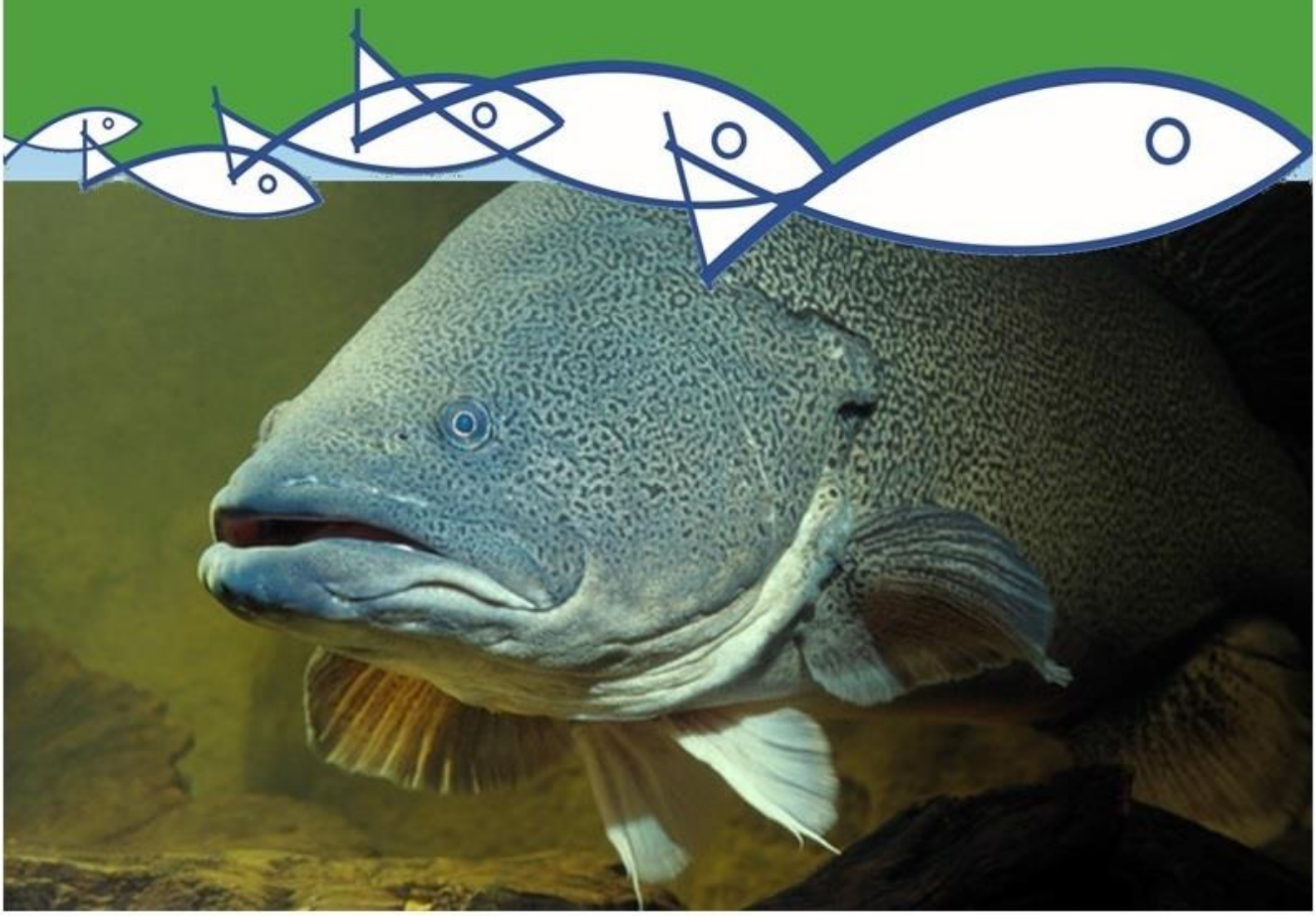
Fish and Flows in the Northern Basin:

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



Literature Review

prepared for the Murray-Darling Basin Authority

November 2014

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).

CONTENTS

1. Introduction

The following document outlines the findings from the scientific literature review undertaken 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 MDBA's Northern Basin Review, which aims to conduct research and investigations into aspects of the Basin Plan in the northern Murray-Darling Basin.

1.1 Background and objectives

Fish and Flows in the Northern Basin aims to improve the understanding of Environmental Water Requirements (EWRs) for fish in the Northern Murray-Darling Basin (MDB), with a particular emphasis on the Barwon-Darling, Condamine-Balonne and other regulated systems in the Northern Basin where there is sufficient existing information to support the project (Figure 1).

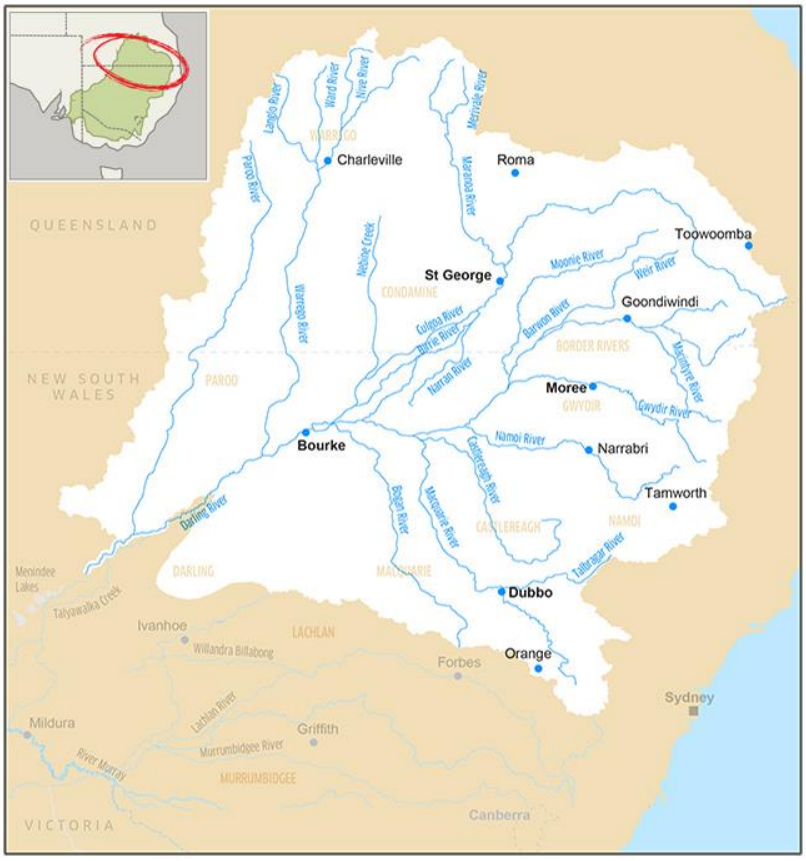

Figure 1: Map of the Northern Basin as defined by the MDBA and for the purposes of the Fish and Flows in the Northern Basin project (source: MDBA, 2011).

The project is being delivered in three stages:

- Stage 1 – literature review and project planning
- Stage 2 – Valley scale and preliminary reach scale assessments
- Stage 3 – Reach scale assessments.

Stage 1 focuses on project planning, including this literature review and planning for field work to map fish habitat along key sections of the Barwon and Darling Rivers during Stage 2. The second stage will use the information from Stage 1, as well as the outcomes from an Expert Panel workshop, to develop fish functional groups and conceptual flow diagrams, and determine the priority reaches where flow requirements could be specified.

Stage 3 will produce a consolidated technical report that identifies the findings of the project and provides recommendations for EWRs (e.g. flow magnitude, volume, duration, seasonality, frequency) at key locations. This stage of the project will also consider information on likely flow responses of carp to determine if flow requirements can be specified in a way that does not unnecessarily benefit carp over native fish.

As part of Stage 1 for the project, NSW DPI were asked to undertake a 'scientifically rigorous literature review to determine the specified systems and river reaches where existing information is sufficient to deliver the project activities and outputs' with a specific emphasis on information to improve the understanding of key fish community responses to specific flows. In broad terms, the review relates to:

- describing the fish communities present in each specified system, including any known carp hotspots
- defining fish functional groups based on fish life cycles and their relationship to flows, and categorising the species present into functional groups
- identifying different flow requirements that would benefit each fish functional group through the development of conceptual flow diagrams and consolidating existing information on flow requirements for these fish species.

Requirements for the *Fish and Flows in the Northern Basin* project also specify that the literature review should:

- summarise how the identified literature is relevant to the project
- focus on catchments-specific information, but also consider other information if demonstrated to be directly relevant
- include peer reviewed and unpublished work, as well as identified 'grey literature'
- provide an assessment of the relative merits of the information (such as the Best Available Scientific Knowledge or BASK categorisation system).

The review undertaken will inform the definition of specified systems for further investigation and the project methodologies and activities for Stage 2 and 3. Information from the review may also inform discussion at the Expert Panel workshop for the project, which is to be undertaken as part of Stage 2.

Consistent with project requirements, the literature review considered information relevant to the Barwon-Darling and the Condamine-Balonne (with a focus on the section downstream of St George) systems, with additional information collated for the regulated Border Rivers, Gwydir, Namoi, and Macquarie systems. The review also considered some information relating to unregulated Northern catchments and elsewhere, where it was judged to be directly relevant to the project.

2. Methodology

A review of available published academic and 'grey' literature was undertaken using relevant databases and search engines (Google Scholar, CAB Direct, Discovery and others). A number of unpublished reports from NSW DPI and other sources were also considered. Project documentation provided by MDBA identified a number of sources, and the Information Log developed by the science review panel for the MDBA commissioned Northern Basin Science Review project (Sheldon *et al*, 2014) also provided valuable resources.

Based on this review, information sources were categorised by:

- key word/title
- summary of information
- type of information source
- geographic area(s)
- merit of information

- reference(s)
- BASK categorisation (Appendix 1).

Categorisation according to BASK was based on previous approaches used by MDBA, as outlined in SKM 2010. This defines scientific information in terms of 'reliability' (personal opinion, grey literature, peer-reviewed science or consensus-driven science) and 'level of maturity' (proven science, confirmed science, applied science, virtually proven science, evolving science, reproducible evolving science, rationalised science, borderline science, scientific judgement, speculation, fallacious information or faith) (SKM, 2010; pp.17-18).

While acknowledging weaknesses of this approach (for example, Environmental Evidence Australia 2010; p.14), it is still considered a suitable starting point for assessing information as a relatively 'transparent and objective standard for decision-making' (Ryder *et al*, 2010; p.825). Given the absence of baseline information on fish community or ecosystem health, non-scientific information can also provide useful supplementary information, particularly where used in combination with other sources (see, for example Scott, 2005; p.5). This has therefore been included in the information log at Appendix 1.

Information sources were sorted in terms of their relevance to:

- fish presence/absence in the Murray-Darling Basin and Northern Basin as a whole
- fish presence/absence in specific Northern Basin catchments (focussing on the Barwon-Darling, and Condamine-Balonne, as well as other systems where information was sufficient)
- functional groups based on fish life cycles and their relationship to flows
- conceptual models for fish flow requirements that would benefit each functional group.

3. Linkage to the science underpinning the Basin Plan and the Northern Basin Review

The Sustainable Diversion Limits (SDLs) 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 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, referred to as the hydrological indicator site.

The flow requirements of each hydrological indicator site 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 ecological targets 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.

4. Summary of review

4.1 General Northern Basin fish information

Identification of fish species (presence/absence) in NSW Northern Basin catchments (both in terms of native and introduced species) will be relatively straightforward through use of the NSW Freshwater Fish Research Database. These records do not include historical information (prior to 1994); however a number of other sources such as the OZCAM database (OZCAM, 2014), published literature on historical records (for example Scott, 2005), other Basin-wide surveys such as the Sustainable Rivers Audit (SRA) (Davies *et al*, 2012a; Davies *et al*, 2012b; Davies *et al*, 2012c), and collation of fish survey datasets across the Basin (SKM, 2008), will add value to information in the NSW Freshwater Fish Research Database.

Information on fish presence and life cycles within the MDB and Northern Australia is also available through existing scientific and grey literature, for example Morris *et al*, 2001 (MDB-NSW focus); Moffatt and Voller, 2002 (MDB-QLD); Pusey *et al*, 2004 (North-Eastern Australia); Lintermans, 2007 (whole of MDB); and Moffatt, 2008 (MDB-QLD). Information developed by NSW DPI for key fish 'assets' in the Murray-Darling Basin (Gilligan, 2012 unpublished), and on weirs and fish passage in the Northern Basin (Nichols *et al*, 2012) will also provide useful supplementary sources regarding fish habitat and flow needs in the Northern Basin.

Access to information in Queensland MDB catchments may be more challenging as there are a number of different databases involved that are managed by different agencies, for example Queensland Department of Agriculture, Fisheries and Forestry project datasets, South-West NRM data for western systems, and Queensland Department of Science, Information Technology, Innovation and Arts databases. Further discussions are underway with Queensland agencies, and NSW DPI expects to be able to access much of the relevant information within the project time frame to assist in assessing Queensland systems. Additional clarification on Queensland data will also be pursued through discussions with relevant sources before and during the Expert Panel workshop (Stage 2). It is understood that a list of key fish 'assets' in the Queensland Murray-Darling Basin has been developed, which could also provide helpful information, particularly for prioritising reaches in relevant Queensland systems (Department of Environment, pers. comm.).

Queensland's Water Resource Plan (WRP) implementation report (2012-13) has also noted recent work undertaken in Queensland MDB areas, including:

- refined monitoring and research to inform ecological performance of WRPs and review of ecological assets (including the Environmental Flows Assessment Program)
- monitoring of fish and invertebrates from 2011-2013 under the SRA
- a review and synthesis of existing information and monitoring data relating to ecological assets of the Queensland MDB to support the MDB Monitoring and Evaluation Program (Department of Natural Resources and Mines, 2013; p. 125).

Discussions with Queensland agencies will clarify the relevance of information from these processes for the *Fish and Flows in the Northern Basin* project.

4.2 System specific information

4.2.1 Barwon-Darling

Some flow indicators developed by the MDBA for the Barwon-Darling were specifically intended to benefit native fish. For example, in-channel indicators measured at Louth (5,000 ML/day for ten days (49–66% of years); 10,000 ML/day for ten days (37–49% of years), and; 14,000 ML/day for ten days (28–37% of years), with a minimum of two events in a year (preferably one in summer/autumn and one in winter/spring) for each of the three flow indicators) 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 (Murray-Darling Basin Authority, 2012a; p.18, based on Boys, 2007), with the 10 day flow duration based on the known reproductive requirements of Murray Cod (Murray-Darling Basin Authority, 2012a; p.20).

Other flow indicators for in-channel, bankfull and overbank elements of the flow regime in the Barwon-Darling were also 'expected to be sufficient to support life-cycle and habitat requirements of native fish including provision of cues for spawning and migration and access to food resources' (Murray-Darling Basin Authority, 2012a; p.21).

Previous work by NSW DPI under the *Flows for Fish Recruitment in the Barwon-Darling* project provides a comprehensive and current body of knowledge regarding fish presence and flow requirements in the Barwon-Darling (NSW Department of Primary Industries, 2013b). Work under the current project could include a review of NSW fish catch records in the NSW Freshwater Fish Research Database to ensure that more recent records are being reflected. The project could also consider how 'eco-hydraulic recruitment' guilds could be applied in the Barwon-Darling (Mallen-Cooper and Zampatti, in press).

Habitat mapping (a proposed separate component of the *Fish and Flows in the Northern Basin* project) in the Barwon-Darling was recommended as part of the *Flows for Fish Recruitment in the Barwon-Darling* report and will be important in refining flow requirements. Peer review, either informal through the Expert Panel workshop or through some other process, could also be valuable in identifying fish community information for the Barwon-Darling system.

