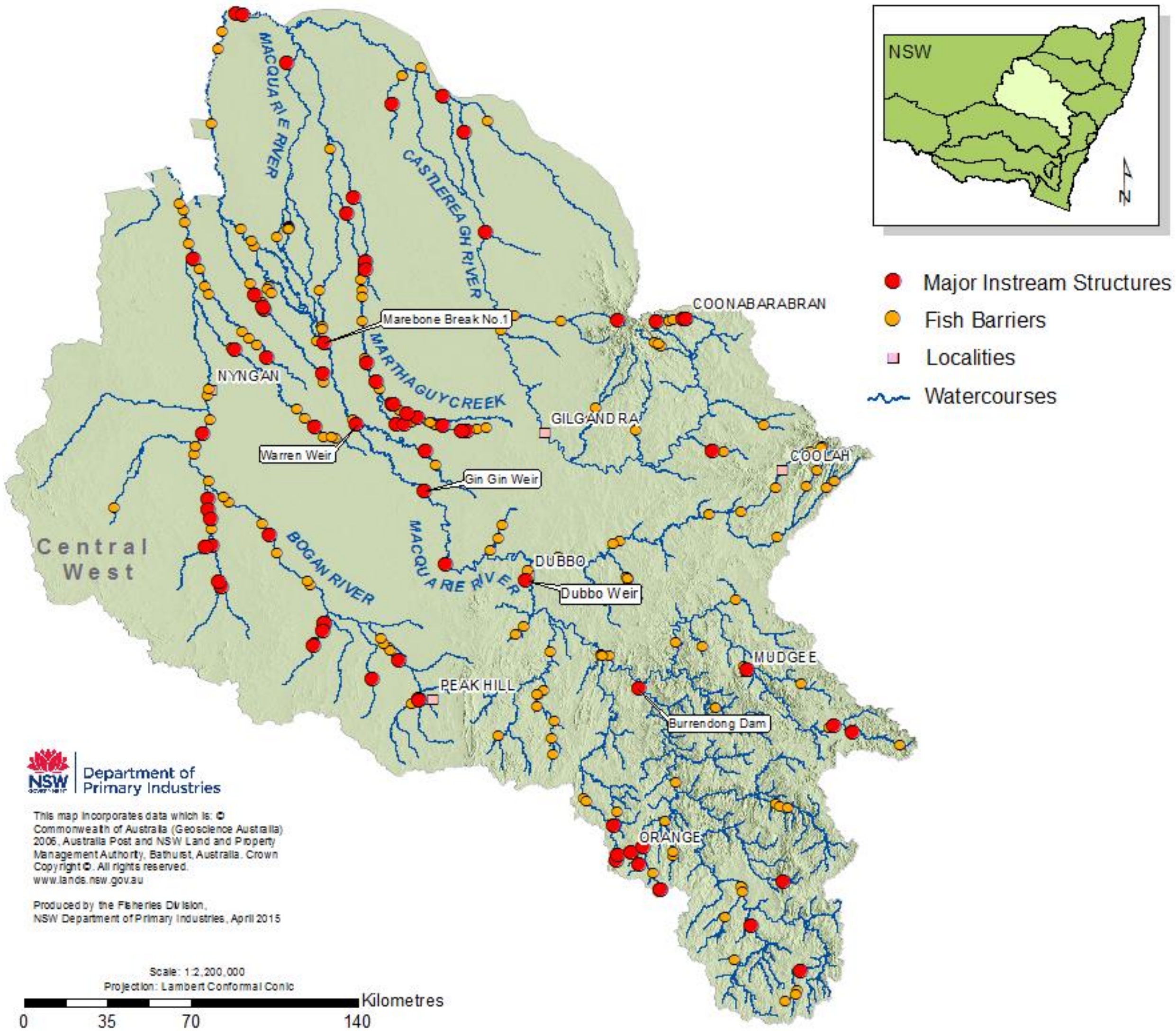
Decreasing channel capacity, irrigation and the presence of numerous effluent channels reduces the mean daily flow of the Macquarie from over 3,000 ML/day at Dubbo to less than 900 ML/day upstream of the Macquarie Marshes (Green *et al*. 2011). Further losses to the channels and wetlands of the marshes result in an average flow of less than 400 ML/day being recorded at the Carinda gauge downstream of the Macquarie Marshes (Green *et al*. 2011). By contrast the flow in the Bogan River increases with distance downstream as a result of the regulated supplies of water that enter the lower Bogan River via the Albert Priest Canal, Gunningbar Creek and Duck Creek (Green *et al*. 2011). Upstream of these effluents at Neurie Plains near Nyngan the mean daily flow is 241 ML, while downstream at Gongolgon the mean flow is over 700 ML/day (Green *et al*. 2011).

There have been several large floods in the Macquarie River at Dubbo, the largest of which since records began was in February 1955 when daily flow peaked at more than 440,000 ML, and despite the generally dry conditions that prevailed over the early half of the 1900s, there were many more small to moderate floods during this period, with peaks of 100,000 to 250,000 ML than in the latter half of the century as a result of there being no means of mitigating the floods (Green *et al*. 2011). Since the regulation of the valley in 1967, which introduced significant flood mitigation capabilities, there have only been three moderately large flood events in 1971, 1990 and most recently in December 2010, which peaked at 143,000 ML/day (Green *et al*. 2011).

For the Castlereagh catchment, flow in the river reaches a maximum at Coonamble, after which flows decrease significantly towards the end of the river system. The long term average annual flow at Mendooran is 86.7 GL (NSW Office of Water, 2011). In the early part of the record, and in the drought conditions of recent years there have been a number of years for which no flow at all has been recorded in the river, whilst the highest annual flows occurred in 1955 and 1956 with 600-700 GL recorded in both years (NSW Office of Water, 2011).

Major water storages in the region include Burrendong Dam (capacity 1,154 GL) on the Macquarie River and Windamere Dam (capacity 361 GL) on the Cudgegong River, whilst irrigation diversions also come from the Ben Chifley Dam (capacity 15 GL) on the Macquarie River. The Castlereagh River is classified as an unregulated system, and whilst there is no major storage dam within the catchment, a number of small weirs along the river provide local storage for irrigation, recreation and town water supplies (NSW Office of Water, 2011).

A number of barriers to fish passage have been identified in the Macquarie–Castlereagh region, with 238 major instream structures that have a head loss over 2m recorded in the valley, including Marebone Weir, Gin Gin Weir, Narromine Weir, Warren Shire Council Weir, Dubbo City Council Weir and Dubbo Weir (NSW DPIa, 2006; Rayner *et al*. 2008; Figure 19). Efforts to improve fish passage include construction of fishways at Gunningbar Creek Weir, Warren Weir, Duck Creek regulator, Crooked Creek regulator, Marebone Weir and Wellington Dam (NSW SWC, 2011).



<u>Figure 19</u>: Location of fish passage barriers in the Macquarie–Castlereagh valley, highlighting major instream regulating structures.

The BWS identifies a number of important asset sites for native fish in the Macquarie–Castlereagh catchment, including:

- Macquarie River – below Burrendong Dam to Warren: 'key movement corridor', 'high biodiversity', 'threatened species' and 'dry period/drought refuge'.
- Macquarie Marshes to Barwon, including lateral connectivity at the Marshes: 'key movement corridor', 'threatened species' and 'dry period/drought refuge'.
- Lower Bogan River to junction with the Darling River: 'key movement corridor', 'threatened species' and 'dry period/drought refuge'.

In addition, the BWS identifies priorities for increasing distribution of specific native fish species (expansion of existing populations and/or establishment of new populations). Those specific to the Macquarie–Castlereagh catchment include:

- Trout Cod (range extension): The distribution of trout cod in the Northern Basin is limited to the Macquarie catchment downstream of Burrendong Dam. Range expansion of the current population is a priority. Additional populations: establish 1-3 additional populations (candidate sites are primarily in within the Macquarie catchment).
- Silver Perch: (range extension): Expand the core range of at least 2 existing populations (candidate sites include populations in the Macquarie catchment).
- Freshwater Catfish: (range extension): Expand the core range of at least 3-5 existing populations (candidate sites include the Macquarie).
- Olive Perchlet (additional populations): Establish or improve the core range of 2-4 additional populations (candidate sites include the Macquarie River)
- Southern Purple-Spotted Gudgeon (additional populations): Establish or improve the core range of 2-5 additional populations (priority catchments include the Macquarie). Additional populations: establish or improve the core range of 2-5 additional populations (priority catchments include the Macquarie).
- Flat-headed Galaxias (potential for longer-term introduction using southern populations). Candidate sites include the Macquarie catchment.

The MDBA's environmental water requirements for the Macquarie Marshes currently include four site-specific flow indicators, measured at Marebone Break in the Macquarie Marshes (Table 20).

<u>Table 20</u>: Existing site specific flow indicators and associated ecological targets for the Macquarie–Castlereagh valley (MDBA, 2012g).

Asset	Site-specific ecological targets	Site-specific flow indicators
Macquarie Marshes (flows measured at Macquarie Marshes)	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 Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain.	100 GL within 5 successive months between June and April, with an event required 85% of years (low uncertainty) to 80% of years (high uncertainty). 250 GL within 5 successive months between June and April, with an event required 50% of years (low uncertainty) to 40% of years (high uncertainty). 400 GL within 7 successive months between June and April, with an event required 40% of years (low uncertainty) to 30% of years (high uncertainty). 700 GL within 5 successive months between June and May, with an event required 17% of years.

These flow indicators were based on a range of typical environmental watering events for the Macquarie Marshes, with a focus on EWRs for floodplain vegetation and colonial nesting water birds (NSW DECCW, 2010; MDBA, 2012g). Flow indicators described for flood dependent vegetation communities and waterbirds are 'expected to provide outcomes to support life-cycle and habitat requirements of native fish including provision of cues for spawning and migration and access to food sources' (MDBA, 2012g).

4.7.2 Aquatic habitat of the Macquarie–Castlereagh

The Macquarie–Castlereagh includes a diverse range of habitats, with the upper Macquarie River and tributaries generally flowing between defined channels and having limited floodplain habitats, whilst the upper reaches of the Cudgegong also flows through narrow valleys, widening into a wide alluvial floodplain above Mudgee (Green *et al*. 2011b; NSW Office of Water, 2011a). Further downstream, the Macquarie River between Burrendong Dam and Narromine is characterised by a well-defined, relatively narrow floodplain, with flooding being confined between the river banks. A number of small ungauged streams also enter the river in this reach (Green *et al*. 2011b).