4.2.2 Condamine-Balonne

The MDBA assessed EWRs for two sites in the Condamine-Balonne catchment, namely the Lower Balonne floodplain system and Narran Lakes (Murray-Darling Basin Authority, 2012c, 2012d). Some flow indicators for the Lower Balonne are particularly relevant for native fish. More specifically, the 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 that provided an indication of how long the waterholes can hold water and what type of flow would be needed to connect waterholes along the entire length of the Culgoa and Narran Rivers, which would also benefit fish passage through the Lower Balonne (Murray-Darling Basin Authority, 2012c; pp.20, 25-26; Webb, 2009; Department of Environment and Resource Management, 2010a).

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. Achieving flow indicators for the Lower Balonne system more broadly were also expected to have benefits for a range of aquatic biota (Murray-Darling Basin Authority, 2012d; p.19). 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.

Other information on fish and flows has been found to be not as readily available for this catchment; however, there is a body of existing material (grey literature, academic work and unpublished information) that can be used for the *Fish and Flows in the Northern Basin* project. Queensland sampling database(s) are likely to provide the most rigorous source of data for the Condamine-Balonne system, whilst the use of supplementary sources such as SRA and others, is also likely to be required to supplement information that can be accessed from the Qld databases.

Recent work on fish and flow needs in the Condamine-Balonne and Border Rivers, including information on assemblage composition and condition in waterholes, and use of floodplain isotopes is also likely to be important in identifying fish communities and flow requirements for the Condamine system (Woods *et al*, 2012). Work by the Riverine Landscapes Research Laboratory on fish and food webs in the Lower Balonne could also provide useful information (Riverine Landscapes Research Laboratory, 2008; Webb, 2009).

Conceptual models developed as part of the Queensland Wetlands Program in the Condamine-Balonne catchment may provide valuable contextual information and also illustrate how flow-ecology relationship concepts can be presented in a visually appealing and engaging way. Case studies include the Dewfish Demonstration Reach; Police Lagoons near Dirranbandi and Lake Broadwater (Department of Environment and Resource Management, 2013a, 2013b, 2013c). For example, the conceptual model for Police Lagoons provides detailed information on Golden Perch lifecycle, diet and habitat as these relate to different aspects of the flow regime (Department of Environment and Resource Management, 2013c).

Earlier studies, which could be used as potential supplementary information, include an environmental assessment that informed the development of the Condamine-Balonne Water Allocation Management Plan (WAMP) (Department of Natural Resources, 2000) and plan review (Moffatt, 2002; Smith *et al*, 2006; Briszga, 2009). Environmental monitoring was undertaken by the (then) Queensland Department of Natural Resources and Environmental Management (DNREM) in the Lower Balonne floodplain (2000 to 2008); however differences in sampling approaches and interpretation for this data require careful consideration. This work varies in its level of focus on flow-ecology relationships, potentially lessening its usefulness. However, it could still provide helpful information on presence/absence of fish species in these systems.

Other work relating specifically to the Condamine catchment includes:

- the Dewfish Demonstration Reach (Condamine catchment, including parts of Myall Creek, Oakey Creek and the Condamine River) (Butcher and Kerezsy, 2009; Norris *et al*, 2011)
- studies of meso-scale movement of fish in the Condamine and Macintyre catchments (relevant for application of 'eco-hydraulic recruitment' guilds) (Hutchison *et al*, 2008). This research provides valuable information on the importance of sequencing and antecedent flows for native fish species, including the endangered Olive Perchlet.
- fish surveys at Nebine Creek, noting protection of base flows as important for retaining key refuge pools (Coleman *et al*, 2012)
- River Blackfish in the upper Condamine (includes other species sampled and habitat mapping) (Balcombe *et al*, 2011)
- laboratory-based research for habitat preferences of small-bodied fish species at Oakey and Myall Creek (King *et al*, 2013)

Research on the ecology of Narran Lakes could also provide useful supplementary information on fish communities and ecology/flow relationships (Thoms *et al*, 2002; E-water Cooperative Research Centre, 2008; Rolls and Wilson, 2010), complementing another Northern Basin Science Review project that focusses on waterbird breeding information.

Knowledge produced through the Northern Basin Review waterholes project, in particular detailed information on waterhole refuges in the Lower Balonne and understandings of how fish use

waterholes during times of low flow will also be relevant for the *Fish and Flows in the Northern Basin* project (Murray-Darling Basin Authority, 2014b).

4.2.3 Border Rivers

Flow indicators particular to fish needs were included in the MDBA's EWR report for the Lower Border Rivers Region (inundation of key habitat and nutrient cycling) (Murray-Darling Basin Authority, 2012e). In particular, indicators for the Lower Border Rivers (measured at the Barwon River at Mungindi) were set as:

- 4,000 ML/day for five days between October and December (24–32% of years)
- 4,000 ML/day for five days between October and March (45–59% of years)
- 4,000ML/day for 11 days with a minimum of two events in a year (preferably one in summer/autumn and one in winter/spring) (27–36% of years).

The MDBA's assessment considered earlier surveys of key habitat in the Lower Border Rivers (Department of Natural Resources and Department of Land and Water Conservation 1999; Boys, 2007) and MDBA analysis of modelled flow data (1895-2009) at Mungindi (Murray-Darling Basin Authority, 2013e; p.14). The reproductive requirements for Murray Cod also informed the choice of event duration from five to 11 days (Murray-Darling Basin Authority, 2013e; p.14).

Flow thresholds required for nutrient cycling (inundation of wet benches and inset floodplain areas) were based on work by Thoms *et al*, 2005, McGinness *et al*, 2002, and MDBA analysis of surveyed cross-sections of bench platforms and inset floodplain areas for the Barwon River upstream of Presbury Weir (Murray-Darling Basin Authority, 2014e; p.15). The EWR report noted the importance of flow pulses for Silver Perch (recorded in the Border Rivers region). It also discussed the importance of the Macintyre River and tributaries for Murray Cod and considered Golden Perch habitat and spawning needs (particularly variable spring and summer flows). However, beyond this the EWR assessment for the Lower Border Rivers did not specify particular fish species or provide detailed conceptual models for fish-flow relationships in the system.

Information on fish species present in NSW Border Rivers could be sought through use of the NSW Freshwater Fish Research Database, with supplementary information through other relevant sources such as the SRA2 results (Davies *et al*, 2012a; Davies *et al*, 2012b; Davies *et al*, 2012c). Where available, information for the Border Rivers from Queensland data will be sought through access to existing databases and supplemented with SRA2 and other sources.

Several sources relevant to the Condamine-Balonne also have application for the Border Rivers, including species abundance, condition and food webs (Woods *et al*, 2012), and meso-scale movement (Hutchison *et al*, 2008). Woods *et al* (2012) focused on sites in the Lower Balonne and Weir Rivers, investigating whether flood-derived benefits translated to more favourable conditions in waterhole refuges after flows cease, and if this confers greater population resilience, particularly for fish (Woods *et al,* 2012; p.vi). Results suggest that 'abundance and biomass of fish found in waterholes increased after flooding and the size of the response was positively correlated with the size of the floodplain adjacent to the waterhole (Woods *et al,* 2012; p.vii). However, this response was less pronounced than for other dryland rivers. The study also found that native fish abundance increased after floodplain inundation, but this was short-lived, whilst Carp also benefited from floodplain inundation, but was not affected by variable flow pulses. Contrary to expectations, individual body condition for fish did not improve significantly following flood events (Woods *et al*, 2012; p.vii).

Research conducted by Hutchison *et al* (2008) considered fish lifecycle movements between habitats and reaches in the Condamine and Macintyre Rivers. Relevant findings included new information on movement-related flow preferences for a number of native species (Carp Gudgeons, Bony Bream, Spangled Perch, Golden Perch, Dwarf Flat-headed Gudgeon, Hyrtl's Tandan, Murray-Darling Rainbowfish, and the endangered Olive Perchlet). This research also highlighted the importance of the

timing of flow releases, with diminished movement behaviour during winter and peak movements of Golden Perch and Bony Bream during autumn (Hutchison *et al*, 2008; p.x).

Other relevant sources for the Border Rivers include ecological condition assessment reports relating to development of the Border Rivers Flow Management Plan (Department of Natural Resources and Department of Land and Water Conservation, 1999); survey data and research relating to the Border Rivers demonstration reach (Butcher, 2007; Australian Wetlands, 2009); fish monitoring undertaken at Pindari Dam (Wilson and Ellison, 2010); and monitoring for Purple Spotted Gudgeon at Tenterfield Creek (Lewis and Growns, 2012).

4.2.4 Gwydir

The MDBA technical report on EWRs for the Gwydir includes specific flow indicators for fish recruitment and movement, based primarily on work by Wilson *et al* (2009) and analysis of the hydrograph (gauged on the Gwydir River at Yarraman Bridge) for 2007 (Murray-Darling Basin Authority, 2012f). Flow indicators for fish included an elevated baseflow with a flow of 150 ML/d or more for a period of 45 days or greater (between October and January), and a short-duration fresh of 1,000 ML/day or more for a period of two days or greater (between October and January), with a target frequency of 85% of years for both flow indicators. The timing of these flows was intended to coincide with the preferences of most native fish (Murray-Darling Basin Authority, 2012f; p.17).

Catch data from the NSW Freshwater Fish Research Database could also establish if any additional species (particularly threatened species or species of other significance) are present in the system. NSW DPI also recently completed aquatic habitat mapping along 100 kilometres of the Horton River for the (then) Border Rivers Gwydir Catchment Management Authority (NSW Department of Primary Industries, 2013c). This project identifies fish species known to be present in the Horton River, based on data from the NSW Freshwater Fish Research Database. It also provides valuable habitat information for fish species in the Gwydir system.

The Commonwealth Environmental Water Office's (CEWO) long-term intervention monitoring program (Commonwealth Environmental Water Office, 2014) is another potential source of information. In particular, the CEWO has advised of a forthcoming report on outcomes of environmental water releases in late 2013 for the Mehi River and Carole and Gil Gil Creeks, including outcomes of fish response monitoring (Department of Environment, pers. comm.).

Research under the NSW Wetlands Program (Wilson *et al*, 2009; Heagney *et al*, 2010; Spencer *et al*, 2010; Wilson *et al*, 2010; Spencer *et al*, 2012) provide additional potential sources of information. This work (undertaken from 2007-2008) surveyed waterbird and fish assemblages and habitats and the effects of specific flow characteristics on growth and condition of juvenile fish. The Gwydir Wetlands Adaptive Environmental Management Plan was also developed under the NSW Wetland Program and may provide useful contextual information (Department of Environment, Climate Change and Water NSW, 2010).

Research undertaken as part of the NSW Integrated Monitoring of Environmental Flows (IMEF) program is also relevant (Growns *et al*, 2001a, 2001b; Growns and Gehrke, 2005). This work considered fish-flow responses, including assemblage structures and native fish abundance in response to natural and managed flow scenarios and responses to flooding of inundated wetlands in the Gwydir and Namoi. However, earlier IMEF sampling in Gwydir and Namoi wetlands has some limitations. For example, annual sampling was not possible in all wetlands and a lack of large flood events over the sampling period (Growns and Gehrke, 2005; p. 23). Information from IMEF sampling programs is also included in the NSW Freshwater Fish Research Database.

Other relevant work that could be used primarily as supplementary or background information, include research on the reproductive biology of the freshwater catfish (Davis, 1975; Davis, 1977a; Davis, 1977b; Davis, 1977c) and an oral history project on fish and their habitat in the Gwydir

(Copeland *et al*, 2003; Schooneveldt-Reid, 2003). Additional historical information may also be sourced from earlier reports on barriers to fish passage in the Gwydir (Mallen-Cooper, 2000), fish species present in the lower Gwydir floodplain (Siebentritt, 1999), and fish distribution in NSW (Llewellyn, 1983).

4.2.5 Namoi

The MBDA technical report for the Namoi identifies flow indicators for bench inundation and draws on information from SRA and other literature (Murray-Darling Basin Authority, 2012g). A flow of 1,800 ML/day, measured as a minimum rate flow in the Namoi River upstream of Bugilbone (duration of 60 days total, with six day minimum, between July and June for 29–39% of years) was selected to 'further increase ecosystem function and provide various aquatic species with greater availability to habitat by wetting banks and benches present in the river channel' (Murray-Darling Basin Authority, 2012g; p.17). This indicator was based on earlier analysis of flows required to inundate in-channel and floodplain features in the Lower Namoi system (Foster, 1999) and MDBA analysis of modelled flow data.

An indicator of 500 ML/day at Bugilbone (75 days total with a 25 day minimum, between July and June for 41–55% of years) was also used to provide longitudinal connectivity in the Lower Namoi floodplain. This indicator was based on an assessment of geomorphic features in the Lower Namoi (Lambert and Short, 2004) and MBDA analysis of modelled flow data (Murray-Darling Basin Authority, 2012g; p.18). However, these indicators give limited consideration to particular fish species, and do not provide detailed conceptual models for fish-flow relationships in the system.

In addition to information from the SRA and NSW Freshwater Fish Research Database, potential information sources include research from the Namoi River Demonstration Reach (between Gunnedah and Narrabri) including monitoring data and key habitat mapping for the length of the demonstration reach (Fish Habitat Network, undated; NSW Department of Primary Industries, 2012a, 2012c, 2013d), and work on thermal pollution associated with releases from Keepit Dam (Preece *et al*, 2002; Boys *et al*, 2009; NSW Department of Primary Industries, 2012c).

Research undertaken on impacts of environmental flows on larval fish in regulated rivers under the IMEF program is also relevant (NSW Department of Primary Industries, 2012c), whilst other potential information includes research on barriers to fish passage (NSW Department of Primary Industries, 2006), and impacts of irrigation pumps on fish in the Namoi River (Baumgartner *et al*, 2011). Information on ecological features of the regulated Peel River produced to inform development of environmental water and access rules under water sharing plans for the Peel catchment is also useful context and identifies important aspects of the flow regime for native and invasive fish species (Foster and Lewis, 2009).

4.2.6 Macquarie

The MDBA's EWR technical report for the Macquarie does not provide specific flow indicators for fish recruitment or movement; however, there is an assumption that the flow indicators that support flood dependent vegetation communities and waterbirds will provide outcomes to support life-cycle and habitat requirements of native fish (Murray-Darling Basin Authority, 2012h).

In addition to the NSW Freshwater Fish Research Database information and SRA results, NSW DPI has also completed mapping of aquatic habitat on the Macquarie River between Burrendong Dam and Marebone Weir (NSW Department of Primary Industries, 2011). This work provides some information on fish species present in the region. Mapping results could also be used to support identification of 'priority reaches' for the *Fish and Flows in the Northern Basin* project.

Other potential supplementary information includes research undertaken by the University of NSW, which considered the role of small environmental flows, drought and refugia for freshwater fish in the

Macquarie Marshes (Rayner *et al*, 2009), climate change impacts on fish species (Jenkins *et al*, 2012) and responses of native and alien fish species to floodplain inundation (Rayner *et al*, 2014). Earlier analysis on ecological assets and values, ecological outcomes and EWRs were also completed under the Macquarie Marshes Environmental Management Plan, including surveys of fish communities and water quality (Jenkins *et al*, 2004; Jenkins and Wolfenden 2006; Jenkins *et al*, 2008). Academic research on temporal and spatial variability of fish communities in the Macquarie and Namoi rivers may also be relevant (Growns *et al*, 2003; Growns *et al*, 2006).

4.2.7 Other unregulated Northern Basin catchments

A non-exhaustive list of information sources for other unregulated Northern Basin catchments and other relevant (primarily arid zone systems in Australia) is provided at Appendix 1. However, given project time frames, and the project's focus on regulated and more heavily developed catchments in the Northern Basin, it is recommended that the *Fish and Flows in the Northern Basin* project focus on the Barwon-Darling, Condamine-Balonne, Border Rivers, Gwydir, Namoi, and Macquarie systems initially, with further investigation potentially undertaken in other systems of the Northern Basin during proceeding activities and stages of the project.

The proposed focus on regulated Northern Basin systems is also consistent with the MDBA's approach to determining EWRs during Basin Plan development. Detailed eco-hydrological assessments undertaken by MDBA explicitly excluded 'regions where current end of system flows are above 80% of without development flows' (Paroo, Ovens, Eastern Mount Lofty Ranges and Warrego) (Murray-Darling Basin Authority, 2011; p.35). 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' (Murray-Darling Basin Authority, 2011; p.36). Notwithstanding this, recent research on fish movement in the Moonie catchment could also be considered for its potential application in other Northern Basin catchments (Department of Environment and Resource Management, 2010a).

Information produced through a recent review of the Queensland Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003 could also be potentially used in other suitable Northern Basin catchments (Department of Science, Information Technology, Innovation and the Arts, 2013a, 2013b, 2013c, 2013d). In particular, risk assessments were undertaken as part of the environmental evaluation for flow spawning fish species and migratory fish species (both represented by Golden Perch) and the absence of exotic fish species (Carp). Development of 'meta-population' models for Golden Perch to assess different scenarios on annual and long-term abundance at a catchment scale is of interest (Department of Science, Information Technology, Innovation and the Arts, 2013d; p.24). Hydrological 'thresholds of concern' for periods of time between migratory opportunities for fish species could also be worthy of further consideration.

4.3 Carp 'hotspots'

Where possible, Carp hotspots within regulated Northern Basin catchments will be identified through analysis of records from the NSW Freshwater Fish Research Database (NSW DPI, 2013a), SRA2 information (Davies *et al*, 2012; Davies *et al*, 2012b; Davies *et al*, 2012c) and supplementary sources such as work in the Northern Basin more generally (Gehrig and Thwaites, 2013). A number of recruitment hotspots for Carp have already been identified in the Northern Basin, including the Barwon River and tributaries (upstream of Bourke), and the Darling River between Tilpa and Burtundy (Gehrig and Thwaites 2013; p.19).

Relevant literature on Carp responses to flow will also be considered, for example, emerging work (primarily focused in the Southern Basin) on Carp-flow population models (Todd *et al*, 2014; Forsyth *et al*, 2013) and quantifying changes to Carp populations from different environmental watering scenarios (Koehn *et al*, 2014). This work may have implications and learnings that would be relevant

to determining EWRs in the Northern Basin in a way that does not provide a disproportionate benefit to Carp over native fish species.

Other useful information relating to Carp-flow relationships (also primarily drawn from the Southern Basin) includes research on:

- river levels and temperature as triggers for Carp dispersal movements (Brown, 2014)
- influence of river flows on Carp nursery habitat and recruitment in the mid-Murray region (McDonald and Crook, 2014)
- comparative habitat use by Carp and other large-bodied native fish species in the Murray (Koehn and Nicol, 2014)
- timing of environmental releases and Carp invasion and recruitment responses (Conallin *et al*, 2012)
- models for Carp and native fish responses to environmental watering in Southern Basin wetlands (Gawne *et al,* 2012; Beesley *et al*, 2011, 2014)
- Carp recruitment in the Murray and Darling drainages and the role of flow regulation (including some Northern Basin catchments) (Driver *et al*, 2005).

Additional Northern Basin sources relevant to Carp include research on responses of Carp and native fish to flows in the lower Balonne (Riverine Landscapes Research Laboratory, 2008; Webb, 2009), and native and alien fish responses to environmental watering in the Macquarie Marshes (Rayner *et al*, 2014).

4.4 Functional groups

There are a range of approaches to classifying fish species in 'guilds' or 'functional groups' that aim to assist in managing river systems for fish outcomes. Models focused on 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 MDB 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).

Conversely, reproductive guilds have classified fish based on the timing of spawning, method of spawning, larval development, parental care and other life history and reproductive characteristics (examples include Humphries *et al*, 1999; Schiller and Harris, 2001; King *et al*, 2003; Growns, 2004). Other recent examples have also included information on spawning substrate components (Sternberg and Keen, 2013).

Recruitment models for 'arid zone refugia' have also been developed, suggesting that spawning and recruitment occurs primarily during zero flows in the channel refugia of arid rivers (Balcombe *et al*, 2006; Kerezsy *et al*, 2011; in Mallen-Cooper and Zampatti, in press; p.3).

Other recent approaches to classifying fish species have combined known recruitment and movement ecology for native fish. Examples include Baumgartner *et al* (2013) classification of four functional guilds in the Edward-Wakool system and modification of this approach in the Murrumbidgee (Cameron *et al*, 2013). Previous work by NSW DPI in the Barwon-Darling applied Baumgartner *et al* functional guild approach with modifications appropriate to the Northern Basin (such as differing temperature tolerances for some species); however further testing and exploration of this approach through an expert panel or research was not undertaken (NSW Department of Primary Industries, 2013b).

Alternative, but not necessarily incompatible, approaches to functional guilds have also been undertaken. For example, Mallen-Cooper and Zampatti (in press) have proposed development of 'eco-hydraulic recruitment guilds' for Murray-Darling fish, based on hydrodynamics, habitat and spatial

scale. Mallen-Cooper and Zampatti have questioned the applicability of recruitment guilds based on differing ecological responses to the same conditions by species within the same reproductive guild. A key difference for this approach is that water temperature and water quality information is not included. These guilds would be unlikely to be applicable in rivers impacted by reduced water temperature or water quality (Mallen-Cooper and Zampatti, in press).

Other guild approaches include development of 'drought'/thermal or resistance and resilience guilds (McNeil, 2004; McNeil *et al*, 2014). These approaches use a range of distribution, abundance and life history information, including spawning and reproductive styles, recruitment, water quality and temperature tolerances, feeding specificity, longevity, age to maturity, and dispersal ability to classify fish species into management groups.

There are advantages and disadvantages associated with adopting any of the approaches proposed by researchers during the *Fish and Flows in the Northern Basin* project. It is recommended that the Expert Panel workshop, an activity associated with Stage 2 of the project, consider available and emerging guild approaches and recommend a preferred approach for further development and adoption in the specified systems of the *Fish and Flows in the Northern Basin* project.

4.5 Conceptual models

Conceptual models are a widespread tool used by fish ecologists and in environmental water theory and practice. Work by NSW DPI in the Barwon-Darling catchment (NSW Department of Primary Industries, 2013b) developed preliminary conceptual models demonstrating the influence of flow scenarios on native fish recruitment (represented in terms of model hydrographs for each functional group). This approach has also been used for the Edward-Wakool and Murrumbidgee systems in the Southern MDB (Baumgartner *et al*, 2013; Cameron *et al*, 2013).

Model hydrographs are consistent with existing work on fish-flow relationships in the Barwon-Darling and several Southern Basin areas. They are also based on 'measurable objectives that can achieve multiple benefits through variability and consider the needs of multiple water users' (NSW Department of Primary Industries, 2013b; p.21). However, model hydrographs have primarily informed environmental water planning with a time frame of up to ten years rather than longer-term modelling scenarios (Baumgartner *et al*, 2013; p.14).

'Meta-population' models integrating hydrological and biological information have also been used recently to assess potential impacts of differing watering scenarios on abundance of Golden Perch, as a representative of flow spawning native fish species, in the Warrego, Paroo, Nebine and Bulloo catchments (Department of Science, Information Technology, Innovation and the Arts, 2013d). Models were used to generate annual time series of (Golden Perch) population abundance at the assessment node (represented by stream flow gauging stations) and catchment scales (Department of Science, Information Technology, Innovation and the Arts, 2013d; p.24). While Golden Perch were used to represent a flow-spawning functional guild for the purposes of these models, it was noted that 'further research is required to identify how nuances of the specific eco-hydraulic requirements for flooding may vary from species to species' (Department of Science, Information Technology, Innovation and the Arts, 2013d; p.23).

A number of approaches to conceptual models were also considered in development of the BEWS. These include Bayesian hierarchical models, which were applied in a range of contexts, for example in linking hydrological components (timing, magnitude, frequency and duration) to predict spawning and recruitment for species (Shenton *et al*, 2010); or conceptual models developed for specific species (Murray Cod, Golden Perch, Silver Perch, Freshwater Catfish and Carp) in Chowilla and the Lower Murray (Mallen-Cooper *et al*, 2011). These models allow for consideration of impacts of various scenarios on native fish in terms of habitat, spawning and recruitment.

Bayesian models have been used widely in environmental decision-making due to their flexibility, and ability to incorporate information of variable quality and uncertainty (Pollino and Henderson, 2010; p. 17). However, they also have a number of limitations, including reliance on expert judgement and challenges in dealing with continuous data or temporal and spatial variability (Pollino and Henderson, 2010; pp.22-30).

Conceptual models developed for species in Chowilla and the Lower Murray were also intended to inform management of the Chowilla Regulator, rather than a wider geographical spread (Mallen-Cooper *et al*, 2011; p.14). These types of models are also dependent on input data, which may be from differing sources and of variable quality (for example, see Mallen-Cooper *et al*, 2011; p.20).

Functionally-based preference or response curves have also been used to model fish responses to flows in the MBD. For example, the Murray Flow Assessment Tool (MFAT) used functional groupings for fish and other water-dependent taxa. Available literature and expert opinion were used to derive response curves for relevant flow-related habitat conditions, such as flow and spawning timing and flow duration (Lester *et al*, 2011; p.2459). However, MFAT has had limited success in predicting responses of real-life fish assemblages or functional groups (Lester *et al*, 2011; p.2463).

Preference curves for fish, waterbird and vegetation 'ecological elements' have also been developed for the SDL adjustment ecological elements method in the Southern Basin (Overton *et al*, 2014). The method tracks the condition of the ecological elements over time in response to a sequence of annual flow events (represented by MDBA's flow indicators). Fish include two ecological elements (classified as long-lived and short lived), and were selected as adequately representing the major responses likely to be exhibited at the scale that the ecological elements method is applied. However, the preference curves for fish are based on a 'simple-eco-hydrological model' and are not intended as a broader tool to inform environmental flow management (Overton *et al*, 2014; p. iii).

Further examples of conceptual models are provided at Appendix 1. It is recommended that the Expert Panel workshop to be conducted as part of Stage 2 of the project consider whether the hydrograph approach used by NSW DPI (2013b) in the Barwon-Darling is the most appropriate approach for this project, or if Bayesian or other model types should be pursued.

Time and resources required for conceptual model development depends on the availability and quality of input data and the type, number and complexity of models required. Models that are intended to be comprehensive can become too complex, while over-simplification can affect both the accuracy of predictions and ability to understand the system (Gawne *et al*, 2012; p.280). It is anticipated that the conceptual model approaches discussed above are able to be developed within the project timeframe; however, the Expert Panel will be asked to provide specific advice on the feasibility and applicability of available models, given project time-frames and resources.

5. Conclusion

NSW DPI considers that there is adequate information available to undertake the *Fish and Flows in the Northern Basin* project. The activities for the next stage of the project will focus on the Barwon-Darling and Condamine-Balonne systems; however there is information available to extend the assessment of flow requirements for fish to the Border Rivers, Namoi, Gwydir and Macquarie systems. Existing information identified will be used to help improve the understanding of EWRs for fish in the Northern MDB, and includes:

- **Fish information**
  A range of resources exist to assist the project in developing a comprehensive database of fish communities in the Northern Basin. At this point in time, the detailed assessment of flow requirements will focus on systems in Northern NSW, where more information has been collected; however discussions will continue with Queensland agencies to ensure the most relevant and current data is used when determining the potential to define flow requirements

for fish communities in the Queensland systems. The aim of the *Fish and Flows in the Northern Basin* project will be to compile fish community information in one resource to assist future management of Northern Basin systems. Information for unregulated Queensland systems (Warrego, Paroo and Moonie rivers) could also potentially addressed through a follow-up project.

- **Functional groups information**
  A number of methods for developing functional groups to inform fish and water management have been proposed across the MDB, including preliminary application of one approach in the Barwon-Darling system (NSW Department of Primary Industries, 2013b). However, no systematic review, application or testing of available approaches has been undertaken across the systems of the Northern Basin. The *Fish and Flows in the Northern Basin* project will assess available information on forming functional fish groups and test their applicability to the Northern Basin through an Expert Panel, determining the best approach to group fish species in Northern Basin systems for water management outcomes.
- **Conceptual models information**
  Numerous conceptual models have been developed for water management in the MDB to determine water requirements of fish in these systems. These models have had limited application in the Northern Basin. To address this gap, the *Fish and Flows in the Northern Basin* project will investigate the effectiveness of developing appropriate models for water management in specified systems of the Northern Basin. Relevant information collected during the project, including fish community details, habitat information, water management aspects, and functional group information, will be used to develop models that outline EWRs for fish in key Northern Basin systems.

Fish and Flows in the Northern Basin will help coordinate the compilation of existing information about native fish and water management in the Northern Basin, as well as generate new critical information through the Expert Panel workshop and field work activities, which will significantly improve understanding of fish and flow requirements in the Northern Basin. The project will also consider information on likely flow responses of Carp to determine if there are EWRs that can be specified in a way that does not give Carp an unnecessary advantage over native fish species.

Discussions and investigations with relevant Queensland agencies and other sources will continue to improve knowledge and information for the systems of the Northern Basin where the project has collected limited information to date.

Work undertaken during the *Fish and Flows in the Northern Basin* project is primarily intended to inform review of the science underpinning SDLs in the Northern Basin; however, project outcomes could also have relevance for other MDBA and Basin jurisdiction business, such as implementation and review of the BEWS, and in the development, assessment and accreditation of state WRPs and Long-Term Watering Plans.