From Narromine, the Macquarie flows across flat alluvial plains to join the Barwon River between Walgett and Brewarrina. The channel capacity of the river decreases progressively downstream of Narromine, with the lower Macquarie valley being characterised by numerous effluent channels (Green *et al*. 2011b). Between Marebone Weir and Carinda the river flows for 120 km through a meandering network of effluent channels and anabranches including the Macquarie Marshes. The marshes are a large wetland complex of shallow swamps, lagoons, creeks and floodplains that cover more than 200,000 ha when fully flooded (Green *et al*. 2011b).

The Bogan River starts in the Hervey Range near Peak Hill and flows north-west to Nyngan with a catchment area of approximately 18,000 km^2 (Green *et al*. 2011). The western side of the catchment is drained by four major tributaries: Bullock, Bulbodney, Pangee and Whitbarrow Creeks. The eastern catchment between the Bogan and Macquarie Rivers is ill-defined and has only one major tributary, Mulla Cowal with a catchment area of 1,000 km^2 (Green *et al*. 2011b).

The Castlereagh River rises in the Warrumbungle Range at elevation of about 850 metres. At the end of the valley the floodplain between the Barwon and Castlereagh Rivers is intersected by Wombat and Wanourie Creeks, which carry flows from the Barwon to the Castlereagh River during major floods (NSW DPI, 2008). The Castlereagh also includes extensive and high value ecological wetlands, which have been identified as resilient to the impacts of prolonged drought compared to other MDB wetlands (Thompson, 2010; Cairns and Driver, 2012). The headwaters of the Castlereagh River above Coonabarabran also provides good aquatic habitat, particularly the stretch just upstream of Teridgerie Creek (Baker and Raisin, 2000; Cairns and Driver, 2012).

NSW DPI has completed comprehensive habitat mapping for a 391 km stretch of the Macquarie River from Burrendong Dam to Marebone Weir (NSW Industry and Investment, 2010). The project identified 4,232 snags in the study area, equating to an average of less than 11 snags/km, with 16 out of the 20 reaches were found to be below the accepted benchmark of 13 snags/km (NSW Industry and Investment, 2010). Snags were either high stage (only accessible during periods of high flow) or low stage (able to be utilised at all times, which accounted for an average of 9.75 snags/km (NSW Industry and Investment, 2010).

A number of refuge pools were also identified, defined as areas deeper than 3 m during low flow conditions, with the deepest hole being greater than 9 m (NSW Industry and Investment, 2010). Availability of significant refuge areas was highly variable and generally decreased in a downstream direction, with tight river bends associated with deeper refuge pools (NSW Industry and Investment, 2010). The mapping also recorded presence of aquatic macrophytes, with submerged macrophytes being found to prefer water less than 1.4 m deep (NSW Industry and Investment, 2010). In addition to this, other habitat information is also available for the Little River and Bell River. Analysis of the available habitat in these rivers suggests that the region is in good condition, from an aquatic habitat perspective, comparable with streams in the Upper New England area (Little River Landcare Group Inc., 2003).

Ten barriers to fish passage were identified during the mapping, with major structures including Burrendong Dam, a low level cross on Wellington Falls Road (creating a barrier to passage during low flows), South Dubbo Council Weir (drowns out at flows >14,385 ML/day), North Dubbo State Weir (drowns out at >7,000 ML/day), Narromine Weir (prevents fish passage at 13,500 ML/day), Gin Gin Weir (drown out value unknown), Warren State Water Weir (not a barrier when fishway is operational), Warren State Weir (drown out rate not determined, but likely to be during major flooding), and Marebone Weir and Marebone break regulator (drown out rates not specified) (Figure 19).

The Macquarie–Castlereagh has also been recognised as a High Value Aquatic Ecosystem (NSW DPI, 2008). There is a native fish Demonstration Reach established in the Upper Castlereagh, comprising 48 km of river in three locations. Achievements in the Upper Castlereagh include introduction of 120 km of snags, removal of 400 tonnes of willow debris and sediment slugs, 3 km of riparian fencing, 1,400 trees planted and re-instatement of 14 km of fish passage (Molloy, 2007). Complementing these activities, similar action have been undertaken along the lowland Macquarie River, guided by management recommendations from the detailed habitat mapping project.

4.7.3 Fishes of the Macquarie–Castlereagh

The Macquarie–Castlereagh valley fish community includes 19 native species recorded or expected to occur in the catchment, and up to five alien species, two of which primarily occur in upland regions and are therefore not considered as part of functional groupings (Table 21). This list was compiled by reviewing current species distributions from the NSW DPI FFRD (records collected between 1994 and 2011; NSW DPI, 2012b) as well as Australian Museum records (as cited in Morris *et al*. 2001). The NSW DPI FFRD was analysed to determine fish community health (NSW DPI, 2015; Figure 20).

Of this community, the Lower Macquarie River is expected to support a total of 13 native species under reference conditions, including Murray Cod, Silver Perch, Olive Perchlet, Golden Perch, Purple-Spotted Gudgeon, Flat-Headed Gudgeon and Freshwater Catfish; however, only 11 species (including three alien species) were recorded during recent surveys (Rayner *et al*. 2009).

The upper Macquarie is expected to have historically supported 16 native fish species, including a number of threatened species such as Macquarie Perch, Trout Cod, Flat-Headed Galaxias, Silver Perch, Southern Purple-Spotted Gudgeon and Freshwater Catfish (GHD 2011; Cardno, 2011; Truman, 2012; Davies *et al*. 2012; Miles, 2013).

The Castlereagh is expected to support up to 14 native fish species, including Freshwater Catfish, Golden Perch, Macquarie Perch, Murray Cod, Flat-headed Galaxias, Olive Perchlet, River Blackfish, Silver Perch and Purple-Spotted Gudgeon (Davies *et al*. 2012; p.9).

Table 21: Fishes of the Macquarie–Castlereagh and associated Northern Basin functional group

(Threatened Species shaded green and indicated by an asterisk; alien species shaded red and indicated by a hash).

Functional group	Species	Zones	Valley comments
Flow Dependent Specialists	Golden Perch	Upland, slopes and lowland (both valleys)	Historical records/oral history suggests the species was once abundant in the lowland zone; locally abundant in the slopes zone (although not as abundant as Silver Perch); caught sporadically in the upland zone (particularly after major flood events); and rare in the montane zone (Truman, 2012; p8-10). Suggested causes of decline include construction of Burrendong Dam and introduction of Carp (Truman, 2012; pp.15-16). Only recorded in upland zone (low numbers) for Castlereagh and in low numbers (all zones) for Macquarie (Davies *et al*. 2012a; 151; 2012b; p.9).
*Flow Dependent Specialists	Silver Perch	Upland, slopes and lowland (both valleys)	Historically recorded as occurring in upper Macquarie catchments (Fish, Campbell and Duckmaloi Rivers) (Truman, 2007; Australian Government Department of Environment, 2013; p. 2). Silver Perch have been sampled in the Bogan, Macquarie or Castlereagh catchments since 2002 (Australian Government Department of Environment, 2013; p. 12). However, the NSW DPI FFRD includes records from the Macquarie River at Dubbo (2012), Narromine (2006) and Warren (2005). Also an earlier record (1975) from the Bogan River at Nyngan. Recorded at Macquarie Marshes in 2008 for the first time since 1989 (DECCW and Water NSW, 2010; p.19).
Flow Dependent Specialists	Spangled Perch	Upland, slopes, lowland (Castlereagh), slopes and lowland (Macquarie)	Second most abundant native species in Castlereagh catchment for SRA 2 data (primarily slopes and lowland) (Davies *et al*. 2012a; p.151). Not recorded in Macquarie for SRA 2 (Davies *et al*. 2012b; p.9).
*Inchannel Specialists	Murray Cod (2A)	Upland, slopes and lowland (both valleys)	National recovery plan identifies Macquarie River Murray Cod population (lowland zone) as being under 'serious threat', including form river regulation (including water extraction for irrigation), and no or low levels of recruitment (National Murray Cod Recovery Team, 2010; p.20). Recorded in low numbers in Macquarie system (slopes zone) for SRA 2 (Davies *et al*. 2012b; p.9) but not recorded in Castlereagh system (Davies *et al*. 2012a; p.151). NSW key asset sites include Macquarie River (Wellington to Warren and including Little River).
*Inchannel Specialists	Trout Cod (2A)	Upland and slopes zone (Macquarie) (not recorded in Castlereagh)	NSW FFRD records the species on the Macquarie River near Geurie and Dubbo. Also known to occur around Little River (Hassall and Associates, 2003; p.2). NSW Trout Cod recovery plan identifies species was once widespread in upper half of the Macquarie River (NSW DPI, 2006b; p.1). Stocked populations occur at the Macquarie River, near Dubbo and primary stocking sites include Namina Falls and Devil's Elbow in the Macquarie system (NSW DPI, 2006b; p.9). Historical/oral history records suggest the species was found in the Macquarie montane zone (particularly Fish and Macquarie Rivers), upland and slopes zones, but rare in the lowland zone (Truman, 2012; p.10).