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Appendix 1 – Information log for *Fish and Flows in the Northern Basin* project

General – Northern Basin

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
NSW Fisheries Freshwater Fish Research Database	NSW DPI Freshwater Fish Research Database, including primary catch data from the Barwon-Darling. Data is collated from a range of sources, (dates range from 1994 to 2013). Includes coordinate data for catch/observation information.	Varies depending on source data (some peer-reviewed, some grey literature), reproducible evolving science	MDB (NSW), NSW - other	Most comprehensive body of information regarding fish species presence/absence in NSW (including unpublished data). Potential limitations include differences between sampling/monitoring approaches from source programs. Does not include historical records (pre 1994) and does not include Queensland sampling data.	NSW DPI, 2013a	2-B1 (Adequate)
Queensland DRNM sampling databases	Advice from Queensland NRM agencies (Hutchison, pers. comm.) suggests there are a range of existing databases and other sources including relevant data on fish in Queensland MDB catchments. There does not currently appear to be a centralised information source for fish survey data in Queensland and information is handled/owned by a number of government and non-government sources.	Varies depending on source data (some peer-reviewed, some grey literature), reproducible evolving science	MDB (QLD)	NSW DPI access to databases for the purposes of this project is likely to be variable, depending on the type of information and system under consideration. A database managed by DSITIA may be the most readily accessible under project time frames. Subject to project time and resources, NSW DPI will also follow up with other suggested Queensland contacts to clarify access to relevant information.	Hutchison pers. comm.	2-B1 (Adequate)
Queensland key fish assets	Key fish assets in the Queensland Murray-Darling Basin - identified during Basin Plan development.	Grey literature, reproducible evolving science	MDB (QLD)	Supplementary information. May be particularly useful as a starting point for reach prioritisation for the Queensland streams. Relatively recent work (less than 10 years since work was undertaken) and potentially relevant to a number of Northern Basin catchments.	Department of Environment pers. comm.	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Australian Museum OZCAM database	Online database of records aggregated from faunal collections databases in Australian museums. Allows search for fish and IBRA region (Darling riverine plains, for example).	Peer reviewed, reproducible evolving science	MDB (general) Australia	Useful supplementary source for cross-checking of species presence/absence (particularly for historical records). Only includes records from museums (not comprehensive).	OZCAM, 2014	2-B1 (Adequate)
Fishes of the Murray-Darling Basin	Guide to fish of the Murray-Darling Basin (diversity, distribution and ecology of native and alien fish). Includes distribution maps for species based on Sustainable River Audit (SRA) valleys. Records sourced from state and territory fisheries agencies, museums, scientific papers and the Murray-Darling Basin Commission (MDBC).	Peer reviewed, reproducible evolving science	MDB (general)	Key information source/authoritative text. Does not include post 2007 records and notes a lack of information/data for fish distribution in some valleys (e.g. Castlereagh).	Lintermans, 2007	2-B1 (Adequate)
Sustainable Rivers Audit (SRA) 2 reports	Provide assessments of overall river condition for 23 river valleys in the Murray-Darling Basin, including fish theme based on expectedness, nativeness and recruitment. Also identifies numbers of native and alien fish species found across all sites in a valley or zone, biomass and trends in condition. Seven sampling sites for each zone (minimum of 18 sites per valley) – sampling undertaken in 2007-2008. Technical Report volumes 2 and 3 provide detailed assessment findings for individual valleys.	Peer reviewed (some elements include expert judgement and opinion), reproducible evolving science	MDB (general)	Useful supplementary source for cross-checking of species presence/absence. Non-comprehensive (does not include historical records, for example).	Davies *et al*, 2012a, 2012b, 2012c	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Distribution of fish in NSW	Survey of distribution of fish species in NSW (including NSW and ACT portions of the Murray and Darling drainage basins). Information is amalgamated from a number of sources, including museum records and surveys. Covers period from 1960 to 1983. Does not attempt to compare relative abundance across regions.	Grey literature, reproducible evolving science	MDB (general)	Useful supplementary source for cross-checking of species presence/absence. Relatively dated (more than twenty years since publication) and does not provide abundance information. Not concerned with flow-ecology relationships.	Llewellyn, 1983	3-B1 (Borderline)
Historical evidence of native fish in the Murray-Darling Basin	Collects, collates and reports observations of native fish in the Murray-Darling Basin from diaries of early explorers and settlers (including the Balonne, Barwon, Macquarie, Castlereagh, Darling, Lachlan, Macquarie, Namoi and Peel rivers).	Peer-reviewed, speculation	MDB (general)	Useful supplementary source for historical records. Non-comprehensive and not based on scientific observations.	Scott, 2005	2-C1 (Borderline)
Freshwater fishes of north-eastern Australia	Provides information on 79 fish species (primary focus on easterly flowing coastal rivers of Queensland and northern NSW), including distribution patterns and abundance, habitat requirements and biology.	Peer reviewed, reproducible evolving science	MDB (QLD), MDB (Northern NSW), outside MDB	Background/secondary source for some northern systems. Not primarily concerned with Murray-Darling Basin drainage species.	Pusey *et al*, 2004	2-B1 (Adequate)
Threatened and potentially threatened freshwater fishes of coastal NSW and the Murray-Darling Basin	Reviews biological and ecological characteristics and conservation status of thirty species of threatened and potentially threatened freshwater fishes in rivers and streams of coastal NSW and the Murray-Darling Basin. Information from NSW Rivers Survey (1997) and Australian Museum	Grey literature, reproducible evolving science	MDB (NSW)	Background/secondary source for threatened species in NSW. Relatively dated (more than 10 years since publication) and includes non-Murray-Darling Basin species.	Morris *et al*, 2001	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	records, NSW fisheries and independent consulting services and commercial catch records.					
Environmental flows for fish in the Queensland Murray-Darling Basin	Includes information on Border Rivers, Moonie River, Condamine-Culgoa, Warrego and Paroo Rivers.	Peer reviewed, reproducible evolving science	MDB (QLD)	Contextual/background information.	Moffatt, 1998	2-B1 (Adequate)
Key environmental assets	Information on NSW DPI key fish assets information	Grey literature, reproducible evolving science	MDB (NSW), NSW (other)	Contextual/background information.	Gilligan, unpublished	3-B1 (Borderline)
Fishway options for weirs of the Northern Murray-Darling Basin	NSW DPI report identifying priority sites for improved fish passage in the northern MDB. Includes information on migratory species of the Northern MDB (data from MDBA SRA to 2009, Darling and Warrego Rivers), Condamine (Moffatt, pers. comm.), Charlies Creek (M Hutchinson, pers. comm.) and NSW DPI Freshwater Fish Research Database.	Grey literature, reproducible evolving science	MDB (NSW - North), MDB (QLD)	Contextual/background information. Relatively recent information, including summary of unpublished sampling records.	Nichols *et al*, 2012	3-B1 (Borderline)
Fish and fish habitat of the Queensland Murray-Darling Basin	Provides information on fish and habitat in the Queensland MDB (focus on Darling River system).	Grey literature, reproducible evolving science	MDB (QLD)	Contextual/background information. Relatively dated (more than 10 years since publication).	Moffatt and Voller, 2002	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Collation and analysis of Murray-Darling Basin native fish sets	Project to collate all fish survey information from around the MDB and provide a basin scale overview of the status of native fish in the MDB and trends in abundance and distribution. Includes summary of records for Darling River Basin, Northern BEWS tributaries (Macquarie, Castlereagh, Namoi and Gwydir Basins), Border rivers, Paroo, Warrego and Condamine-Balonne basins.	Grey literature, reproducible evolving science	MDB (general)	Contextual/background information, relatively recent (less than 10 years since publication).	SKM, 2008	3-B1 (Borderline)
Wetland and river channel conceptual models	Conceptual models developed through the Queensland Wetlands Program, including area-specific case studies for the Dewfish Demonstration Reach, Police Lagoons complex near Dirranbandi and Lake Broadwater (Condamine-Balonne catchment) and Macintyre River (Goondiwindi to Boomi) (Border Rivers)). Case studies provide an outline of flow regimes and connectivity and information on different aspects of the flow regime. Also identify benefits to fish populations (e.g. role of low flows, flow pulses, high flow, overbank flows and receding flows for fish). Case study for Police Lagoons in particular details importance of the Lagoons to Golden Perch and other fish (including pictorial life-cycle conceptual models).	Grey literature, reproducible evolving science	MDB – North (CD, BR)	Contextual/background information, particularly for Condamine-Balonne and Border River catchments. Relatively recent information (less than 10 years since publication). Some case studies place a strong emphasis on flow-ecology relationships for native fish species at a number of life-stages.	DERM, 2013a, 2013b, 2013c, 2013d	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Integrated Monitoring of Environmental Flows (IMEF) - river flows and fish	Part of NSW IMEF project (Barwon-Darling, Gwydir, Hunter, Lachlan, Macquarie, Murrumbidgee and Namoi Rivers). Includes fish sampling conducted under the IMEF program (study period 1999 to 2002). Included thirteen sites on the upper, mid and lower Gwydir. Results are included in the NSW Freshwater Fish Research Database. The project also considered effects of flooding on permanently inundated wetlands in the Gwydir, Namoi and Lachlan. However, there are some limitations for sampling data in this part of the project (annual sampling not possible in all wetlands and lack of major floods during the sampling period (Growns and Gehrke, 2005; p.23).	Grey literature, reproducible evolving science	MDB – Gwydir, Barwon-Darling, Lachlan, Macquarie, Murrumbidgee and Namoi. Outside MDB – Hunter River	Supplementary information. Includes primary sampling information on fish species present and considers responses to flow (such as improved protection of low-flow habitats, wetland replenishment and rehabilitation of fish communities). Relatively dated (date of publication more than 10 years ago in some cases) and limitations with some sampling data.	Growns *et al*, 2001a, 2001b; Growns and Gehrke, 2005.	3-B1 (Borderline)

Barwon-Darling

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Fish in the Barwon-Darling	Assessment of fish communities in Barwon-Darling River (including tributaries).	Peer reviewed, reproducible evolving science	MDB (BD)	Contextual/background information. Relatively dated (more than 10 years since publication).	Harris, 1995	2-B1 (Adequate)
MDBA environmental water requirements reports (Barwon-	MDBA technical reports on environmental water requirements for Barwon-Darling (upstream of Menindee Lakes) and Lower Darling (Menindee Lakes, Darling Anabranch	Grey literature, reproducible evolving science	MDB (BD, Darling)	Context/background – outline existing environmental water requirements for the Barwon-Darling and Lower Darling systems, including knowledge base for fish.	MDBA, 2012a, and 2012b	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Darling and Lower Darling).	and Lower Darling) to inform establishment of Sustainable Diversion Limits. Barwon-Darling report notes the system as containing vital habitat for native fish populations including Murray Cod and Silver Perch and importance of flow patterns and variability for Golden and Silver Perch, Murray Cod, Flathead Gudgeons and Australian Smelt. Some flow indicators based on nutrient cycling, Murray Cod reproduction and inundation of key habitat. Suggests that 'flow indicators for in-channel, bankfull and overbank elements of the flow regime are expected to be sufficient to support life-cycle and habitat requirements of native fish, including provision of cues for spawning and migration and access to food resources' (p.21). Lower Darling flow indicators take fish passage into consideration, but are not specific to fish.					
Flows for fish recruitment in the Barwon-Darling	Assessment of flows for native fish recruitment in the Barwon-Darling River developed under the MDBA's Northern Basin program. Identifies fish species (native, including threatened species and non-native species). Classifies species by 'functional groups' and develops conceptual models demonstrating influences of flow scenarios on native fish recruitment.	Grey literature, reproducible evolving science	MDB (BD)	Relatively up to date and comprehensive analysis of fish species present in the Barwon-Darling system. Fish data derived from NSW DPI Freshwater Fish Research Database (collected between 1994 and 2011), Gehrke and Harris (2004) and Morris *et al* (2001). Does not include new information (e.g. new results of sampling or monitoring).	NSW DPI, 2013b	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	Focuses on Barwon-Darling River upstream of Menindee Lakes and Barwon River to its upstream extent at Barwon/Macintyre junction (main stem).					
Fish in the Darling system	Outline of fish species in the Darling River system	Peer reviewed, reproducible evolving science	MDB (Darling)	Supplementary information. Relatively dated (more than 10 years since publication) and does not apply to Barwon system.	Gehrke and Harris, 2004	2-B1 (Adequate)
Fish habitat assemblage relationships	Provides a framework for assessing fish habitat in large lowland rivers of eastern Australia to determine fish-habitat associations in the Barwon-Darling and Paroo rivers. Also reports on condition of fish habitat and fish assemblages in these rivers. Identifies fish species present in the Barwon-Darling (Boys *et al*, 2005). Proposes method for assessing fish-habitat assemblages in Barwon-Darling River at multiple scales (five 'river zones' between Goondiwindi and Wentworth) and sampling of three river reaches within each zone (12 in all) (mesohabitat, sites, zones and river system). One-off sampling conducted between 2001 and 2002.	Peer reviewed, reproducible evolving science	MDB (BD, Paroo)	Supplementary information. Relatively recent information (less than 10 years than publication in most cases) and applies to both Barwon and Darling systems.	Boys *et al*, 2005; Boys and Thoms, 2006; Boys, 2007; Boys *et al*, 2013.	2-B1 (Adequate)
The influence of changes to river hydrology on freshwater fish in regulated rivers of	Examines fish assemblage structure and abundances of individual fish species in six regulated rivers in the Murray-Darling Basin (Barwon-Darling, Gwydir, Lachlan, Namoi, Macquarie	Peer reviewed, reproducible evolving science	MDB (BD, Gwydir, Namoi, Macquarie, other)	Supplementary information. Does not include sampling information post 2002.	Growns, 2008	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
the Murray-Darling Basin	and Murrumbidgee) in response to hydrological change. Sampling conducted in 1999/2000, 2001/2001 and 2001/2002.					
Lowland Darling Aquatic Ecological Community	Ecological community listed as endangered in NSW, including 21 native fish species. Records based on Australian Museum and literature records (notes data deficient for many areas of Darling River drainages).	Grey literature, reproducible evolving science	MDB (Darling)	Supplementary information. Relatively recent information (less than 10 years since publication).	NSW DPI, 2007; Fisheries Scientific Committee, undated.	3-B1 (Borderline)
Fish assemblages, abundance and size (Barwon and Macintyre Rivers).	Examines fish assemblage structure, abundance and size frequency and hydrology across two sampling occasions and four reaches in the Macintyre and Barwon river catchments. Provides baseline data on distribution, size structure and assemblage structure.	Peer reviewed, reproducible evolving science	MDB (Barwon, BR)	Supplementary information, confined to Barwon River.	Balcombe *et al*, 2010	2-B1 (Adequate)
Fish passage – Darling River	Assesses barriers and priorities for improved fish passage in the Barwon-Darling system.	Grey literature, reproducible evolving science	MDB (Darling)	Supplementary information/background. Relatively dated (more than 10 years since publication).	Cooney, 1994	3-B1 (Borderline)
Golden Perch – spawning	Assesses reproductive ecology of golden perch at Menindee Lakes, Darling River. Identifies lower spawning temperatures for Golden Perch (<18.8°C), spawning occurrence at all times of the year and spawning in absence of floods.	Peer reviewed, reproducible evolving science	MDB (Darling)	Supplementary information/background to inform development of guilds and conceptual models.	Ebner *et al*, 2009	3-B1 (Borderline)

Condamine-Balonne

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
MDBA EWR technical reports	MDBA technical reports on environmental water requirements for Lower Balonne River Floodplain and Narran Lakes to inform establishment of Sustainable Diversion Limits. Lower Balonne Floodplain report notes that fauna in the Lower Balonne floodplain are included in threatened Lowland Darling River ecological community (based on Smith *et al*, 2006) and notes listed Commonwealth and state threatened fish species. Includes a flow indicator for 'broad scale floodplain inundation' (including long-term persistence of fish assemblages in lowland rivers (p.19) and 'critical in-channel habitat'. Narran Lakes flow indicators for native vegetation and waterbirds and Lower Balonne indicators expected to 'support life-cycle and habitat requirements of native fish '(p.18).	Grey literature, reproducible evolving science	MDB (Lower Balonne)	Context/background – outline existing environmental water requirements for the Lower Balonne and Narran Lakes, including knowledge base for fish.	MDBA, 2012c and 2012d	3-B1 (Borderline)
Lower Balonne Aquatic Environments – Review of data 2000-2004	Summary of data collected during monitoring events in the Lower Balonne since June 2000-Nov 2004 (privately funded). Provides baseline and trend data on ecological condition of aquatic environments within Lower Balonne region and comparison in nearby regions (Warrego and Moonie). Includes results of fish catch at sampling sites.	Grey literature (some peer review), scientific judgement	MDB (Lower Balonne)	Potential supplementary information (confined to the Lower Balonne). Relatively dated. Notes potential discrepancies between sample results. Privately funded monitoring. Does not 'provide a context for ecological response to wetting or drying events' (Sheldon *et al*, 2014, p.11).	EM, 2005a	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Lower Balonne Environmental Condition Reports	Results of monitoring in the Lower Balonne (privately funded) in May and November 2005 and 2006, March 2007 and May 2008, including fish catch data.	Grey literature (some peer review), scientific judgement	MDB (Lower Balonne)	Potential supplementary information (confined to the Lower Balonne). Privately funded monitoring. Does not 'provide a context for ecological response to wetting or drying events' (Sheldon *et al*, 2014, p.11).	EM, 2005b; 2005c; 2006a; 2006b; 2007a; and 2008.	3-B1 (Borderline)
Condamine-Balonne Environmental Flows Technical Report	Outlined environmental flow requirements for rivers and streams in Condamine-Balonne WAMP (including fish communities – based on research under 'Drought Impacts and Recovery of Wetlands and Fisheries Habitat' project – assessment based on abundance, richness, evenness of species, proportion of native fish and proportion of expected native species.	Grey literature, scientific judgement	MDB (CB)	Potential supplementary information. Relatively dated information and not primary data. Does not 'provide a context for ecological response to wetting or drying events' (Sheldon *et al*, 2014, p.11).	Department of Natural Resources, 2000	3-B1 (Borderline)
Riverine and ecosystem responses to flow in the lower Balonne and Border Rivers	Study conducted to improve understanding on the role of floods for the viability of populations of aquatic and floodplain organisms, including effects of floods on fish and other aquatic biota. Work conducted at sites in the lower Balonne and Weir Rivers (five sites on three occasions). Includes assessment of total species level abundance/biomass condition in relation to floodplain width, flow pulses and waterhole isolation.	Peer reviewed, reproducible evolving science	MDB (Lower Balonne, BR)	Supplementary information. Relatively recent work, including results of sampling in the catchment and information/analysis on relationships between fish and flow.	Woods *et al*, 2012b	2-B1 (Adequate)
Dewfish demonstration reach	Study of fish data for the Dewfish Demonstration Reach (Condamine Catchment, incorporating parts of Myall Creek, Oakey Creek and the	Grey literature, reproducible evolving science	MDB (Condamine)	Supplementary information. Relatively recent work, including sampling data. Restricted to a specific location and does not 'provide a context for ecological	Norris *et al* 2011; Butcher and Kerezsy, 2009	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	Condamine River). Monitoring and evaluation undertaken from September 2008 to late 2011 (intervention control and reference sites within and adjacent to the Reach).			response to wetting or drying events' (Sheldon *et al*, 2014, p.11).		
Fish survey of Nebine Creek	Fish surveys undertaken by Melbourne Water on Murra Murra and Bendee Downs properties (Nebine Creek, near Bollon and Cunnamulla). Eight sites surveyed in July 2012 (all within Murra Murra and Bendee Downs properties). Includes data on total fish abundance and distribution and size ranges.	Grey literature, reproducible evolving science	MDB (Condamine)	Supplementary information. Relatively recent work, including sampling data. Restricted to a specific location and does not focus on ecology-flow relationships (although does note protection of base flows as important for retaining key refuge pools).	Coleman *et al*, 2012	3-B1 (Borderline)
Lake Broadwater	Survey of bony fishes in Lake Broadwater (Condamine-Culgoa River) from 1984 to 1986. Includes species, abundance, food type and habitat.	Grey literature, reproducible evolving science	MDB (Condamine)	Supplementary information. Relatively dated (more than 20 years old). Restricted to a specific location and does not focus on ecology-flow relationships.	Leggett, 1988	3-B1 (Borderline)
Lower Balonne Science Review	Independent Scientific Review Panel report on the ecological condition of the Lower Balonne system. Discusses fish sampling undertaken by SKM/EM and NRM in Lower Balonne and adjacent Warrego and Moonie Rivers (notes sampling and design difficulties).	Grey literature, scientific judgement	MDB (Lower Balonne, Warrego and Paroo)	Background/supplementary information. Relatively dated (over 10 years old) and includes little to no quantitative information. Restricted to Lower Balonne Rivers (includes discussion on Warrego and Paroo).	Cullen *et al*, 2003	3-B3 (Borderline)
Lower Balonne Scoping Study – Environment Report and related reports	Informing five yearly review of Queensland Water Resource (Condamine Balonne) Plan 2004 (excluding Narran Lakes), includes a comprehensive listing of existing data and information sources and critical	Grey literature, scientific judgement	MDB (Lower Balonne)	Supplementary/background information. Does not provide primary data and some sources are relatively dated. Restricted to Lower Balonne system.	Smith *et al*, 2006; Moffatt, 2002; Briszga, 2009	3-B3 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	data and information needed to define water requirements. Literature review). A 5 year assessment review of science for the Condamine-Balonne WRP was also completed in 2009 (Briszga, 2009).					
River Blackfish in upper Condamine catchment	Report on distribution and abundance of northern River Blackfish in the Upper Condamine catchment, based on results of field surveys undertaken in May 2010 and 11. Also includes results of other species sampled and habitat mapping.	Peer reviewed, reproducible evolving science	MDB (upper Condamine)	Supplementary information. Relatively recent information, including sampling data. Restricted to specific location (upper Condamine) and species (River Blackfish). Does not focus on flow-ecology relationships.	Balcombe *et al*, 2011b	2-B1 (Adequate)
Mesoscale movements of fish species	Project investigating mesoscale movements of fish species and/or life history stages based on tagging and release. Study areas Condamine River and Macintyre River (both river pool and lagoon habitats). Species include Carp Gudgeon, Murray-Darling Rainbowfish, Hardyhead, Olive Perchlet, Spangled Perch, Hyrtl's Tandan, Freshwater Catfish, Bony Bream and juvenile Golden Perch and Murray Cod.	Grey literature, reproducible evolving science	MDB (Condamine and Macintyre)	Supplementary information on fish movement and life history in the Condamine River. Relatively recent work including sampling information (likely to be supplemented by information sourced from Queensland database(s). Location specific (Condamine and Macintyre).	Hutchison *et al*, 2008	2-B1 (Borderline)
Narran Lakes Ecosystem Project	Research on ecology of Narran Lakes and Lower Balonne floodplain by the CRC for freshwater ecology and others. Thoms *et al*, 2002 provides a review of hydrology, ecology and cultural issues of the system, including fish species/communities. Fish A fish	Peer reviewed, reproducible evolving science	MDB (CB - Narran Lakes)	Supplementary information, including primary sampling data. Part of integrated flow-ecology research project for Narran Lakes. Relatively recent information (e Water CRC work less than 10 years since publication). Restricted to a specific location.	Thoms *et al*, 2002; E-water Cooperative Research Centre, 2008	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	sampling program was subsequently undertaken under the project (e Water CRC, 2008; pp.20-21). Sampling at six sites (two river sites and four lake sites) on four occasions in 2004.					
Narran Lakes	Examines spatial and temporal patterns of fish assemblages in river and floodplain habitats following flooding at Narran Lakes.	Peer reviewed, reproducible evolving science	MDB (CB - Narran Lakes)	Relatively recent work, including a focus on fish-flow relationships. Associated with a specific location.	Rolls and Wilson, 2010	2-B1 (Adequate)
Habitat preferences of small-bodied native fish (Oakey and Myall Creeks)	Tank-based assessment of habitat preference for small-bodied native fish species in Oakey and Myall Creeks, Condamine system. Includes Murray-Darling Rainbowfish, Carp Gudgeon, Un-specked Hardyhead, juvenile Murray Cod and juvenile Golden and Silver Perch.	Grey literature, reproducible evolving science	MDB (CB)	Supplementary/background information for flow requirements applying to small-bodied fish in the Condamine. Not directly flow related and focused on a specific location.	King *et al*, 2013	3-B1 (Borderline)
Fish and food webs in the Lower Balonne	Research by Riverine Landscapes Research Laboratory on fish species in the Lower Balonne (Culgoa, Birrie, Bokhara and Narran waterholes) (part of broader project on food web complexity in Lower Balonne waterholes). Includes commentary on influence of flow regime on native and introduced species (suggests native fish may be better able to cope with less predictable flow).	Grey literature, reproducible evolving science	MDB: Lower Balonne	Supplementary/background information: includes information on ecology-flow relationships and primary sampling data. Relatively recent (<10 years since publication). Confined to a specific location (waterholes of the Lower Balonne).	Riverine Landscapes Research Laboratory, 2008	3-B1 (Borderline)
Waterhole persistence and refugia in the Lower Balonne	Overarching research for above project. Research on waterhole refugia and persistence in the Lower Balonne. Identifies 22 important 'refugial	Peer reviewed, reproducible evolving science	MDB: Lower Balonne	Supplementary/background information: includes information on ecology-flow relationships and primary sampling data. Relatively recent (<10 years since	Webb, 2009; Webb *et al*, 2011a; Webb *et al*, 2011b	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	waterholes' (twelve on the Culgoa River, three on the Bokhara and five on the Narran river. Used to inform MDBA critical 'in-channel habitat' flow indicator for the Lower Balonne (Culgoa River at Brenda – 1,200 ML/day for 7 days with1.8 years maximum period between events – low uncertainty and 2.3 years maximum period between events – high uncertainty) (Murray-Darling Basin Authority, 2012c; p.26). Includes one-off sampling of fish communities following waterhole connecting flows and in no-flow conditions and commentary on the influence of flow regime on native and introduced species (suggests native fish may be better able to cope with less predictable flow). Also suggests that 'fish abundance, size and assemblages were primarily influenced by the flow regime rather than physical characteristics of waterholes (Webb, 2009; p.87).			publication). Confined to a specific location (waterholes of the Lower Balonne).		

Border Rivers

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
MDBA environmental water requirement reports	MDBA technical reports on environmental water requirements for Lower Border rivers region (including Macintyre, Severn, Dumaresq, and	Grey literature, reproducible evolving science	MDB (BR-Lower)	Context/background – outline existing environmental water requirements for the Lower Border Rivers region.	MDBA, 2012e	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	Weir rivers). Includes flow indicators for inundation of key habitat and nutrient cycling (notes Murray Cod, Golden Perch and Silver Perch in particular), but none specifically for fish species.					
Ecological condition assessment reports	Ecological condition assessment to inform Border Rivers Flow Management Plan (joint NSW and Queensland). Volume 2 includes information on fish communities and flow (pp.25-36), based on field inspections during July 1999 (habitat inspection only) and sampling of four sites (Stuartville and Karloo on the Macintyre, Collarenebri on the Barwon River and Farnbro on the Severn) in the Border River system (1998).	Grey literature, reproducible evolving science	MDB (BR – QLD & NSW)	Supplementary/background information, including sampling results. Relatively dated (more than 10 years since publication).	DNR and DLWC, 1999	3-B1 (Borderline)
Border Rivers demonstration reach	Work relating to Border Rivers Demonstration Reach (Macintyre and Dumaresq rivers, 335 km of rivers between Mungindi and Lake Glenlyon). Supported by fish characterisation survey for Macintyre and Dumaresq Rivers and Macintyre Brook (Butcher, 2007). Survey based on ten data sets from different research projects in the area (date ranges from 1901 to 2007). Notes data gaps for Macintyre Brook and impacts of declining lateral and longitudinal connectivity on fish population and abundance.	Grey literature, reproducible evolving science	MDB (BR – Macintyre and Dumaresq Rivers)	Supplementary/background information. Relatively recent (less than 10 years since publication) and includes fish sampling data. Relatively location-specific (Macintyre and Dumaresq.	Butcher, 2007; Australian Wetlands, 2009	2-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Macintyre River diet studies	Study of diets of native fish (Olive Perchlet, Spangled Perch and Bony Herring) in floodplain waterholes on the Macintyre river. Study period over 2002 and 2003, with fish collected from a variety sites on Macintyre River floodplain.	Peer reviewed, reproducible evolving science	MDB (BR – Macintyre)	Supplementary information regarding needs for fish needs (diet) in Border Rivers region. Relatively recent (published in last 10 years. Not directly focused on flow-ecology relationships requirements and location-specific (Macintyre).	Medeiros and Arthington, 2008	2-B1 (Adequate)
Mesoscale movements of fish species	Project investigating mesoscale movements of fish species and/or life history stages based on tagging and release. Study areas Condamine River and Macintyre River (both river pool and lagoon habitats). Also considers importance of sequencing/antecedent flows, particularly sequential inundation of off stream wetlands for recruitment of Olive Perchlet.	Grey literature, reproducible evolving science	MDB (CB – Condamine and BR – Macintyre)	Supplementary information on fish movement and life history in the Macintyre. Relatively recent work including sampling information (likely to be supplemented by information sourced from Queensland database(s). Location specific (Condamine and Macintyre).	Hutchison *et al*, 2008	3-B1 (Borderline)
Riverine and floodplain ecosystem response to flooding in the lower Balonne and Border Rivers	Study conducted to improve understanding on the role of floods for the viability of populations of aquatic and floodplain organisms, including effects of floods on fish and other aquatic biota. Work conducted at sites in the lower Balonne and Weir Rivers (five sites on three occasions). Includes assessment of total species level abundance/biomass condition in relation to floodplain width, flow pulses and waterhole isolation.	Grey literature, reproducible evolving science	MDB (CB – Lower Balonne and BR – Weir River)	Supplementary information. Relatively recent work, including results of sampling in the catchment and including information/analysis on relationships between fish and flow.	Woods *et al*, 2012b	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Fish assemblages and responses to flow in the Moonie, Weir and Macintyre/Barwon Rivers	Study compares fish assemblages at 15 waterholes (floodplain and in-channel) within the Macintyre-Balonne River (representative of regulated channel and floodplain sites) and Moonie and Weir Rivers (representative of smaller, unregulated rivers). Study period 2002-2003. Also recorded physical waterhole and floodplain variables. Identifies species presence, relative abundance and distribution, catch per unit effort and species richness.	Peer reviewed, reproducible evolving science	MDB (BR – Moonie, Weir and Macintyre) and BD (lower Barwon).	Supplementary information. Relatively recent work (less than 10 years since publication), including results of sampling in the catchment and information on species present and response to flows.	Balcombe *et al*, 2011a	2-B1 (Adequate)
Anabranches, nutrient cycling and connectivity in the Macintyre River	McGinness *et al,* 2002 provides data on carbon pools present in the Macintyre River (15.8km reach between Goondiwindi and Boomi) and implications of changing hydrological connectivity for carbon cycling from anabranch channels to the main system. Thoms *et al*, 2005 considers influence of water resources development on the character of floodplain-river fragmentation in the Macintyre River. Analyses impacts on potential supply of dissolved carbon from anabranch channels over a 98 year period. Used to inform MDBA EWR assessment for Lower Border Rivers (nutrient cycling).	Peer reviewed, reproducible evolving science	MD (BR – Macintyre)	Supplementary information regarding nutrient cycling (particularly relevant to MDBA EWR assessment for the Lower Border Rivers). Relatively dated (more than 10 years since publication for McGinness *et al*, 2002) and not directly focused on fish-flow relationships.	McGinness *et al*, 2002; Thoms *et al*, 2005	2-B1 (Adequate)
Golden Perch: spawning in the Border Rivers	Study undertaken as part of Queensland's Environmental Flows Assessment Program to investigate	Grey literature, reproducible evolving science	MDB (BR – Macintyre and Weir)	Supplementary information. Relatively recent work (less than 10 years since publication) and includes	DERM, 2010b	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	environmental conditions (flow triggers and temperature) for Golden Perch (Weir and Macintyre Rivers). Suggests that Golden Perch requires temperatures >23°C to spawn, coupled with elevated flows (post winter). However, results from the Macintyre also suggest continued flows may reduce spawning triggers and limit availability of larval food supplies.			information/analysis on relationships between fish and flow. Single species focus (Golden Perch). Does not identify if overbank/flood flows are needed for long-term population viability, or if Golden Perch can spawn under no-flow conditions.		
Ecosystem responses to Carp control	Study investigating ecosystem responses to Carp control in Condamine and Macintyre Rivers in Queensland, including monitoring of fish response variables.	Grey literature, reproducible evolving science	MDB (CB – Condamine and BR – Macintyre)	Supplementary information to inform identification of Carp hotspots in Northern Basin. Relatively recent work and includes native-Carp interactions. Location specific (Condamine and Macintyre).	Gehrke *et al*, 2010	3-B1 (Borderline)
Fish monitoring at Pindari Dam	Four year study undertaken by University of New England and NSW Office of Water to 'establish temporal and spatial patterns in the distribution of fish early life history stages between the Severn, Mole and Macintyre rivers'. Sampling between 2005 and 2009 to establish environmental factors associated with distribution patterns and timing of spawning activity between rivers and seasons. Further work, including surveys of flows, water quality, water temperature and stream bank and bed stability was undertaken by the NSW Office of Water to assess impacts of the 2012 Pindari Stimulus Flow	Peer reviewed, reproducible evolving science	MDBA (BR – Severn, Mole and Macintyre)	Supplementary information, including sampling data. Includes flow-ecology relationships and relatively recent work. Location specific.	Wilson and Ellison, 2010; Foster, 2012.	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	Release of 16,000 ML into the Severn River (Foster, 2012). The latter does not include new fish sampling, but considers water temperature and fish spawning thresholds. Also includes anecdotal information regarding fish abundance from recreational anglers.					
Integrated Monitoring Program: Tenterfield Creek	NSW Office of Water-managed program including a fish survey for Purple Spotted Gudgeon in Tenterfield Creek (Dumaresq River) (21 sites sampled between 27 and 31 October 2008). Notes further work on fish habitat availability and suitability being undertaken between NOW and UNE.	Grey literature, reproducible evolving science	MDBA – BR (Dumaresq)	Supplementary information, including primary data. Relatively recent work (published less than 10 years ago). Discusses relationships between fish communities and unregulated systems. Location-specific and focused on a single species.	Lewis and Growns, 2012	3-B1 (Borderline)