Functional group	Species	Zones	Valley comments
*Inchannel Specialists	Freshwater Catfish (2B)	Montane, upland, slopes and lowland (both valleys)	Historical records/oral history suggests the species was once abundant in the slopes and lowland zones, relatively common in the upland zone and rare in the montane zone (Truman, 2012; p.11). Suggested causes of decline include construction of Burrendong Dam (Truman, 2012; p.15) and introduction of Carp (Truman, 2012; p.16). NSW DPI FFRD includes records from Castlereagh River (Binnaway and Coonabarabran), Macquarie and Bogan Rivers, Turon River, Cudgegong River Talbragar River, Duck Creek, Crooked Creek and Gunningbar Creek (Macquarie catchment). Recorded in low numbers (upland zone only) for Castlereagh in SRA 2 (Davies *et al*. 2012a; p.151) and in lowland zone (low numbers) for Macquarie (Davies *et al*. 2012b; p.9). NSW key asset sites include Macquarie River (Wellington to Warren and including Little River).
Inchannel Specialists	River Blackfish (2B)	Upland and slopes (Castlereagh) Upland, slopes and lowlands (Macquarie)	Historical research suggests that Blackfish were present in the Macquarie catchment's montane and upland zones; Fish and Cudgegong Rivers (near Rylestone and upper catchment), Lachlans Creek and Macquarie River near Bathurst (Truman, 2012; p.17). Also in larger rivers and creeks in the slopes zone near Wellington and Bells Creek (Truman, 2012; p. 17). Not recorded in the lowland zone. Population declines noted in most areas from 1930s onwards (now scarce in the region) (Truman, 2012; p.16). NSW DPI FFRD records species at Jews Creek, Winburndale Rivulet, Bell River, Cudgegong River, Molong Creek. Not recorded in SRA 2 data for either Macquarie or Castlereagh (Davies *et al.* 2012a; p.151; 2012b; p.9).
*Inchannel Specialists	Macquarie Perch (2B)	Upland and slopes (Macquarie).	Historical records suggest the species occurred in the Macquarie River around Bathurst, Turon River and near Oberon (including Duckmaloi and Campbell's river) and the Fish River (Truman, 2012; p.4,8). Also records in the lower Cudgegong and Bell Rivers (Truman, 2012; p.10). Rarely present in the lowland zone. Now considered extinct in the Macquarie system.
*Inchannel Specialists	Purple Spotted Gudgeon (2B)	Montane, upland, slopes and lowland (both valleys)	NSW DPI FFRD records species at Wuuluman Creek (Macquarie) in 2005. A unique population of the species also identified in the Little River catchment in 2013 (Wellington Times, 2014). Captive breeding and reintroduction actions have been undertaken to attempt to reintroduce Purple Spotted Gudgeon into catchments where they are believed to be locally extinct including the upper Castlereagh River (NSW DPI, 2013; p.3). Historical/oral history records suggest the species was found at Kings Creek, near Bathurst (Truman, 2012; p. 24) and Wuuluman Creek and Curra Creek (near Wellington) (Truman, 2012; p.27). NSW key asset sites include Wuuluman Creek.
*Floodplain Specialists	Olive Perchlet	Slopes and lowland (both valleys)	NSW DPI FFRD records species in the Bogan river. Historically also recorded at Nyngan (Morris *et al*. 2001). NSW key asset sites include Nyngan Weir Pool at Bogan. Not recorded in either Macquarie or Castlereagh for SRA 2 data (Davies *et al*. 2012a; p.151; 2012b; p.9).
*Floodplain Specialists	Flat-Headed Galaxias	Upland, slopes (Macquarie only)	Generally a Southern Basin species, but an isolated record exists from a lagoon near Bathurst and historical distribution included Macquarie (Lintermans, 2007). Not recorded in SRA 2 data (Davies *et al.* 2012b; p.9).

Functional group	Species	Zones	Valley comments
#Floodplain Specialists	Gambusia	Upland, slopes and lowland (both valleys)	Most abundant alien species for both Castlereagh and Macquarie (primarily slopes zone for Castlereagh and equally abundant in Macquarie) (Davies *et al*. 2012a; p.151; 2012b; p.9).
Generalists	Australian Smelt	Upland, slopes and lowland (both valleys)	Recorded in upland and slopes zones for both Castlereagh and Macquarie (Davies *et al*. 2012a; p.151; 2012b; p.9). Not recorded in lowland zones for both catchments.
Generalists	Bony Bream	Upland, slopes and lowland (Castlereagh) Slopes and lowland (Macquarie)	Recorded in all zones (primarily lowland zone) for Castlereagh (third most abundant native species (Davies *et al*. 2012a; p.151). Third most abundant native species also for Macquarie (primarily lowland zone) (Davies *et al*. 2012b; p.9).
Generalists	Carp Gudgeon	Upland, slopes and lowland (both valleys)	Most abundant native species in SRA 2 for Castlereagh (upland and slopes zones) (Davies *et al*. 2012a; p.151). Also most abundant native species for Macquarie (mainly slopes and lowland zones (Davies *et al*. 2012b; p.9).
Generalists	Flat-Headed Gudgeon	Upland and slopes zones (Macquarie only)	Recorded in slopes and upland zones for Macquarie (primarily slopes zone) (Davies *et al*. 2012b; p.9).
Generalists	Dwarf Flat-headed Gudgeon	Upland zone (Macquarie only)	Not recorded in SRA 2 data for Macquarie (Davies *et al*. 2012b; p.9).
Generalists	Mountain Galaxias	Upland zone (Castlereagh) and upland and slopes (Macquarie).	Not recorded in SRA 2 data for Castlereagh (Davies *et al*. 2012a; p.151). Second most abundant native species for Macquarie (all upland zone) (Davies *et al.* 2012b; p.9).
Generalists	Unspecked Hardyhead	Upland, slopes and lowland (both valleys)	Recorded in low numbers for Macquarie (all slopes zone) in SRA 2 data (Davies *et al*. 2012b; p.9). Not recorded in the Castlereagh (Davies *et al*. 2012a; p.151).
Generalists	Murray–Darling Rainbowfish	Upland, slopes and lowland (both valleys)	Not recorded in SRA 2 data for Castlereagh (Davies *et al*. 2012a; p.151). Recorded in slopes zone only for Macquarie (Davies *et al*. 2012b; p.9).
#Generalists (alien)	Carp	Upland, slopes and lowland (both valleys)	Second most abundant alien species for Castlereagh and Macquarie (primarily lowland zones) (Davies *et al*. 2012a; p.151; 2012b; p.9).
#Generalists (alien)	Goldfish	Upland, slopes and lowland (both valleys)	Third most abundant alien species for Castlereagh (mainly slopes and lowland zones) (Davies *et al*. 2012a; p.151). Also third most abundant for Macquarie (primarily upland zone) (Davies *et al*. 2012b; p.9).
#Generalists (alien)	Redfin Perch	Upland zone (Macquarie only)	Fourth most abundant alien species for Macquarie (all in upland zone) (Davies *et al*. 2012b; p.9).

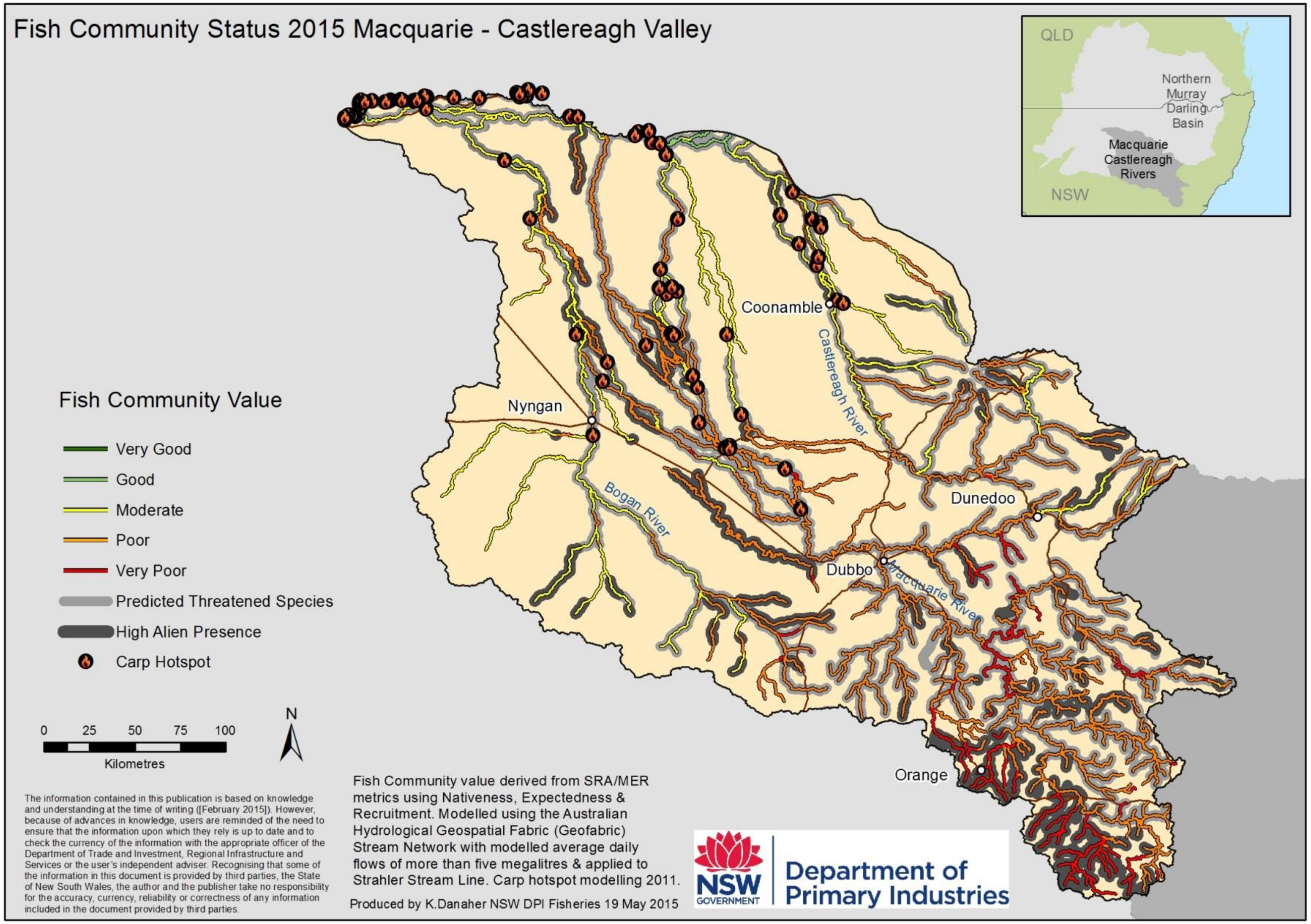


Figure 20: Fish Community Status for the Macquarie–Castlereagh valley, highlighting condition of fish communities and Carp hotspots.

Overall, the fish community of the Macquarie–Castlereagh valley is in poor health, with some reaches of waterway in a moderate condition, especially the Bogan and Castlereagh systems, and minimal reaches in a very poor condition, mainly restricted to upland tributaries (Figure 20). The valley also contains threatened species distributions, with the predicted range of threatened species covering the majority of major systems in the valley (Figure 20). Five of the species recorded in the Namoi valley are listed as threatened in NSW waters (Table 21), driving the predicted threatened species distribution across the Namoi. Purple Spotted Gudgeon, Freshwater Catfish of the Murray–Darling Basin, and the western population of Olive Perchlet are listed as Endangered under the FM Act 1994, whilst Silver Perch and Murray Cod are listed as Vulnerable under the FM Act 1994 and EPBC Act 1999, respectively. All of these species have an expected distribution across the Macquarie–Castlereagh valley, with historical and recent records indicating their presence throughout the area (Table 21; Figure 20).

Many factors have contributed to the deterioration of native fish in the Macquarie–Castlereagh valley including barriers to fish passage, changes to water flow, degradation of in-stream habitat and riparian vegetation, poor land management, and alien fish species (NSW DPI, 2007); however with some reaches of the fish community being in moderate to good condition there is a strong platform for fish recovery if management actions are developed and implemented appropriately.

Alien species recorded or expected in the Macquarie–Castlereagh valley include Carp, Gambusia, Goldfish, and Redfin Perch (Table 21). Rainbow Trout have also been recorded in some upland areas of the catchment, but have not been considered as part of functional groupings for the Fish and Flows in the Northern Basin, due to the restriction to upland systems. A number of alien species 'hotspots' are identified, including tributaries of the Macquarie River around Orange and downstream of Dubbo, and some tributaries of the Bogan River (Figure 20). This is consistent with initial Carp 'hotspot' identification, which includes the Macquarie Marshes and lower reaches of the Bogan, Macquarie and Castlereagh Rivers (Gilligan and Faulks, 2005; Gilligan, 2007; Gehrig and Thwaites, 2013). Carp recruitment hotspot analysis undertaken by NSW DPI also identifies hotspots in the lowland Bogan, Macquarie and Castlereagh Rivers (Figure 20). Differences between alien species mapping and Carp recruitment hotspots may be accounted for through methodological differences and the presence of other alien species in the fish community status mapping.

4.8 Other Northern Basin systems

Information sources from other unregulated Northern Basin systems were considered during Stages 1 and 2 of the project (for example, data from the Warrego, Paroo and Moonie Rivers provided by Expert Panel participants). Knowledge specific to the Northern Basin, such as the important role of cease-to-flow and low flow conditions for fish outcomes in ephemeral Northern Basin systems was also discussed during the workshop and has been incorporated in the functional groupings and conceptual models outlined in this report.

However, consistent with the approach identified in earlier project stages, NSW DPI has focused the Stage 2 assessments on the Barwon–Darling, Condamine–Balonne and priority reaches within regulated Northern Basin catchments. The proposed focus systems are also consistent with the MDBA's approach to determining EWRs during Basin Plan development. Detailed eco-hydrological assessments were not considered necessary for 'regions where current end of system flows are above 80% of without development flows' (Paroo, Ovens, Eastern Mount Lofty Ranges and Warrego) (MDBA, 2011; p.35). The MDBA recognised that there may be flow stress issues in these systems, however MDBA considered the issues to not be volumetric issues requiring a reduction in diversions, but rather issues that could be resolved through changes to river management. The Moonie was also excluded as 'it has the lowest contribution to the Basin's water availability and close to 80% of its natural flow' (MDBA, 2011; p.36).

On this basis, a detailed analysis of these other Northern Basin systems has not been included in this report. All information gathered over the course of the project (especially through the Literature Review in Stage 1 and the Expert Panel Workshop – see Appendix A) will continue to be considered for its relevance for fish and flow outcomes during Stage 3 of the project. Information gathered from these other systems could also be used inform future work for environmental water planning and delivery in the Northern Basin, such as development and review of LTWPs, WRPs or annual watering priorities.

5. Conclusion

The *Fish and Flows in the Northern Basin* project will improve the understanding of environmental water requirements for fish in the Northern Murray–Darling Basin, helping to ensure that the science underpinning the EWRs for fish species in the Northern Basin is current and based on best available knowledge. Targeted valley scale assessments for particular areas of the Northern Basin have helped describe flow related attributes of each valley, including BWS and existing flow indicators, fish barriers and connectivity issues, aquatic habitat condition, and fish community status, improving and consolidating the understanding of hydrological and ecological information for the Barwon–Darling, Condamine–Balonne, Border Rivers, Gwydir, Namoi and Macquarie–Castlereagh systems.

River regulation has had significant impacts on the natural flow regime in the majority of Northern Basin valleys, with increased surface water use reducing flows into most systems. Initial analysis of water management related information (not included in this document) has shown that the high degree of water development across the six focus valleys has impacted the frequency, occurrence and magnitude of flow events across the Northern Basin, influencing the hydrological, hydraulic and ecological conditions that native aquatic biota, including fish are reliant on for survival. The degradation of key habitat features across most major systems has been exacerbated by the modification of natural flows, having a significant effect on the status of native fish populations in the Northern Basin. A large portion of fish communities across northern systems are in a poor to moderate condition, with very few reaches containing fish communities in a good or very good status (Sections 2 and 4). However, the identification of these reaches, particularly fish communities in a moderate condition, presents excellent potential for population recovery if management decisions are developed and implemented based on best available science in a holistic adaptive framework.

The *Fish and Flows in the Northern Basin* project has provided the opportunity to assess the latest information related to fish and flow interactions across the Basin. The review of the most current literature and use of expert knowledge from the Northern Basin has helped to refine fish functional groups specific to conditions of the Northern Basin based on biological, hydrological and hydraulic similarities related to spawning, recruitment and movement. The formation of Northern Basin fish functional groups has enabled overarching conceptual flow models to be developed that identify the importance of certain flow characteristics and hydrological variability for groups of species. This information can be used to guide the development of the EWRs that can be used within Basin Plan Integrated Modelling Framework to model environmental outcomes of water recovery scenarios. The information will also guide environmental water management for a system over long term planning frameworks to maximise water use and environmental benefits; however further refinement of conceptual flow models is dependent on the availability of system specific flow related information to progress specific watering requirements.

6. Recommendations for future management in the Northern Basin

Fish and Flows in the Northern Basin project has considerably advanced information and thinking for water management in key valleys of the Northern Basin related to fish and river health outcomes. However, knowledge gaps still exist that require attention to enhance the development of future environmental water requirements. The outcomes achieved from water recovery and management in the Northern Basin would be greatly enhanced by the development and implementation of a complementary aquatic habitat rehabilitation and adaptive monitoring program. Consideration of the complementary actions are largely outside the scope of the *Fish and Flows in the Northern Basin* project; however it is important to acknowledge and progress the implementation of such programs, as addressing these gaps will be critical in enhancing the effectiveness of water recovery and management for the Northern Basin.

To improve native fish populations and river health throughout the Northern Basin, future environmental water management need to consider:

- **Undertaking further habitat mapping along other systems of the Northern Basin**
  As part of the *Fish and Flows in the Northern Basin* project detailed habitat mapping is being undertaken along the Barwon–Darling River between Mungindi and Wilcannia, with outcomes to be discussed in Stage 3. These activities will develop a comprehensive habitat database, including important habitat features such as large woody debris, in-channel benches, aquatic macrophytes, deep pools, and lateral connections for the system, allowing commence-to-inundate flow information to be developed. Complementing this activity, mapping and investigation of persistence for priority refuge holes in the Barwon–Darling and Lower Balonne is also being completed under the Northern Basin Review. These activities will significantly improve the knowledge of flow, habitat and connectivity requirements in the Barwon–Darling, providing greater certainty in developing specific environmental water requirements for fish in this system.
  Significant gaps still exist in our understanding of habitat features and their relationship to river flow across the remainder of the Northern Basin. Priority reaches for future habitat mapping similar to that being undertaken along the Barwon–Darling include the Lower Balonne, Gwydir and Border Rivers. Fine-scale habitat mapping in these systems would help develop a comprehensive habitat database for the Northern Basin, whilst further work in the Namoi and Macquarie valleys, which have had some level of habitat mapping completed but would benefit from flow interaction analysis of existing data, would help gain a better understanding of habitat and flow interactions for these systems. This information, coupled with fish community details and water management information, would allow critical flow thresholds to be identified in relation to inundation values, structure drown out requirements, and bankfull capacity volumes, helping to develop specific water requirements and strengthen water management actions across the Northern Basin.
- **Developing a fish management strategy for the Northern Basin**
  In addition to addressing key knowledge gaps related to environmental watering it is also important to acknowledge that flow management actions in isolation may not achieve the desired objectives and outcomes for river health and native fish populations in the Northern Basin. The critical riverine components of habitat and connectivity will also need to be considered in management planning and implementation, and whilst aspects of these components are integrated with flow management, additional complimentary actions will also be needed to achieve the most effective and efficient outcomes.
  These actions should include targeted habitat rehabilitation such as riparian management, including native revegetation, aquatic planting, and weed control; resnagging; erosion control; fish passage/connectivity remediation; cold water pollution mitigation, and; alien fish management. The development of valley scale aquatic management plans would benefit from and be guided by fine-scale habitat mapping activities, which would also collect information on the condition of aquatic and riparian habitat, and provide a prioritised and coordinated strategy that maximises water management for improved river health.
  The development of a fish management strategy for valleys will also need to consider and manage for potential negative impacts associated with the implementation of environmental water programs. In the Northern Basin this may include the proliferation of alien fish species and the occurrence of water quality impacts such as cold water pollution and black water

events. Using relevant flow related information of all fish species to form functional groups and develop flow regimes will ensure that the effects of both alien and native fish are considered, allowing water requirements that do not provide an unnecessary advantage to alien fish over native fish to be developed. The historical occurrence of cold water pollution and black water events in the Northern Basin also provides a challenge for the responsible delivery of environmental water. The impacts of cold water pollution are exacerbated downstream of major impoundments when water is delivered during warmer periods, with cold water releases from the bottom of dams severely reducing the natural warmer water temperatures, whilst black water events are intensified when periods of drought are punctuated by floodplain inundating flows that return organic matter to the river channel. Both of these impacts have the potential to reduce water quality and affect aquatic biota responses, with their consideration required in the development and implementation of flow regimes, as well as the implementation of appropriate mitigation actions, such as the installation of thermal curtains.