Gwydir

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
MDBA EWR Report	MDBA technical reports on environmental water requirements for Gwydir Wetlands. Notes that 'several native fish species that breed in the channels of the Gwydir Wetlands are listed as threatened under state legislation' (p.11) and refers to work by Wilson *et al* (2009) (Lower Gwydir, Gingham and Mehi systems). Includes specific flow indicators for fish recruitment and movement.	Grey literature, reproducible evolving science	MDB - Gwydir	Context/background – outlines existing environmental water requirements for the Lower Border Rivers region, including knowledge base for fish recruitment and movement.	MDBA, 2012f	3-B1 (Borderline)
Horton River habitat mapping	Aquatic habitat mapping along 100 km of the Horton River (Gwydir	Grey literature, evolving	MDB (Gwydir)	Key supplementary information to be used in conjunction with NSW Freshwater	NSW DPI, 2013c	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	catchment) completed by NSW DPI for Border Rivers Gwydir Catchment Management Authority. Identifies fish species present in the Horton River (based on information from NSW Freshwater Fish Research Database). Also applies a Decision Support System (DSS) developed by NSW to categorise river management units and prioritise habitat features and overall reach condition.	reproducible science		Fish Research Database. Relatively recent work (less than 10 years since publication), including information on species present and key habitat features (potentially informing selection of priority reaches for the Project). Associated with a specific location (Horton River) and does not directly focus on flow-ecology relationships.		
Catfish reproductive biology	Research on the biology of the Freshwater Catfish in the Gwydir river (particularly focusing on Copeton Dam impacts).	Peer reviewed, reproducible evolving science	MDB-Gwydir	Background/supplementary information on flow requirements for Freshwater Catfish in the Gwydir system. Relatively dated (date of publication more than 10 years ago) and location/species specific.	Davis, 1975, 1977a, 1977b, 1977c	2-B1 (Borderline)
Oral history	Study undertaken by NSW Fisheries on ecological changes to fish and fish habitat of the Gwydir River and local community opinions of those changes, using an oral history methodology. Focus on main channels below Copeton Dam.	Grey literature, scientific judgement	MDB-Gwydir	Supplementary/background information. Relatively dated (date of publication more than 10 years ago) and non-science information.	Copeland *et al*, 2003, Schooneveldt-Reid, 2003	3-C1 (Borderline)
Commonwealth Environmental Water Office (CEWO) monitoring and evaluation – Gwydir river program	The CEWO has established a Long-Term Intervention Monitoring project in seven key areas, including the Gwydir river system. Monitoring in the Gwydir is being led by Eco Logical and the University of New England. Monitoring indicators include fish populations at Carole Creek and Mehi-Moomin and Fish movement at Carole	Grey literature, reproducible evolving science	MDB-Gwydir	Supplementary information. Relatively recent and includes primary data (research undertaken within the last 10 years). Results may not be available under project time frames.	CEWO, 2014; Department of Environment pers. comm.	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	Creek, Lower Gwydir-Gingham, Gwydir River and Mehi-Moomin. A report detailing results of fish response monitoring to environmental watering in the Mehi River and Carole and Gil Gil Creeks is expected to be available in early 2015 (Department of Environment, pers. comm.).					
NSW Wetlands Program Project	Research undertaken under the NSW Wetlands Program, including a waterbirds and fish project in the Lowbidgee and Gwydir catchments. Surveyed waterbird and fish assemblages and habitats and effects of specific flow characteristics on growth and condition of juvenile fish. Surveys undertaken from 2007 to 2008, including otolith-based surveys.	Peer review, reproducible evolving science	MDB (Gwydir and Lowbidgee)	Supplementary information. Relatively recent information (date of publication less than 10 years ago) and includes consideration of flow impacts on growth and condition of juvenile fish.	Wilson *et al*, 2009; Spencer *et al*, 2010; Heagney *et al*, 2010; Spencer *et al*, 2012	2-B1 (Adequate)
Gwydir Wetlands Adaptive Environmental Management Plan	Plan developed under the NSW Wetland Recovery Plan, Recommends 'various actions and strategies to improve the condition of the (Gwydir) wetlands' (DECCW, 2010; p.1). Includes description of ecological assets and values of the Gwydir Wetlands and wetland environmental water needs. Identifies fish species present (based primarily on Spencer *et al*, 2010) and provides a general outline of flow needs and threats.	Grey literature, reproducible evolving science	MDB - Gwydir	Supplementary information. Relatively recent information (date of publication less than 10 years ago). Provides general outline of fish species and flow needs in the Gwydir wetlands and summarises relevant research and management actions. Synthesis of existing knowledge.	DECCW 2010	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Gwydir fish passage	Study to identify barriers to fish passage in the Gwydir catchment and Gingham Watercourse. Also identifies a general decline in native fish populations for the Gwydir over the last thirty years, with exotic species (particularly Carp and Gambusia) now dominating floodplain habitats. Suggests most native species still occur in the middle Gwydir catchment.	Grey literature, reproducible evolving science	MDB (Gwydir)	Supplementary information. Relatively dated (more than 10 years since publication) and focuses on fish movement.	Mallen-Cooper, 2000	3-B1 (Borderline)
Fish – Lower Gwydir floodplain	Identifies fish present on the Lower Gwydir floodplain.	Grey literature, reproducible evolving science	MDB (Gwydir)	Supplementary information. Relatively dated material (more than 10 years since publication).	Siebentritt, 1999	3-B1 (Borderline)

Namoi

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
EWR Report	MDBA technical report on environmental water requirements for Lower Namoi River (in-channel flows). Notes information on fish populations from SRA1, earlier work by CRC for Freshwater Ecology/NSW Fisheries (Thoms *et al*, 1999) and information on Murray Cod populations (National Murray Cod Recovery Team, 2010). Notes that 'flow indicators described herein for the in-channel flows related to bench inundation as well as high flow elements of the flow regime primarily based on the water requirements of flood dependent	Grey literature, reproducible evolving science	MDB (Lower Namoi)	Context/background – outlines existing environmental water requirements for the Lower Namoi region, including knowledge base for fish recruitment and movement.	MDBA, 2012g	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	vegetation communities are expected to be sufficient to support life-cycle and habitat requirements of native fish including provision of cues for spawning and migration and access to food sources' (p.20).					
Temperature/thermal pollution (Keepit Dam)	Research investigating impacts of thermal pollution on fish (with a particular focus on releases from Keepit Dam).	Peer review, reproducible evolving science	MDB (Namoi – Keepit Dam)	Supplementary/background information. Relatively recent (less than 10 years since publication). May be particularly relevant for development of conceptual models for functional groups in the system.	Preece and Jones, 2002; Boys *et al*, 2009; NSW DPI, 2012c; Rolls *et al,* 2013	2-B1 (Adequate)
Namoi River Demonstration Reach	Demonstration reach (120 km of Namoi River between Boggabri and Narrabri Creek) established 2007. Includes data collection by anglers. Monitoring focuses on long-term condition of fish populations and intervention-based monitoring based on major fish passage activities. NSW DPI Fisheries have also undertaken habitat mapping of some parts of the Demonstration Reach.	Grey literature, reproducible evolving science	MDB (Namoi)	Supplementary information. Includes primary monitoring information and habitat mapping. Relatively recent (less than 10 years since publication).	Fish Habitat Network, undated; NSW DPI, 2012a.	3-B1 (Borderline)
Namoi Valley environmental scan	Developed to support Namoi River management plan (literature review). Notes research undertaken under NSW Rivers Survey, Gehrke and Harris 1997 and earlier NSW fisheries surveys in Peel River (Bishop and Harris, 1990).	Grey literature, reproducible evolving science	MDB (Namoi)	Background/contextual information. No new information and relatively dated (more than 10 years since publication).	Thoms *et al*, 1999	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Impacts of irrigation pumps	Research on irrigation pump impacts on riverine fish (over a two year period in the Namoi River).	Peer reviewed, reproducible evolving science	MDB (Namoi)	Background/contextual information. Relatively recent but not specifically focused on fish EWR requirements.	Baumgartner *et al*, 2011	2-B1 (Adequate)
Barriers to fish passage	Project to assess barriers to fish passage in the Namoi catchment (funded by Namoi Catchment Management Authority). Includes details on freshwater finfish species present in the catchment.	Grey literature, reproducible evolving science	MDB (Namoi)	Supplementary information. Relatively recent (date of publication less than 10 years ago) and potentially relevant to EWR requirements and habitat mapping for the system.	NSW DPI, 2006	3-B1 (Borderline)
Key Fish Habitat mapping	NSW DPI key fish habitats mapped in the Namoi region, including Chaffey Dam reservoir, Peel River upstream of Chaffey Dam and upstream tributaries and Peel River downstream of the dam.	Grey literature, reproducible evolving science	MDB-Namoi, Peel	Supplementary information – includes primary data directly relevant to determination of flow requirements. Confined to specific locations.	NSW DPI, 2012a	3-B1 (Borderline)
Integrated Monitoring of Environmental Flows (IMEF) program	Monitoring program managed by NSW Office of Water (NOW). Includes assessment of environmental flow rules developed for the Regulated Peel River (focus on aquatic macroinvertebrates and benthic periphyton) and project to assess impacts of environmental flows on larval fish in regulated rivers (Gwydir and Namoi catchments).	Grey literature, reproducible evolving science	MDB-Namoi, Peel	Supplementary information. Relatively recent work including primary data (less than 10 years since publication) and ecology-flow focus. Confined to a specific location (regulated Peel River).	NSW DPI, 2012b	3-B1 (Borderline)
Namoi wetland assessment and prioritisation project	Wetland assessment and prioritisation project within the Namoi catchment. Prioritisation process includes presence of threatened species and	Grey literature, reproducible evolving science	MDB-Namoi	Background/contextual information. Relatively recent (less than 10 years since publication) but does not include new	Eco-logical Australia, 2008	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	threatening processes (data on fish from NSW Freshwater Fish Research Database).			information and not specifically focused on fish.		
Ecological values of the Peel River	Background (using available information and regional expert knowledge) on ecological features of the regulated Peel River to support development of environmental water and access rules under sharing plans for the Peel Regulated Water Source. Includes fish as an 'ecological feature' (including general commentary on significance, conservation status, location, likely ecological importance, likely flow response and relevant flow parameters. Also identifies known and expected native fish and alien fish species of the regulated Namoi River, including special flow requirements and reasons for decline.	Grey literature, reproducible evolving science	MDB – Namoi (Peel River)	Background/contextual information. Relatively recent (less than 10 years since publication) and provides a synthesis of fish and flow requirements for the Peel system and Namoi more broadly. Does not include new information and information may be subjective/not quantified in some instances.	Foster and Lewis, 2009	3-B1 (Borderline)
Geomorphic features of the Lower Namoi floodplain	Study using the River styles framework to assess geomorphic features of the Lower Namoi floodplain, including analysis of channel cross-sections at a number of representative sites. Identifies benches, bars and low flow channel features. Used to inform MDBA flow indicator for longitudinal	Grey literature, reproducible evolving science	MDB-Namoi (Lower)	Background/contextual information (informed development of flow indicator for longitudinal connectivity in the Namoi). Relatively dated (more than 10 years since publication) and not specifically focused on fish.	Lampert and Short, 2004	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	connectivity in the Lower Namoi (Murray-Darling Basin Authority, 2012g; p.18).					
Inundation of channel and floodplain features in the Lower Namoi system	Assessment of commence-to flow levels of wetlands and in-channel features of the lower Namoi Valley, including surveys of key locations (downstream of Duncan's Junction, Bugilbone, Goangara and downstream of Goangara) to identify benches and anabranch levels.	Grey literature, reproducible evolving science	MDB – Namoi (Lower)	Background/contextual information (informed development of flow indicator for bench inundation in the Namoi). Relatively dated (more than 10 years since publication) and not specifically focused on fish.	Foster, 1999	3-B1 (Borderline)

Macquarie

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
EWR Report	MDBA technical report for Macquarie Marshes. Does not include specific flow indicators for fish recruitment or movement.	Grey literature, reproducible evolving science	MDB – Macquarie Marshes	Context/background – outline existing environmental water requirements for the Macquarie Marshes.	MDBA, 2012h	3-B1 (Borderline)
Habitat mapping – Macquarie River	Habitat mapping undertaken by NSW DPI on 391 kilometres of the Macquarie River (Burrendong Dam to Marebone weir) for RiverSmart Australia (funded by Central West Catchment Management Authority and MDBA Native Fish Strategy). Includes consideration of historical sources to inform assessment of condition. Identifies 20 'Management Reaches' for the study area.	Grey literature, reproducible evolving science	MDB-Macquarie River (Burrendong Dam to Marebone Weir)	Key supplementary information to be used in conjunction with NSW Freshwater Fish Research Database. Relatively recent work (less than 10 years since publication). Information on species present and key habitat features (potential to inform selection of priority reaches for the Project). Associated with a specific location (Macquarie River) but does not directly focus on flow-ecology relationships.	NSW DPI, 2011.	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Macquarie Marshes –fish research	Research undertaken by UNSW. Includes work on role of small environmental flows, drought and the role of refugia for freshwater fish in the Macquarie Marshes (Rayner *et al*, 2009), climate change adaptation (including summary of fish species present and potential impacts of climate change) (Jenkins *et al*, 2012) responses of native and alien fish species to floodplain inundation (Rayner *et al*, 2014).	Peer reviewed, reproducible evolving science	MDB - Macquarie Marshes	Supplementary information. Includes primary data and scientific analysis (peer reviewed). Relatively recent (less than 10 years since publication) and includes ecology-flow relationships (including native and alien species).	Rayner *et al*, 2009; Jenkins *et al*, 2012; Rayner *et al*, 2014	2-B1 (Adequate)
Spatial and temporal variation in the composition of riverine fish communities	Research on temporal and spatial variability in fish community structure in Macquarie and Namoi Rivers.	Peer reviewed, reproducible evolving science	MDB - Macquarie Marshes, Namoi	Supplementary information, including primary data and scientific analysis (peer reviewed). Relatively recent (although some work more than 10 years since publication). Some focus on ecology-flow relationships.	Growns *et al*, 2003; Growns *et al*, 2006	2-B1 (Adequate)
Macquarie Marshes Adaptive Environmental Management Plan	Plan developed under the NSW Wetland Recovery Program, including definition of ecological assets and values, ecological outcomes and water requirements. A number of surveys on fish communities and water quality were undertaken to support development of the plan (Jenkins *et al*, 2004; Jenkins and Wolfenden, 2006; Jenkins *et al*, 2008).	Grey literature/peer reviewed, reproducible evolving science	MDB- Macquarie Marshes	Supplementary information, including some primary data and scientific analysis. Relatively recent (less than 10 years since publication). Some focus on ecology-flow relationships.	Jenkins *et al*, 2004; Jenkins and Wolfenden, 2006; Jenkins *et al*, 2008; DECCW, 2010.	3-B1 (Borderline) (grey literature), 2-B1 (Adequate) (peer reviewed)
Early surveys	Brock (1998) provides an overview of physical environment of Macquarie Marshes, including fish species	Grey literature/peer reviewed,	MDB- Macquarie Marshes	Contextual/background information. Does not include primary data and relatively	Swales, 1994; Swales and	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	recorded in the area (p.86). Notes previous surveys by Swales and Curran (1995) and Swales (1994).	reproducible evolving science		dated (more than 10 years since publication).	Curran, 1995; Brock, 1998	

Other Northern systems (within and outside MDB)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Moonie and Warrego	Comparison of productivity of two fish species (Australian Smelt and Macquarie Perch) in Moonie and Warrego rivers.	Peer reviewed, reproducible evolving science	MDB (Moonie and Warrego)	Background/contextual information (relatively recent) – potential baseline information for fish condition.	Balcombe *et al*, 2010	2-B1 (Adequate)
Moonie	Assessment of fish responses to low flow at Moonie River and Cooper Creek.	Peer reviewed, reproducible evolving science	MDB (Moonie)	Background/contextual information (relatively recent) – potential baseline information for fish condition.	Balcombe and Sternberg, 2012	2-B1 (Adequate)
Genetic diversity, Moonie	Study of gene flow for Golden Perch and Freshwater Catfish and a crustacean (*Macrobrachium australiense*) in Moonie River catchment.	Peer reviewed, reproducible evolving science	MDB (Moonie)	Background/contextual information (relatively recent) – potential baseline information for fish condition.	Huey *et al*, 2011	2-B1 (Adequate)
Fish condition/diet, movement and population genetics: Moonie River	Study undertaken as part of Queensland's Environmental Flows Assessment Program. Considers fish condition, primary production and diet in the Moonie (Bony Herring and Golden Perch). Results suggest both species shift from high quality to low quality food sources during prolonged isolation of waterholes. Movement component (study period 2007 to 2009) involved acoustic tagging of Bony Herring, Golden Perch,	Grey literature, reproducible evolving science	MDB (BR – Moonie)	Supplementary information. Recently recent work (less than 10 years since publication), including primary information relating fish responses to flow, with a focus on movement. Location-specific (Moonie River).	DERM, 2010a	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	Freshwater Catfish and Spangled Perch, with recording stations along an 85 km reach of the Moonie River. Golden Perch and Spangled Perch identified as more likely to move (most within a 20-30km stretch, but some ranging over 70km within a season). Bony Herring and Freshwater Catfish were more likely to remain in the same waterhole. Research also suggests the majority of fish move on the first post-winter flow, regardless the magnitude of the event.					
Other arid-zone systems	Research on fish-flow relationships in arid zone rivers (primarily Coopers Creek, outside MDB).	Peer reviewed, reproducible evolving science	Outside MDB	Contextual/background information. Relatively recent work and with potential application to the MDB. However, it has been suggested that results from Coopers Creek and other arid zone systems are not always relevant to Northern MDB catchments (e.g. Woods *et al*, 2012).	Arthington *et al*, 2005; Balcombe *et al*, 2005; Balcombe *et al*, 2007; Balcombe and Arthington, 2009; Kerezsy *et al*, 2011; Kerezsy *et al*, 2014	2-B1 (Adequate)
Environmental risk assessment – Warrego, Paroo, Bulloo and Nebine catchments	Underpinning environmental assessments for review of the Queensland Water Resource (Warrego, Paroo, Bulloo and Nebine) Plan 2003. Identifies nine 'prioritised assets', including flow spawning fish species, absence of exotic fish species and migratory fish species (DSITIA, 2013a; pp.6-7). Uses 'meta-population' models for Golden Perch in each	Grey literature (including some peer review through independent science review), reproducible evolving science	MDB (Warrego, Paroo), outside MDB	Supplementary information. Relatively recent information (less than 10 years since date of publication) and includes focus on fish-flow relationships (flow-spawning species, migratory fish and invasive species). Also includes use of conceptual models based on hydrology and biological information to assess relative impacts of different water regime scenarios. Location-specific (Warrego and	DSITIA, 2013a, 2013b, 2013c, 2013d	3-B1 (Borderline)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	catchment area based on hydrology and biological information to 'integrate eco-hydraulic habitat elements' including first post-winter flows, waterhole persistence and size, waterhole connectivity and waterhole pumping (DSTIA, 2013d; p.24). Golden Perch are also used as an indicator of migratory fish species, with a minimum event duration that would allow migration between habitats as eight days (DSITA, 2013d; p.30). Thresholds of concern for periods of time between migratory opportunities are identified (<4 years low risk, 4-10 years moderate risk and >10 years as high risk (DSITA, 2013d; p.31). Rules for absence of exotic fish species (Carp) are based on spawning and recruitment through overbank flows and dispersal of recruitments (flows >2 ML/day within 12 months of an overbank event) (DSITIA, 2013d; p.41).			Paroo catchments). Excludes some fish species (such as Carp Gudgeon, Murray-Darling Rainbowfish, Desert Rainbowfish and Purple Spotted Gudgeon) due to lack of knowledge on flow requirements (DSITA, 2013b; pp.51, 53, 54). Australian Smelt also excluded due to 'lack of evidence for a specific flow requirement' (DSITIA, 2013b; p.56).		

Functional groups (fish-flow relationships) - Recruitment

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Flood-recruitment model	Junk *et al* (1989) 'flood-pulse concept' – annual inundation as principal driving force responsible for the existence, productivity and interactions of the major biota in river-floodplain systems'. Lake (1967)	Peer reviewed, reproducible evolving science	MDB (general)	Background/contextual information. Relatively dated (more than 10 years since publication.	Lake 1967; Cadwallader and Lawrence 1990; Gehrke *et al*, 1995;	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	emphasised the role of flooding in the breeding history of inland fish. Assumption that flooding is essential for recruitment (Cadwallader and Lawrence 1990; Gehrke *et al*, 1995; Humphries 1995) (summarised in Graham and Harris, 2005; pp.5-6).				Humphries 1995	
Low flow recruitment hypothesis	Suggests Golden and Silver Perch spawn and recruit during both within-channel flows and floods.	Peer reviewed, reproducible evolving science	MDB (Southern)	Background/contextual information. Relatively dated (more than 10 years since publication).	Harris and Gehrke, 1994.	2-B1 (Adequate)
Low flow recruitment hypothesis	Questions importance of flooding and floodplain to all MDB fishes – emphasise significance of in-channel habitats and flow variability (low flow recruitment hypothesis). Suggests three life history models based on spawning timing, style and development intervals of larvae.	Peer reviewed, reproducible evolving science	MDB (general)	Background/contextual information. Relatively dated (more than 10 years since publication).	Humphries *et al*, 1999	2-B1 (Adequate)
Refined low flow recruitment hypothesis	Classified native fish of the MDB into reproductive guilds based on importance of floods to spawning. Identify species as 'flood-dependent', 'flood-triggered spawning migration' or non-flood dependent (instead relating to availability of suitable habitat).	Peer reviewed, reproducible evolving science	MDB – general	Background/contextual information. Relatively dated (more than 10 years since publication.)	Schiller and Harris, 2001	2-B1 (Adequate)
Refined low flow recruitment hypothesis	Questions flood-recruitment/flood pulse model for Golden and Silver Perch (Murray River and other sites in the MBD).	Peer reviewed, reproducible evolving science	MDB (South)	Background/contextual information. Relatively dated (more than 10 years since publication).	Mallen-Cooper and Stuart, 2003	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Refined low flow recruitment hypothesis	Provides a conceptual model of 'optimum environmental conditions for use of the inundated floodplain for fish recruitment'. Classifies fish fauna in the Ovens River in guilds based on their likelihood to use the floodplain for recruitment (includes spawning information, larval drift, rate of development, adaptation to poor water quality and life span).	Peer reviewed, reproducible evolving science	MDB (South)	Background/contextual information. Relatively dated (more than 10 years since publication). Southern focus.	King *et al*, 2003	2-B1 (Adequate)
Refined low flow recruitment hypothesis/life history characteristics	Divides fish in the Chowilla Anabranch and associated Murray River into five life history modes based on duration of spawning, spawning style and time, cues for spawning and parental care.	Grey literature, reproducible evolving science	MDB (South)	Key information – relatively recent work potentially applicable in a Northern Basin context (or as part of a hybrid approach). Southern basis focus.	Mallen-Cooper *et al*, 2011	3-B1 (Borderline)
Life history/reproductive characteristics	Classifies freshwater fishes of south-eastern (ACT, Victoria and NSW) Australia into five major reproductive guilds, based on life history or reproductive characteristics (egg size and larval size, fecundity, adhesive eggs, spawning style, breeding style and timing, temperature of spawning, parental care, migration associated with spawning, age at maturity and size.	Peer reviewed, reproducible evolving science	MDB (South), MDB (General)	Background/contextual information. Relatively dated (more than 10 years since publication).	Growns, 2004	2 – B1 (Adequate)
Life history/reproductive characteristics	Assesses spatial variation in freshwater fish life-history traits (longevity, age and length at maturation, spawning substratum, spawning frequency, style of reproduction, fecundity, egg size, parental care and body length) and	Peer reviewed, reproducible evolving science	Australia (General)	Supplementary information. Relatively recent (less than 10 years since publication). Australia-wide focus and does not include movement focus for fish.	Sternberg and Keen, 2013	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	functional trait components of Australian river basins.					
Life history/reproductive characteristics and habitat use	Research on fish assemblage structures, microhabitat cover and fish-habitat associations (in-channel) in response to low and high flow events in the lower River Murray. Classifies fish based on body size and as either periodic, opportunistic or equilibrium strategists based on life history traits. Identifies small-bodied fish as opportunistic or equilibrium strategists: abundant in low flows and associated with submerged macrophytes, but absent/less abundant after flooding and large-bodied periodic strategists (such as Golden Perch).	Peer-reviewed, reproducible evolving science	MBD-South	Supplementary information. Relatively recent (less than 10 years since publication) and includes specific focus on flow-ecology relationships. Based in the Southern Basin – may require amendment for use in the North.	Bice *et al*, 2013	2-B1 (Adequate)

Functional groups (fish-flow relationships) – Recruitment and Movement

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Reproductive and movement guild (Baumgartner's model) – Edward Wakool	Development of flow guilds for fish community in the Edward-Wakool system based on reproductive (spawning and recruitment) and movement ecology of fish species. Identifies four guilds.	Peer reviewed, reproducible evolving science	MDB (South)	Key information. Relatively recent (less than 10 years since publication). Southern Basin focus (Edward-Wakool system) – may require review to ensure Northern Basin species needs are addressed (as per NSW Department of Primary Industries, 2013b). Does not include 'eco-hydraulic' guilds (Mallen-Cooper and Zampatti, in press).	Baumgartner *et al*, 2013	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Reproductive and movement guild – (Baumgartner's model – modified) Edward Wakool	Applies Baumgartner's approach to flow guilds for fish assemblages in the Murrumbidgee river system.	Grey literature, reproducible evolving science	MDB (South)	Key information. Relatively recent (less than 10 years since publication). Southern Basin focus (Murrumbidgee system) – may require review to ensure Northern Basin species needs are addressed (as per NSW Department of Primary Industries, 2013b). Does not include 'eco-hydraulic' guilds (Mallen-Cooper and, Zampatti, in press).	Cameron *et al*, 2013	3-B1 (Borderline)
Reproductive and movement guild – (Baumgartner's model – modified) Barwon-Darling	Applies Baumgartner's approach (largely unchanged) for fish/flow relationships in the Barwon-Darling (NSW DPI 2013b) (varied to reflect temperature tolerances and rainfall of Barwon-Darling).	Grey literature, reproducible evolving science	MDB (North – Barwon Darling)	Key information. Relatively recent (less than 10 years since publication). Northern Basin focus (Barwon-Darling). May require review for other Northern Basin catchments to ensure species needs/preferences are addressed. Does not include 'eco-hydraulic' guilds (Mallen-Cooper and Zampatti, in press).	NSW DPI, 2013b	3-B1 (Borderline)
Habitat guilds	Describes 'eco-hydraulic recruitment guilds' for Murray-darling Basin fish, based on hydrodynamics, habitat and spatial scale. Guilds identified are 'macro-lotic guilds' (Golden Perch, Silver Perch, Murray Cod and Short-headed Lamprey), meso-lotic (Murray Cod, Blackfish, Trout Cod and Macquarie Perch) and meso-lentic (habitat generalists, lentic and intermittent arid river specialists).	Peer reviewed, reproducible evolving science	MDB (General)	Key information. Relatively recent (less than 10 years since publication) and important underpinning work for the MDBA's Basin-wide Environmental Watering Strategy (BEWS). Whole of Basin focus (not specific to Northern Basin) and does not focus on temperature or water quality considerations (may not be applicable in rivers where thermal pollution and/or poor water quality is an issue.	Mallen-Cooper and Zampatti, in press	2-B1 (Adequate)
Thermal guilds/drought clusters	Drought tolerance 'clusters' using a range of MDB based on various behavioural and physiological tolerance indicators and respiratory modes.	Peer reviewed, reproducible evolving science	MDB (General)	Supplementary/background information. Relatively dated (10 years since publication. Whole of Basin focus and chiefly concerned with drought/low flows.	McNeil, 2004	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Resistance and resilience guilds	Assesses whether fish guilds can be developed based on responses and tolerances to drought impacts resistance (e.g. abundance, distribution, patchiness, low flow tolerances, temperature and water quality tolerances and feeding specificity) and resistance (e.g. longevity, age to maturity, no flow spawning, dispersal, fecundity and spawning constraints). Identifies three separate 'Drought Response Groups'; DRG1 (poor dispersal ability, limited distribution and high patchiness), DRG2 (long-lived, highly fecund species that are usually flow dependent spawners and less susceptible to predation as adults) and DRG3 (widely distributed, have a high tolerance of low flows and poor water quality and possess high dispersal ability).	Grey literature, reproducible evolving science	MDB (General)	Supplementary/background information. Relatively recent (less than 10 years since publication). Whole of Basin focus and chiefly concerned with drought/low flows.	McNeil *et al*, 2013	3-B1 (Borderline)