- **Committing to a long term, adaptive management plan driven by monitoring and evaluation**
  The hydrological and hydraulic variation required to restore key elements for fish in the Northern Basin will differ across functional groups, and whilst some benefits will be experienced across groups from different flow regimes, a long term commitment to adaptive management to flow and aquatic habitat management is required to maximise outcomes. Management plans that consider flow, habitat and connectivity need to include objectives for each functional group to ensure benefits are experienced across all native fish communities over relevant spatial and temporal scales. The development and implementation of a rigorous monitoring program is essential to help validate program assumptions and measure the success of flow delivery and water requirements against the program objectives. Information about the use of habitat by fish and their response to certain flow delivery scenarios will allow management plans to be evaluated and flow hydrographs to be adapted to ensure that outcomes are optimised, whilst providing confidence in stakeholders that decision making is being informed by biological information. Monitoring activities are being implemented as part of Commonwealth environmental watering actions (Long-Term Intervention Monitoring) and Basin Plan implementation; however it is important that any gaps in existing programs are identified and prioritised for action to ensure that outcomes from environmental watering across a range of different valley types are captured and used to guide management decisions. In addition to this, it is essential that monitoring information and research outcomes are communicated and readily accessible to advance knowledge and management actions across related systems where applicable.
- **Continued and sustained cross-disciplinary and inter-jurisdictional collaboration on information and knowledge of ecological relationships in the Northern Basin.**
  The Northern Basin Expert Panel workshop held as part of the project effectively established and fostered linkages between relevant academic and government experts. The *Fish and Flows in the Northern Basin Project* also gathered a range of relevant knowledge, expertise and information related to fish and flow relationships in the Northern Basin. While much of this information is readily accessible, other material occurs in variable formats and is held by a number of different institutions and agencies. To support the proposed long-term adaptive management plan and Northern Basin fish management strategy, it would also be useful to review existing data management and sharing arrangements relating to fish and flow information in the Northern Basin. This could form the basis of a knowledge management sub-strategy and development of appropriate information sharing arrangements that protect intellectual integrity and effort, while also promoting a collaborative and open approach to management of existing and future data and shared commitment to identifying and addressing knowledge gaps.

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Appendixes

Appendix A – Fish and Flows in the Northern Basin Expert Panel workshop outcomes

Purpose

The *Fish and Flows in the Northern Basin* project aims to improve the understanding of Environmental Water Requirements (EWRs) for fish in the Northern Murray–Darling Basin, with a particular emphasis on the Barwon–Darling, Condamine–Balonne and other regulated systems in the Northern Basin where there is sufficient existing information.

The purpose of the Expert Panel workshop was to:

- identify additional relevant supporting information, including data, grey literature, and unpublished work that may assist the project;
- define fish functional groups based on fish life cycles and their relationship to flows for Northern Basin systems;
- develop conceptual models that identify flow requirements for each fish functional group; and
- identify priority reaches for further investigation during Stage 3 of the project, which will specify EWRs for fish functional groups at key locations

Participants: Michael Hutchison (QLD DAFF), Jon Marshall (QLD DSITI), Stephen Balcombe (Griffith University), Neal Foster (NSW Office of Water), Ivor Growns (NSW Office of Water), Peter Jackson (consultant), Dean Gilligan (NSW Fisheries), Sam Davis (NSW Fisheries), Craig Boys (NSW Fisheries) Lee Baumgartner (MDFRC), Martin Mallen-Cooper (Fishways Consultant Services), John Koehn (Vic DELWP), Brenton Zampatti (SARDI), Heleena Bamford (MDBA), Adam Sluggett (MDBA), Andrew Warden (CEWO), Anthony Townsend (NSW Fisheries), Katherine Cheshire (NSW Fisheries) and Liz Webb (NSW Fisheries).

Overall Outcomes

1. Panel members agreed that a guild approach is suitable and necessary to support the *Fish and Flows in the Northern Basin* project. A hybrid approach based on Mallen-Cooper and Zampatti (2015), and Baumgartner *et al*. (2013) guild approaches was discussed and supported as a preferred method (noting that these focus on spawning as the main outcome. However, this will be validated through an expert opinion 'matrix' process, which was proposed during the workshop, for Northern Basin fish species based on known life history characteristics and expected responses to different aspects of the flow regime.
2. A range of conceptual model approaches were discussed, including population modelling and the development of 'model hydrographs' for fish guilds. Given the project time frame and resource constraints, it was recommended and agreed that a modified hydrograph approach be developed for the project. The approach will use agreed flow regime attributes discussed during the development of guilds, including Cease to Flow; Base Flow; Small in-channel Pulse; Large in-channel Pulse; Over Bank Flow, and; Stable Flows, to determine influence of life history outcomes for native fish, with the systems of the Northern Basin classified as *perennial* (characterised by continuous flow, but may experience short periods of low or no flow during drought or dry spells e.g. Border Rivers, Namoi); *occasionally intermittent* (generally semi-arid, experiencing up to 5 percent zero flows on a long-term basis); and *highly intermittent* (arid, experiencing up to 50 percent zero flows).

Actions

- Panel members are requested to provide any further written comments on the Northern Basin fish life history tables circulated prior to the workshop by **11 March 2015**. These comments could include corrections of factual errors in the table, suggestions regarding life history requirements and flow preferences for individual species and identification of additional references/supporting evidence. **COMPLETED**

- NSW Fisheries to undertake further work on the 'matrix' approach in consultation with relevant panel members (proposed to include Michael Hutchison, Jon Marshall, Harry Balcombe, Dean Gilligan, Craig Boys and Martin Mallen-Cooper) and provide to the Expert Panel for review by **20 March 2015**. The completed matrix will be used to validate and refine the proposed grouping approach for inclusion in the Stage 2 report. **COMPLETED**
- Panel members with relevant fisheries data/reports related to the Northern Basin systems are requested to provide this information to NSW Fisheries by **13 March 2015**. **COMPLETED**
- NSW Fisheries to contact people external to the Workshop Panel identified as potentially having access to relevant information to determine applicability and availability. **COMPLETED**

Introduction

Key points

- Adam Sluggett (MDBA) provided an overview of the Northern Basin Review (defined as catchments in the MDB upstream of Menindee Lakes), outlining what the program is trying to achieve, the new seven projects being undertaken, and what information is needed to determine the Environmental Water Requirements (EWRs).
- Anthony Townsend (NSW Fisheries) provided an overview of the *Fish and Flows in the Northern Basin* project, highlighting the three stages of implementation, and the objectives and proposed outcomes of the workshop.
- The Panel highlighted the importance of independent scientific input into the remaining stages of the Review (including in reviewing how the evidence base is used to define EWRs and having transparency for any proposed SDL amendments).
- It was mentioned that the Review is one part of a broader adaptive management framework. Future review processes should consider emerging research through the EWKR program, LTIM activities, and other related research projects, as well as outcomes of future planning processes (Long Term Watering Plans, Water Resource Plans, etc.). There is a need for longer-term research and monitoring projects in the Northern Basin, and this could potentially build on projects initiated under the Northern Basin Review.
- A collective approach to complementary actions as part of broader environmental water management is needed due to impacts on flow regimes and hydraulics (for example, the proposal to raise Walgett Weir by 0.8 m is likely to reduce lotic habitat between Walgett and Culmundi from 41 km to 21 km, increasing the drown-out value required to achieve environmental outcomes). **Stages 2 and 3 of the Project should highlight the importance of complementary actions both in terms of achieving EWRs and in managing risks.**

Fish functional groups

Key points

- A range of guild approaches currently exist to simplify a complex operational environment for the purposes of environmental planning and management. While these have been useful for ecology and river health, they are often difficult to apply directly to fish-flow relationships. Recent efforts include development of flow or 'functional guilds' based on 'physiological or behavioural similarities that could be linked to flow' and including migration, spawning and recruitment (Baumgartner *et al*. 2013; Cameron *et al*. 2013; NSW Department of Primary Industries, 2013). These approaches represent a significant step forward, but did not consider hydraulic information (velocity, turbulence and depth) and gave limited consideration to spatial scale. However, in practice fish often respond to hydraulic effects rather than simple flow volumes and discharges.

- Also discussed that discharge is not always a reliable indicator because a 10,000 ML/day flow can mean different things in different systems (and also within systems depending on channel morphology).
- Mallen-Cooper and Zampatti (2015) developed eco-hydraulic functional groups based on the hydrodynamics of habitats (either lotic or lentic) and the minimum spatial scale for spawning and recruitment to occur (micro <100 metres, meso (100s metres to 10s kilometres) and macro (100s of kilometres)). Spawning and recruitment were defined as including larval drift, but it did not include recruitment to mature adults. Broad life-cycle habitats (channel, off-channel/wetland, intermittent arid rivers, or generalists) were also considered. Importantly, this work focused on one aspect of life history and was not intended to measure long-term population resilience or meta-population dynamics. Recruitment and habitat guilds were defined as macro-lotic, meso-lotic or micro-lentic and flexible guilds of meso lotic-lentic and micro lotic-lentic. Threatened species tend to be channel specialists, along with wetland specialists and arid river specialists. Two species with flexible requirements (Freshwater Catfish and Dwarf Flat-Headed Gudgeon) also appear to be declining.
- Some potential limitations of the eco-hydraulic recruitment guild approach were discussed and included lack of information on some specific spawning/recruitment requirements (e.g. there was significant discussion on flow requirements for Murray Cod spawning and recruitment, and whilst the species does not appear to be a 'flow-spawner' it does require stable water levels during nesting season, but it is unclear whether Murray Cod benefit from low flow conditions with larvae appearing likely to survive low flows), and some species requiring low turbidity and access to aquatic vegetation rather than particular hydrology or hydraulics (including some threatened species in the Northern Basin).
- Unpublished analysis undertaken by NSW Fisheries using NSW River Survey data and flow information suggests the 'meso-lotic' guild includes some species that are negatively impacted by high flows (such as Murray Cod); however this is not confirmed by other research. It was suggested that this may be due to hydraulic or other factors rather than response to flow. It was agreed that existing scientific consensus on flow requirements for Murray Cod be used during the Project, but noted that this information may be subject to change following peer review/publishing of analysis.
- Many fish species have some 'plasticity' in terms of recruitment (particularly in relatively variable systems of the Northern Basin), which may relate to 'meta-scale processes'. Productivity is critical in driving recruitment, and especially vital for the survival of larval and early juvenile life-stages, particularly for some 'meso-lotic' species. Specific flows could be delivered to 'prime' areas for productivity prior to fish spawning and recruitment.
- Movement flow requirements for fish in the Northern Basin were also discussed. Recent acoustic tagging work by Queensland DSITI on fish movement (Bony Bream, Golden Perch and Freshwater Catfish) in the Moonie catchment suggests some fish species (Golden Perch and Freshwater Catfish) may move in response to relatively small flow changes (2 metre rise in water level, regardless of season or temperature). Numbers of (adult) fish undertaking upstream and downstream movement were relatively equal, but upstream distances were greater than downstream (up to 30 kilometres in some instances). Fish generally demonstrated high levels of philopatry. Freshwater Catfish appeared more mobile than expected.
- The concept of 'resilience' was raised, particularly in relation to arid river specialists. Drought refugia are critical in Northern Basin systems (varies between catchments). Existing work on drought resilience identifies a range of relevant variables including population stock, fecundity, ability to re-colonise, longevity, coping with lentic versus lotic flows and temperature and water quality tolerances, that could be used during development of fish guilds (McNeil *et al.* 2011; McNeil *et al*. 2013).
- Alternative approaches to developing functional guilds were discussed and included:

- developing a short-list of fish species based on vulnerability and proposing guilds accordingly, or focus just on threatened species (however, these species may not demonstrate immediate responses, making them less useful as an indicator);
- excluding generalist species as they are unlikely to be sensitive to changes in flow regime;
- using existing work by Queensland DSITI in developing the Warrego-Paroo-Nebine-Bulloo Water Resource plan, which modelled eco-hydraulic outcomes for fish-related assets (flow-spawning fish based on population viability of Golden Perch; migratory fish species based on maintenance of movement opportunities; absence of exotic fish species based on minimised abundance and distribution of Common Carp; Waterholes as refugia and river-forming process) to develop a risk assessment that could feed into a broader modelling framework (Queensland DSITIA, 2013);
- A 'bottom-up' approach using a full species list for Northern Basin systems and identifying likely responses (positive, neutral or negative) of life history stages (including spawning, dispersal and adult movement; spawning; recruitment; maintenance, and; condition) to particular aspects of the flow regime (cease to flows, base flows, small pulses, large pulses and overbank events, event stability and rate of rise). The matrix would also identify how often a species is likely to need these requirements over a given time period. Statistical analysis based on results would be used to develop groups of similar species, with some form of weighting or scoring possibly used for different aspects.

Outcomes summary

- There was general agreement from panel members that a guild approach is suitable and necessary to support the *Fish and Flows in the Northern Basin* project. Whilst there are a range of approaches to grouping freshwater fish in functional guilds developed for a variety of purposes, there is significant agreement between recent fish and flow guild approaches (Mallen-Cooper and Zampatti, 2015; Baumgartner *et al*. 2013; Cameron *et al*. 2013; and NSW Department of Primary Industries, 2013). Fish groupings based on resilience and resistance are also likely to be complementary to these approaches and may be worthy of further investigation.
- Martin Mallen-Cooper reviewed the eco-hydraulic recruitment guilds in comparison with the flow functional guilds outlined in Baumgartner *et al*. 2013. Based on this review, it was suggested that elements of spawning, recruitment, migration and some measure of scale were needed. Four groupings were identified (Figure 1 – noting that Freshwater Catfish could be added to Group B). Flows required to maintain and enhance fish maintenance and condition are also important overarching principles, along with the resilience of particular species and/or populations. Further refinement of groupings for individual species or systems identified in Figure 1 may be required (any such changes will be documented in the Stage 2 Report); however, the panel agreed that this approach was a suitable starting point for next stages of the project.

<u>Table 1</u>: Proposed groupings of Northern Basin fish species (Credit: Martin Mallen-Cooper) based on review of Mallen-Cooper and Zampatti (2015) and Baumgartner *et al*. (2013).

Proposed groupings of Northern Basin fish species	**Important attributes**
Group A • Golden perch • Silver perch	• Spawning cued by temperature and increased flow • Spawning migration over long distances • Larval drift and recruitment over long distances in perennial and semi-arid rivers; potentially shorter in arid river in small flow pulses • Migration for dispersal and recolonization cued by temperature and increasing flow.
Group B • Murray cod • Trout cod • Macquarie perch • blackfish	• Spawning cued by temperature • Nesting species (or specific spawning substrate – Macq perch) • Spawning migrations variable – short to moderate distances • Spawning in either 1) flowing-water habitats, or 2) Stillwater habitats (e.g. catfish) • Larval drift and recruitment over short to moderate distances, and potentially longer in large floods • Migration for dispersal and recolonization cued by temperature for most species, for Murray cod, cued by temperature and increasing flow.
Group C • Bony herring • Spangled perch • Freshwater catfish • Murray-Darling rainbowfish • Un-specked hardyhead • Carp • Dwarf flat-headed gudgeon • Flat-headed gudgeon • Carp gudgeons • Australian smelt • Goldfish	• Spawning cued by temperature • Spawning migration short • Spawning in both 1) flowing-water habitats, or 2) Stillwater habitats • Larval drift and recruitment over short to moderate distances, and potentially longer in large floods • Migration for dispersal and recolonisation cued by temperature

Proposed groupings of Northern Basin fish species	Important attributes
• Redfin perch • Eastern gambusia	
Group D • Southern pygmy perch • Yarra pygmy perch • Southern purple-spotted gudgeon • Flat-headed galaxias • Murray hardyhead • Olive perchlet • Darling River hardyhead	• Spawning cued by temperature • Spawning migrations short, potentially to off-channel habitats • Spawning in still water (or very slow flowing) habitats • Spawning may be dependent on macrophytes • Recruitment may be dependent on low turbidity • Larval drift minimal • Dispersal from nursery habitats (e.g. wetlands) to channel cued by flows and reconnection
Group E • Desert rainbowfish • Rendahl’s tandan • Hyrtl’s tandan	No input

Specific water requirements for fish at specific locations

Key points

- It was suggested that specific reach-scale EWRs include a 'context statement' identifying caveats around species groupings and identifying relevant threats and pressures for that system (e.g. weirs and other barriers, sedimentation, loss of channel complexity)
- EWRs should also identify likely outcomes from different flow scenarios, along with risks and a rationale for its inclusion. They could also include information on the flow velocity required, ARIs and flow volume over a given time period, and have applicability for use as a stakeholder communication tool identifying needs for particular species and likely consequences of failing to deliver the needed flow regime(s).
- 'Natural' hydrographs could be used as a starting point and grouping species based on their likely responses to key parts of the hydrograph. Threats and water management options could also be considered in adapting hydrographs for a specific location. It may also be possible to establish flow requirements on relationships between hydrology and hydraulics based on gauged stream flow data (i.e. what type of flow results in velocities greater than 0.3 m/s; weir drown out flow rates for stretches of rivers, etc.).
- EWRs may also need to consider rates of rise and fall – timing of recession events and whether they differ for different flow guilds. The natural hydrograph could be used as guidance for rates, noting that the natural hydrograph is currently used for determining the shape of an environmental demand in systems where the models can call water from storage. Rise/fall information could be included in terms of rates of rise per day (pass/fail in modelling framework).
- In addition to overbank events, flows that inundate flood runners are also important in increasing habitat availability for in-channel species (such as Murray Cod) and species benefiting from floodplain/wetland inundation.
- Current flow indicators for the Barwon–Darling are based on flows required for Murray Cod habitat inundation and connectivity. The target number of years currently identified are based on a 60-80% progress towards 'without development' frequency; however, there may be a better way to represent this (such as a number of events in a 10 year ARI). Murray Cod reproductive requirements were based on best available knowledge at the time EWRs were determined and included duration for eggs to hatch (and mean durations of the flow threshold under 'without development'), depth requirements and access to habitat. Timing was also based on Southern Basin Murray Cod spawning windows; however, Northern Basin Murray Cod appear to spawn earlier (August to September) based on Border Rivers data (Butler, 2013; pers. comm.; Growns, 2015; pers. comm.). The time frame for Murray Cod spawning and recruitment may also be insufficient (20 days as minimum but may be difficult to achieve in intermittent systems). Habitat mapping being undertaken as part of the Project will provide more detailed information on commence-to-flow thresholds for a variety of habitat features between Walgett and Wilcannia.
- Information for other native fish species in the Barwon–Darling is limited, but new studies on movement responses for Bony Bream, Golden Perch and Freshwater Catfish in the Moonie could be useful. This work is being replicated in the Culgoa and Narran systems to better understand the role of small flow pulses in triggering movement, however the outcomes of this research will most likely not be available in the timeframe of the Northern Basin Review.

Outcomes

- The development of specific EWRs for fish as part of the Project to remain focussed on the Condamine–Balonne and Barwon–Darling systems, using information sources identified as part of the workshop and Stage 1 literature review, including:
    - Species information for the Condamine (from external datasets and reports) provided as presence/absence format by site and sampling method.
    - Mesoscale movement project data provided as presence/absence format by site from the Condamine River, and Weir and Macintyre systems (Border Rivers).
    - Data from the Long-Term Intervention Monitoring Program in the Condamine and Warrego (key contact - Darren Smallwood).
- The potential to focus on other systems to develop specific EWRs will be possible through the information identified in the literature review and through the identification of additional information sources as part of the workshop, including:
    - Queensland DRM research on Golden Perch in the Weir River (incudes annual recruitment and otolith aging; key contact - Andrea Prior) and Moonie River sampling (key contact - Charlie Ellway).
    - Monitoring from the Warrego and Moonie regions (key contact - Harry Balcombe.
    - Water Resource Plan monitoring held by DSITI (including larval/spawning information from 2008-2009 on Freshwater Catfish and Murray Cod - Requests to access should be directed to Jon Marshall).
    - Research undertaken by David Moffatt in the Paroo, Warrego and Condamine systems (include age and class information). There may be difficulties in gaining access to this work. MDBA and CEWO could follow up as the work was funded through the National Heritage Trust - Murray–Darling 2001 – Fish Rehab Program (Zampatti, pers. comm.).
    - A range of data from the Condamine and Border Rivers, including external reports and long-term monitoring program information held by Queensland Fisheries (Darren Smallwood).
    - Reports on complementary monitoring undertaken by Glenn Wilson (University of New England) at Mole River and Tenterfield Creek.
    - Reports and supporting data on fish assemblages and responses to flows at Pindari Dam (Border Rivers) (NSW Department of Primary Industries, 2012; Wilson and Ellison, 2010; Growns, pers. comm.).
    - Gwydir monitoring provided by University of New England under the CEWO’s Long-Term Intervention Monitoring (Gavin Butler in NSW Fisheries may have more information on this).
    - Recent work undertaken by SARDI on reproduction and recruitment of Golden Perch in the Southern Basin in 2013-14 (including larval sampling and otolith analysis) (Zampatti *et al.* 2015).

Conceptual models

Key points

- John Koehn (Vic DELWP) gave a presentation on recent work to develop Carp population models (focused on the Southern Basin), with major points including:
    - Model structure was based on both life cycle history and movement as it contributes to population dynamics, and used best available science which was then applied to different populations, habitats and scenarios, with case studies focussed on Southern Basin systems.
    - Modelling suggests that overbank flows which inundate floodplain wetlands are more likely to boost high population growth for Carp, whilst artificial inundation

events are a slightly higher risk than natural floods (though difficult to quantify). It was suggested that terminology clearly distinguish between artificial floodplain inundation and natural flood events.
    - Populations are expected to decline under low flows, in-channel pulses or in-channel flows that inundate benches, but recurring floods every three years were associated with a strong population response.
    - Terminal lakes and weir pools also appear to have a large standing stock.
    - Next steps for the Carp modelling project include finalising of a technical report and development of summary materials and stakeholder engagement.
- The panel considered how current carp population modelling outputs for the Southern Basin could be adapted for the Northern Basin. Key differences are likely to relate to habitat types and presence of drought refuges; differences in river flow (more intermittent and variable); Carp standing stocks; fewer flow management levers (primarily reducing pumping rates in some systems), and; potentially also Carp mobility rates, inundation rates and levels of access to floodplain habitats. Input parameters for the model (biological information) would also need to be reviewed to ensure these are appropriate for the Northern Basin. Panel members suggested that artificial floodplain inundation is less prevalent in the Northern Basin, but that parts of the North have a high level of swampy marshes or terminal wetlands supporting greater densities of Carp populations relative to the river channels, and that high flows generally occur in the window for Carp spawning.
- Possible flow regimes that may benefit native species in preference to Carp could include delivery of large flows later in the season when native fish are more likely to respond (but prior to spawning temperature window for Carp if possible). However, this would severely limit options for environmental watering in some systems (down to 3 months or less for some Western systems). It is unlikely that flow management alone can advantage native species over Carp, and will require complementary actions; however, in general, environmental watering for in-channel outcomes (possibly earlier in the season) is unlikely to advantage Carp, relative to overbank events.
- Following on from the Carp population modelling, it was noted that Arthur Rylah Institute has been engaged by the MDBA to develop similar population models for a number of native fish species, incorporating both northern and southern features, noting that population modelling for some native fish species has already been undertaken in the Murray–Darling Basin, including Murray Cod (Todd and Koehn, 2009) and Trout Cod (Todd *et al*. 2004).
- In addition to this, two population models for Golden Perch have been developed for the Northern Basin (the Moonie catchment in Bond *et al*. in press; and the Warrego in Queensland DSITIA, 2013). These use a similar format to Carp population modelling and highlight the importance of spatial scale and refuge networks for Golden Perch in these systems. This modelling suggests that drying of refugia (for example, through excessive pumping off-take and reduction in connecting flows) has the biggest impact, particularly in areas where refuges are sparse. Warrego modelling for Golden Perch will be extended to the rest of the Queensland Murray–Darling Basin.
- NSW Fisheries noted other potential approaches to conceptual modelling (such as the life history model used in the BWS (Murray–Darling Basin Authority, 2014; p.41). This identifies flow influences on different life history stages for fish, and could be adapted for different systems and species to identify and quantify required flow attributes (such as seasonality, duration or ARI for different parts of the flow regime). It was suggested that Basin Plan objectives be used as the overarching framework for developing model objectives and targets. MDBA noted that Basin Plan objectives formed the basis of existing

EWRs. This project could potentially identify more detailed site-specific targets related to fish and aquatic biota and could draw on QEOs from the BWS.

- The model hydrograph approaches used in Baumgartner *et al*. (2013) could also be used in conjunction with the life history model, with some adaption for fish recruitment in the Barwon–Darling already undertaken (NSW DPI, 2013) and making some seasonality changes for the Northern Basin, including an earlier spawning season for Murray Cod and later high flows in late summer to early autumn. These hydrographs have primarily focused on spawning or recruitment; however, movement, condition, productivity or resilience may require different hydrographs (for example, movement for some species is triggered by relatively small pulses).
- Additional considerations discussed for development of hydrograph models in the Northern Basin included:
    - Sequencing of flows to incorporate follow-up pulses and development of longer term (decadal) flow regimes to address life history needs and assist with the maintenance for adult fish populations.
    - Converted flow volume to 'river rise' information to understand how flow relates to hydraulics. For example, 1 year ARI pulse of 4,762 ML/d for the Darling at Bourke represents a 3 metre rise in river levels (current conditions pulse is 623 ML/d) whilst a 1.5 year ARI of 20,000 ML/d (current conditions pulse is 12,000 ML/d) represents a 7 metre rise. In the Darling (which has a relatively narrow channel), continuous lotic habitat is likely to be provided at a 1 year ARI.
    - It was suggested that the differences between modelled and 'actual hydrology' be considered, focussing on areas of the hydrograph that have been impacted by water resource development for management action. For example, modelled flow history for the Barwon–Darling at Bourke suggests the system would have experienced periods of 'no flow'. While 'spell periods' may be useful ecologically, in reality these were generally of short duration (<30 days), with the river likely to have been flowing most of the time. It may be more important to focus on 'reliable conditions' (those that could be expected every year for short-lived species, or every five years for long-lived species), rather than either low flows or floods.
    - Flow related attributes were defined for consideration in model hydrographs, and included cease-to-flow (zero flows); base flow (minimal flows that connect pools); small pulses (inchannel flow pulses incapable of inundating in-channel features such as benches); large pulses (bankfull events that inundate benches and other in-channel features), and overbank (large flood events that inundate and connect off-channel habitat features).
- In general, cease to flow, base flows and small pulses are particularly important for ephemeral systems, and whilst they can be detrimental to fish maintenance and condition, they are important for productivity (promoting growth of biofilms). Base flows are also important in topping up and maintaining refugia in regulated systems. Large in-channel pulses that inundate benches are also important in promoting condition and maintenance in carbon cycling. Thresholds for pulses are likely to vary depending on the geomorphology and conditions of the particular system and reach.

Outcomes

- Panel members generally supported use of a modified hydrograph approach based on key components of the flow regime and expected outcomes for the life history stages of fish (e.g. spawning, recruitment, movement). Hydrographs should include relevant aspects of fish life cycles (spawning and recruitment, movement, maintenance, and condition). Where possible, both hydrological and hydraulic aspects should be included. Hydrographs should be based on the 'natural hydrograph' for the system under consideration and distinct hydrographs may be developed for each fish grouping. Flow components may have different characteristics depending on whether the system is perennial, occasionally intermittent or highly intermittent (Table 1).

- Other conceptual model approaches, such as population modelling were largely considered to be too complex and resource-intensive for the purposes of this project. Development of native fish population models for the MDBA through a separate process will provide valuable information relevant to the Northern Basin. The panel recommended that the MDBA consider any available outputs from population models at the conclusion of the project and through the broader Northern Basin Review.

Table 2: Expected fish outcomes to flow regime components in Northern Basin systems.

Highly intermittent = arid, experiencing up to 50 percent zero flows. Occasionally intermittent = generally semi-arid, experiencing up to 5 percent zero flows on a long-term basis. Components of flow regime, attributes, outcomes and ARIs are expected to be similar to highly intermittent systems, but with a decreased emphasis on cease to flow. Perennial = continuous flow under current levels of regulation, but may experience short periods of low or no flow during drought or dry spells). Northern Basin perennial systems can be divided into systems with terminal wetlands such as the Gwydir and Macquarie–Castlereagh; and connected systems such as the Border Rivers, Namoi and upper Condamine.

Type	Flow regime component	Attributes	Outcomes	ARI
Highly intermittent	Cease to flow	Defined as a series of disconnected pools. Relevant to naturally intermittent streams only. Key statistics include duration and period between two cease to flow events. Disconnected pools may have greater productivity (to a point and levels out for biofilm carrying capacity). Rate of drying and wetting are important. Negative aspects include vulnerability of populations: habitats need to provide enough waterholes to support regional biodiversity networks. The natural base flow period for the Northern Basin is August to September. Maximum drying and wetting cycle to promote productivity for wetland species could be 18 months (Beesley *et al*. 2011; Beesley *et al*. 2014)	Important for fish condition (productivity) and keeps Carp numbers in check. Critical depth and water quality are important. Supports structuring fish communities and overall resilience, also unique invertebrate fauna requiring access to dry river beds. Carbon cycling and biochemical processes quite different in dry periods, providing different nutrients to wet spells. Environmental outcomes and resilience depend on network of refuges (spatial scale determined by dispersal capacity of specific species).	Expected to occur annually. Maximum dry spell period defined relative to the natural hydrograph for the system.
Highly intermittent	Base flows	N/A	N/A	N/A
Highly intermittent	Small in-channel pulse	Defined as 'no bench inundation' but in-channel connection. Provides some level of longitudinal connectivity.	Supports all species for spawning and recruitment (necessary in preventing the drying of a system). Important for movement and connectivity for some species (can end isolation stage and 'reset' system even without movement). Small flow pulses (e.g.	Often annually but sometimes every second year. 700 days is the longest period without flow in Moonie (over 100 years). Events can be protected through changes to water sharing and pumping rules.