Conceptual Models

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Bayesian hierarchical model for multi-scaled environmental determinants of riverine fish	Uses a Bayesian zero-inflated Poisson model to understand influence of landscape-scale versus local-scale environmental variables for freshwater fish species distribution and patch quality. Uses distribution and	Peer-reviewed, reproducible evolving science	Australia – outside MDB	Key information to be considered for conceptual models. Referred to in background documents for the BEWS. Relatively recent information (less than 10 years since publication). Outside the Basin	Stewart-Koster *et al*, 2013	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
distribution and abundance	abundance data for *Hypseleotris galii* in Mary and Albert rivers, South-East Queensland.			and not specifically concerned with recruitment/flow relationships.		
Fish recruitment and productivity model – Ovens river	Tests models of fish recruitment and productivity in floodplain rivers based on growth during early life stages of a common, short-lived fish (Australian smelt) in the Ovens river. Uses a mixed-effect linear modelling approach.	Peer-reviewed, reproducible evolving science	MDB (South – Ovens)	Key information to be considered for conceptual models. Relatively recent information (less than 10 years since publication) and includes a focus on fish recruitment and productivity. Southern Basin focus (may require modification for the North).	Tonkin *et al*, 2011	2-B1 (Adequate)
Multi-response artificial neural network: spatial and temporal variation for fish assemblages in Eastern Australia.	Assesses multi-scale influences of environmental and hydrological features of the riverine landscape on spatial and temporal variation in fish assemblages in Eastern Australia. Models species presence-absence, relative abundance and relative biomass for fish assemblages in the Mary River (South-East Queensland) using a multi-response artificial neural network.	Peer-reviewed, reproducible evolving science	Australia (outside MDB)	Supplementary/background information. Relatively recent (less than10 years since publication). Outside the MDB and does not include a specific focus on flows and recruitment/movement.	Kennard *et al*, 2007	2-B1 (Adequate)
Bayesian models – species occurrence in Goulburn-Broken catchment	Uses a Bayesian, model-averaged, binomial regression to predict probabilities of occurrence for 13 fish species (including five non-native species) based on hydrologic variables (heavily regulated, moderately regulated and unregulated for Broken and Boosey Creeks (Goulburn-Broken catchment).	Peer reviewed, reproducible evolving science	MDB (South)	Supplementary/background information. Relatively recent (less than 10 years since publication). Southern Basin focus (may require modification for application in the Northern Basin) and does not focus on recruitment.	Bond *et al*, 2010	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Bayesian network models	Provides an environmental flow Bayesian Network model linking hydrological components (timing, magnitude, frequency and duration) to predict spawning and recruitment for Australian Grayling and River Blackfish (La Trobe River, Victoria).	Peer reviewed, reproducible evolving science	MDB (South)	Key information to be considered in development of conceptual models. Includes a specific focus on flows and recruitment and considered in development of BEWS. Relatively recent work (less than 10 years since publication). Southern Basin focus (may require amendment for application in the North) and does not include movement focus.	Shenton *et al*, 2010	2-B1 (Adequate)
Bayesian network models	Uses Bayesian Network Modelling for dry season flows and biology of Barramundi and Sooty Grunter, Daly River, Northern Territory.	Peer reviewed, reproducible evolving science	Australia (outside MDB)	Key information to be considered in development of conceptual models. Includes a specific focus on flows and recruitment and considered in development of BEWS. Relatively recent work (less than 10 years since publication). Developed outside the MDB and focuses on two specific species.	Chan *et al*, 2012	2-B1 (Adequate)
Bayesian network models – including Carp responses to flow	Uses Bayesian Belief Network Decision Support Tool for watering wetlands to maximise native fish outcomes, based on modelled abundance, population structure and fish condition for Carp, Carp Gudgeon, Australian Smelt and Golden Perch. Species were selected as they 'represent a diversity of life history traits' and have sufficient ecological knowledge to construct and populate the Bayesian network model. Model validation based on data from	Peer reviewed, reproducible evolving science	MDB (South)	Key information to be considered in development of conceptual models. Includes a specific focus on flow and fish-ecology relationships. Relatively recent work (less than 10 years since publication). Southern Basin focus (may require amendment for application in the North) and does not include movement focus. Largely Murray Valley specific and only operates at the scale of an individual wetland. Only predicts responses to single watering events.	Gawne *et al,* 2012; Beesley *et al*, 2011	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	River Murray wetlands (survey period 2008 and 2009, Beesley *et al*, 2011). Adopted for use in management of Coonacoobil Lagoon (Murrumbidgee catchment).					
Bayesian hierarchical models	Use Bayesian hierarchical models to test ecological effects of flow variation, including effects of discharge on Australian smelt in the Thompson river (Victoria) Suggests that hierarchical Bayesian models in particular can 'greatly improve inferential strength in the data-poor situations that are common in ecological monitoring' and are useful in assessing effectiveness of environmental flow programs.	Peer reviewed, reproducible evolving science	Australia (outside MDB – South)	Key information to be considered in development of conceptual models. Includes a specific focus on flow-ecology relationships. Relatively recent work (less than 10 years since publication). Developed outside the MDB and focuses on a specific species.	Webb *et al*, 2010	2-B1 (Adequate)
Bayesian hierarchical models – juvenile fish responses to wetland inundation and antecedent conditions	Research on effects of floodplain inundation of fish abundance in mid-Murray wetlands using a 'hierarchical multi-species model'. Model approach 'links single-species models together by imposing a community-level hierarchal layer'. Evaluates effects of antecedent conditions, including patterns in long, medium and short-term wetland inundations. Suggests native fish respond positively to frequent inundation, while non-native fish respond positively to long-to-medium term dry periods followed by short-term inundation events.	Peer reviewed, reproducible evolving science	MDB – South	Key information to be considered in development of conceptual models. Relatively recent work (less than 10 years since publication) and includes a specific focus on flow-ecology relationships. Developed for use in the Southern Basin (may require modification for use in the North). Focus on wetlands (does not consider in-channel responses) and juvenile life-stages.	Beesley *et al,* 2014	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Fish ecology in arid zone catchments	Outlines a conceptual model for fish ecology (recruitment and migration) in the Australian arid zone (waterhole, catchment and reach scales) – 'modified source/sink model'. Species include Hyrtl's Tandan, Welch's Grunter, Golden Perch, Australian Smelt, Carp Gudgeon, Banded Grunter, Barcoo Grunter, Cooper Creek Catfish, Silver Tandan, Glassfish, Rainbowfish, Bony Bream and Spangled Perch.	Peer reviewed, reproducible evolving science	Australia (Outside MDB – North)	Key information to be considered in development of conceptual models. Relatively recent (less than 10 years since publication) and includes focus on flow-ecology relationships (recruitment and migration). Developed outside the MDB (may not be directly applicable for Northern Basin catchments).	Kerezsy, 2010	2-B1 (Adequate)
Fish-habitat dynamics in small tropical rivers	Provides a conceptual model of seasonal fish-habitat dynamics (main channel) for a typical Wet Tropics river, based on surveys (fish species and hydrogeomorphology/vegetation habitat/water quality variables) at Mulgrave River, Queensland.	Peer reviewed, reproducible evolving science	Australia (Outside MDB – North)	Supplementary information. Relatively recent (date of publication less than 10 years ago). Does not have a specific focus on recruitment and flows and developed outside the MDB.	Rayner *et al*, 2008	2-B1 (Adequate)
Testing conceptual models of floodplain fish production	Tests floodplain fish production models in response to low-flow and flow pulse years (recruitment and spawning) using larval sampling data from lower Murray-River. Species include Unspecked Hardyhead, Carp Gudgeon, Flathead Gudgeon, Australian Smelt and Golden and Silver Perch. Suggests that a 'combination' of conceptual models for small-bodied and large-bodied native fish should be used. Uses min/max autocorrelation analysis and dynamic factor analysis.	Peer reviewed, reproducible evolving science	MDB (South)	Key information to be considered in development of conceptual models. Relatively recent information (less than 10 years since publication). Includes a specific focus on recruitment/flow relationships (but not movement). Developed for Southern MDB (Lower Murray) – may require modification for Northern Basin catchments.	Vilizzi, 2012	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Chowilla Regulator models	Conceptual models for Murray Cod, Golden Perch, Silver Perch, Freshwater Catfish and Carp in Chowilla and the Lower Murray.	Peer reviewed, reproducible evolving science	MDB (South)	Key information to be considered in development of conceptual models. Relatively recent information (less than 10 years since publication) and considered in BEWS development. Includes a focus on habitat, recruitment (lotic and lentic habitats) and movement. Southern Basin focus (may require modification for use in Northern Basin catchments).	Mallen-Cooper *et al*, 2011	2-B1 (Adequate)
Preference curve conceptual models - Murray-Flow Assessment Tool (MFAT)	Developed to predict ecological benefits/outcomes of different flow scenarios along the River Murray System. Uses conceptual models based on preference curves and functional groups for fish and other water-dependent taxa), Includes some capacity to measure varying responses based on location. Uses seven grouping of native fish (flood spawners, Macquarie Perch, wetland specialists, Freshwater Catfish, main channel generalists, main channel specialists and low flow specialists.	Peer-reviewed, reproducible evolving science	MDB (South)	Supplementary information to be considered in development of conceptual models. Relatively dated information (more than 10 years since publication). Southern Basin focus and later assessment suggests method does not predict 'on-ground' fish assemblages (Lester *et al*, 2011).	Young *et al*, 2003; Lester *et al*, 2011.	2-B1 (Adequate)
Preference curve conceptual models – SDL adjustment ecological equivalence method	'Ecological elements' (fish, birds and vegetation) developed as part of the SDL adjustment ecological elements method. Includes two fish elements (small, short-lived and large, long-lived species). Preference curves include both recovery and stress pathways for fish condition (population structure	Peer reviewed, evolving reproducible science.	MDB (South)	Supplementary information to be considered in development of conceptual models. Relatively recent (less than 10 years since publication). Southern Basin focus (current method) and simplified eco-hydrological model: not intended for use in determining EWRs.	Overton *et al*, 2014; Brookes *et al,* 2014.	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	based on age classes and individual body condition). Curves are based on scientific literature and expert opinion. Meant for use in assessing equivalence of supply measures, not in determining EWRs. Currently applies only to the Southern Connected Basin. A modified method is also being developed for the Northern Basin.					

Carp

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
Northern Basin – Carp aging	Research project to age Carp (oxytetracycle and otiline sampling) in the Northern Murray-Darling Basin.	Grey literature, reproducible evolving science	MDB (Northern Basin)	Supplementary information, including primary data and analysis. Relatively recent (less than 10 years since publication). Particularly relevant for native-Carp interactions.	Hutchison *et al*, 2012	3-B1 (Borderline)
Northern Basin - biological vulnerabilities of Carp	Research project synthesising outputs of various Invasive Animals CRC projects, including identification of Carp recruitment hotspots in the Northern Basin.	Grey literature, reproducible evolving science	MDB (Northern Basin)	Supplementary information, including primary data and analysis. Relatively recent (less than 10 years since publication). Particularly relevant for native-Carp interactions.	Gehrig and Thwaites, 2013	3-B1 (Borderline)
Carp and flows population model	Conceptual model for Carp recruitment dynamics under different flow regimes. Specifies spawning habitat types and allows for regional targeting of species wetlands/reaches in the Murray River. Model is applied to quantify changes to carp populations from a range of environmental watering scenarios.	Peer reviewed, reproducible evolving science	MDB (South)	Supplementary information (also relevant to development of conceptual models). Relatively recent (less than 10 years since publication) and with specific flow-ecology focus. Has a Southern Basin focus (may require amendment in the Northern Basin). Particularly relevant for native-Carp interactions.	Todd *et al,* 2014; Koehn *et al*, 2014.	2-B1 (Adequate)
Carp population dynamics in the Murray-Darling Basin	Conceptual model of Carp populations in the Murray-Darling Basin (including the role of overbank flows in aiding Carp invasion. Uses time series of annual commercial catch and effort data from Murrumbidgee, Riverina, Murray, Lower Murray, Lachlan and Darling areas and gauged flow information. Suggests (contrary to expectations) that managed	Peer reviewed, reproducible evolving science	MDB	Supplementary information. Relatively recent (less than 10 years than publication) and includes consideration of Carp-flow relationships.	Forsyth *et al*, 2013	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
	inundation events may not create major Carp recruitment events.					
Carp dispersal and movement in Murray and Darling Rivers	Acoustic tagging research on dispersal and movement of adult Carp in the Murray and Darling Rivers (study period from 2007 to 2011). Includes evaluation of river levels and temperature as triggers for Carp dispersal.	Peer-reviewed, reproducible evolving science	MDB (Murray and Darling)	Supplementary information. Relatively recent information (less than 10 years since publication) and includes some data directly relevant to the Northern Basin (Barwon-Darling). Particularly relevant to native-Carp interactions.	Brown, 2014	2-B1 (Adequate)
Carp and large native fish habitat use – Murray River	Radio-tracking survey comparing daytime microhabitat use by adult Carp and large native fish species (Murray Cod, Trout Cod and Golden Perch) in the Murray River. Suggests that all species are associated with structural woody habitat, deeper water and slower water closer to the riverbank with varying substrates. Suggests Carp had greatest habitat overlap with Golden Perch (both used structural woody habitat that extends higher into the water column), but Carp tends to use slower water and habitats which are more distant from low-flow channels.	Peer-reviewed, reproducible evolving science	MDB (South)	Supplementary information. Relatively recent (less than 10 years since publication) and includes primary quantified information on differing habitat requirements for Carp and large native fish species. Does not have a strong focus on flow-ecology relationships (notes that seasonal differences in habitat use and impact of flow changes is out of scope). Southern Basin focus (may require amendment for application in the North.	Koehn and Nicol, 2014.	2-B1 (Adequate)
Nursery sources and cohort strength for Carp under different flow regimes (Barmah-Millewa)	Research (using otolith chemistry and standardised catch data) to identify key nursery sources for common carp in the Mid-Murray Region. Also quantifies young-of-year cohort strength under varying hydrological conditions (study period 2005-2009).	Peer-reviewed, reproducible evolving science	MDB (South)	Supplementary information. Relatively recent information (less than 10 years since publication) and includes primary data relating to flow-ecology relationships. Focus on the Southern Basin (may require modification for use in the	McDonald and Crook, 2014	2-B1 (Adequate)

Key words	Summary of relevance to project	Type of information source	Geographic area(s)	Merit of information	Reference(s)	BASK categorisation
				North) and Carp recruitment. Particularly relevant to native-Carp interactions.		
Carp and environmental watering in regulated lowland rivers (movement and spawning)	Investigates invasion and spawning risk posed by adult Carp during an environmental water release delivered from the river Murray to a flow-through wetland in South Australia (survey period June to December 2008). Based on monitoring of off-stream movements. Suggests that adult Carp movements begin in August (in response to increasing water temperature), peak in mid-September before spawning and decline through to December. Makes recommendations on timing of environmental releases t to minimise Carp invasion risk, but suggests benefits may be short-lived without additional Carp management interventions.	Peer-reviewed, reproducible evolving science	MDB (South).	Supplementary information. Relatively recent information (less than 10 years since publication) and includes primary data relating to flow-ecology relationships. Focus on the Southern Basin (may require modification for use in the North). Particularly relevant to native-Carp interactions.	Conallin *et al*, 2012	2-B1 (Adequate)
Flow regulation and Carp recruitment in the Murray-Darling Basin	Research on effects of flow regulation on Carp recruitment (based on biomass, numbers of sub-adult carp and results from NSW Rivers Survey) in lowland Murray-Darling Basin rivers (Murray and Darling catchments, including unregulated lowland, regulated lowland and slopes river types).	Peer-reviewed, reproducible evolving science	MDB (South and some Northern catchments)	Supplementary information. Some focus on flow-ecology relationship (flow regulation and temperature thresholds) for Carp recruitment. Data relevant to Southern and Northern Basin (Barwon-Darling). Slightly dated information (10 years since publication) and focus on recruitment. Particularly relevant to native-Carp interactions.	Driver *et al*, 2005	2-B1 (Adequate)