Type	Flow regime component	Attributes	Outcomes	ARI
			>2 m in the Moonie River, primarily natural events rather than irrigation releases) can be critical in triggering fish movement.	
Highly intermittent	Large in-channel pulse	In-channel flows that provide lateral and longitudinal connectivity and inundation of in-channel features such as benches as well as anabranches with low commence to flow thresholds. Important for productivity and system-scale connectivity, including tributaries.	Spawning, recruitment for all species, movement and productivity (for events of significant duration). Important for maintaining refuges and minimising geomorphological impacts of regulation. Creates some risk of increased Carp movement, particularly for starting access to floodplain.	Every second year (natural hydrograph).
Highly intermittent	Overbank events	Overbank flows, including floodplain and off-channel inundation. Important for productivity and system-scale connectivity, including tributaries.	Spawning, recruitment, movement and productivity, maintenance and condition. Provides 'ecosystem reset' and carbon cycling. Creates some risk of Carp movement and breeding (particularly regular long duration events in off-channel wetlands).	Dependent on individual system and size of the event (2-25 years typical for highly intermittent systems).
Occasionally intermittent	N/A	N/A	N/A	N/A
Perennial	Cease to flow	Disconnected pools. Does not usually occur in perennial systems, other than during periods of significant drought. Generally rare and short-lived (particularly in upstream reaches). May be relevant for management of disconnected wetlands that cannot be reconnected permanently and in identifying critical refuge habitats.	Not needed.	Never
Perennial	Base flows	Supports maintenance of refugia and habitat. Could also support winter conditioning and oxygenation through riffle habitats (Blackfish species and Galaxids)	Assists with spawning for generalist and in-channel spawners, also potentially conditioning (winter time) and maintenance.	Ongoing (all the time), particularly at dry times.

Type	Flow regime component	Attributes	Outcomes	ARI
		and historically may have benefitted small-bodied native species in terminal wetlands. Base flows in upper perennial streams may be higher now due to irrigation flows (but will be lower downstream due to offtakes).	Freshwater Catfish and Blackfish may also spawn on base flows.	
Perennial	Small in-channel pulses	Freshes, no bench inundation.	Movement, connectivity, dispersal, spawning, recruitment (generalists and other species e.g. blackfish with lotic specific spawning requirements). Could also get Murray Cod and Catfish spawning and recruitment with sufficient hydraulic diversity. Pulses may also trigger hatching for Macquarie Perch and Galaxids.	Based on natural hydrograph for each system but potentially annually (or two-three a year). Timing could be based on hatch times for Freshwater Catfish (however, base flow may be more important).
Perennial	Large in-channel pulses	Largely similar to highly and occasionally intermittent systems, including bench inundation, connectivity, increase in habitat flows. Large events may allow tributary connectivity (anabranches)	Similar to outcomes for highly and occasionally intermittent systems.	Based on the natural hydrograph in context of adjusted system and what is optimal for particular species or guilds. Could be between three and five years (using a 20 year time scale may be helpful). Maximum period between events depends on species and/or guild. Probably < five years between events.
Perennial	Overbank events	As for highly and occasionally intermittent systems.	As for highly and occasionally intermittent systems.	As for highly and occasionally intermittent systems.

Appendix B – Fish and Flows in the Northern Basin Expert Panel data matrix

Life history outcome	Species	Life stage	Cease to flow	Base flow	Event Stability	Small pulse	Large pulse	Overbank
Movement	Australian Smelt	adult/juvenile	0	1	0	10	5	5
Movement	Australian Smelt	larvae	0	0	0	20	10	5
Movement	Bony Herring	adult/juvenile	0	0	0	1	10	20
Movement	Bony Herring	larvae	0	0	0	5	10	10
Movement	Carp	adult/juvenile	0	1	0	5	10	20
Movement	Carp	larvae	0	0	0	10	20	20
Movement	Carp Gudgeon	adult/juvenile	0	5	0	10	5	1
Movement	Carp Gudgeon	larvae	0	1	5	1	1	1
Movement	Dwarf flat-headed gudgeon	adult/juvenile	0	5	0	10	5	1
Movement	Dwarf flat-headed gudgeon	larvae	0	1	5	1	1	1
Movement	Flat-headed gudgeon	larvae	0	1	0	10	5	0
Movement	Freshwater Catfish	adult/juvenile	0	5	0	10	10	10
Movement	Freshwater Catfish	larvae	0	1	5	10	10	10
Movement	Gambusia	adult/juvenile	0	5	0	5	1	1
Movement	Golden Perch	adult/juvenile	0	0	0	10	20	20
Movement	Golden Perch	larvae	0	0	0	5	20	20
Movement	Goldfish	adult/juvenile	0	5	0	5	1	1
Movement	Goldfish	larvae	0	5	0	1	1	1
Movement	Hyrtls Tandan	adult/juvenile	0	1	0	5	20	20
Movement	Hyrtls Tandan	larvae	0	0	1	10	10	5
Movement	Macquarie Perch	adult/juvenile	0	0	1	5	5	1
Movement	Macquarie Perch	larvae	0	5	5	1	0	1
Movement	Mountain Galaxias	adult/juvenile	0	5	0	5	1	1
Movement	Mountain Galaxias	larvae	0	5	5	1	1	0
Movement	Murray Cod	adult/juvenile	0	0	0	5	10	10
Movement	Murray Cod	larvae	0	0	0	5	10	10
Movement	Murray–Darling Rainbowfish	adult/juvenile	0	1	0	5	10	10
Movement	Murray–Darling Rainbowfish	larvae	0	10	10	5	5	1
Movement	Northern River Blackfish	adult/juvenile	0	1	1	5	1	1
Movement	Northern River Blackfish	larvae	0	5	10	1	1	1
Movement	Olive Perchlet	adult/juvenile	0	1	0	1	10	20
Movement	Olive Perchlet	larvae	0	1	0	1	1	1
Movement	Purple Spotted Gudgeon	adult/juvenile	0	1	0	5	10	20
Movement	Purple Spotted Gudgeon	larvae	0	1	0	1	1	1
Movement	Redfin Perch	adult/juvenile	0	5	0	10	5	1
Movement	Redfin Perch	larvae	0	1	0	1	1	1
Movement	Rendahls Tandan	adult/juvenile	0	1	0	5	10	10

Movement	Rendahls Tandan	larvae	0	0	1	10	10	5
Movement	Silver Perch	adult/juvenile	0	0	0	5	20	20
Movement	Silver Perch	larvae	0	0	0	5	10	5
Movement	Spangled Perch	adult/juvenile	0	0	0	5	20	20
Movement	Spangled Perch	larvae	0	0	0	5	10	10
Movement	Trout Cod	adult/juvenile	0	0	0	5	10	10
Movement	Trout Cod	larvae	0	0	0	5	10	10
Movement	Unspecked Hardyhead	adult/juvenile	0	1	0	5	10	10
Movement	Unspecked Hardyhead	larvae	0	1	0	1	1	1
Recruitment	Australian Smelt	YOY	0	10	0	10	10	10
Recruitment	Bony Herring	YOY	1	1	0	10	10	10
Recruitment	Carp	YOY	0	1	0	1	10	20
Recruitment	Carp Gudgeon	YOY	0	10	1	5	5	1
Recruitment	Dwarf flat-headed gudgeon	YOY	0	10	1	5	5	1
Recruitment	Flat-headed gudgeon	YOY	5	10	1	5	5	1
Recruitment	Freshwater Catfish	YOY	0	10	5	5	10	5
Recruitment	Gambusia	YOY	0	5	0	5	10	5
Recruitment	Golden Perch	YOY	0	0	0	10	20	20
Recruitment	Goldfish	YOY	0	5	5	1	5	1
Recruitment	Hyrtls Tandan	YOY	0	5	0	10	20	20
Recruitment	Macquarie Perch	YOY	0	0	20	10	1	5
Recruitment	Mountain Galaxias	YOY	1	10	10	5	1	0
Recruitment	Murray Cod	YOY	0	0	0	10	10	5
Recruitment	Murray–Darling Rainbowfish	YOY	0	5	1	5	10	5
Recruitment	Northern River Blackfish	YOY	0	10	10	5	1	0
Recruitment	Olive Perchlet	YOY	1	10	5	1	10	20
Recruitment	Purple Spotted Gudgeon	YOY	1	10	5	1	10	10
Recruitment	Redfin Perch	YOY	0	5	5	1	5	10
Recruitment	Rendahls Tandan	YOY	1	5	5	5	10	10
Recruitment	Silver Perch	YOY	0	0	0	10	10	10
Recruitment	Spangled Perch	YOY	0	5	1	5	20	10
Recruitment	Trout Cod	YOY	0	5	5	1	5	5
Recruitment	Unspecked Hardyhead	YOY	1	10	1	5	10	10
Spawning	Australian Smelt	adult	0	5	0	10	10	10
Spawning	Bony Herring	adult	0	1	0	10	10	10
Spawning	Carp	adult	0	5	0	5	10	20
Spawning	Carp Gudgeon	adult	0	10	20	1	0	0
Spawning	Dwarf flat-headed gudgeon	adult	0	10	20	1	0	0
Spawning	Flat-headed gudgeon	adult	5	10	10	1	0	0
Spawning	Freshwater Catfish	adult	5	5	20	1	1	1
Spawning	Gambusia	adult	0	10	0	5	1	1
Spawning	Golden Perch	adult	0	1	0	10	20	20

Spawning	Goldfish	adult	0	10	10	1	0	0
Spawning	Hyrtls Tandan	adult	0	5	0	10	20	20
Spawning	Macquarie Perch	adult	0	0	20	10	1	1
Spawning	Mountain Galaxias	adult	1	10	20	1	0	0
Spawning	Murray Cod	adult	1	1	20	1	1	1
Spawning	Murray–Darling Rainbowfish	adult	0	10	10	1	5	5
Spawning	Northern River Blackfish	adult	0	5	20	10	1	0
Spawning	Olive Perchlet	adult	0	10	20	0	5	10
Spawning	Purple Spotted Gudgeon	adult	0	10	20	1	0	0
Spawning	Redfin Perch	adult	0	10	10	1	1	1
Spawning	Rendahls Tandan	adult	1	5	10	5	10	10
Spawning	Silver Perch	adult	0	1	0	5	20	10
Spawning	Spangled Perch	adult	1	5	1	10	20	20
Spawning	Trout Cod	adult	0	5	20	1	5	1
Spawning	Unspecked Hardyhead	adult	0	10	20	1	5	5