NSW Department of Primary Industries

Fish and Flows in the Southern Murray-Darling Basin

Condensed summary

30 June 2022

This is a summary document for Phase 2 of a project report titled 'Fish and Flows in the Southern Basin: a review of fish and flow relationships in the Southern Murray-Darling Basin' conducted by NSW DPI Fisheries (Ellis et al. 2016; 2021). This work was developed in collaboration with Fish Ecologist from the Arthur Rylah Institute (ARI) in Victoria and the South Australian Research and Development Institute (SARDI). The full report can be obtained from the Murray-Darling Basin Authority (MDBA) on request.

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Cover image: Lower Murray River, I. Ellis.

The Fish and Flows Program – Southern Basin (DPI Fisheries)

The Fish and Flows Program explores the flow conditions that different native fish in the Southern Murray-Darling Basin (MDB) need to persist and flourish. To do so, a Fish and Flows Management Framework (FFMF) was developed by NSW DPI Fisheries to inform the application of water (either water for the environment or operational delivery of water) to generate river flows that support native fish outcomes (Figure 1). The framework develops conceptual flow hydrographs to describe significant flow components which support the varied life history requirements of fish in different functional groups.

These these flow components can then be translated into fish-specific Environmental Water Requirements (EWRs) targeting native fish outcomes at representative gauging locations (Indicator Sites) in valleys of the Southern Connected MDB (i.e. the Murray, Lower Darling, Lower Lakes-Coorong, Lachlan, Murrumbidgee and Goulburn-Broken river systems). These EWRs provide a useful starting point in the annual and longer-term planning of flow deliveries where objectives include conservation and recovery of native fish populations in Southern Basin valleys (or reaches within valleys).

The conceptual hydrographs and EWRs presented herein are based on the best available scientific understanding of the requirements for native fish (from a whole of life-cycle perspective) at the time of writing. They are not constrained by management and operational elements such as volume of held water for the environment, physical constraints, rivers operations or third-party impacts.

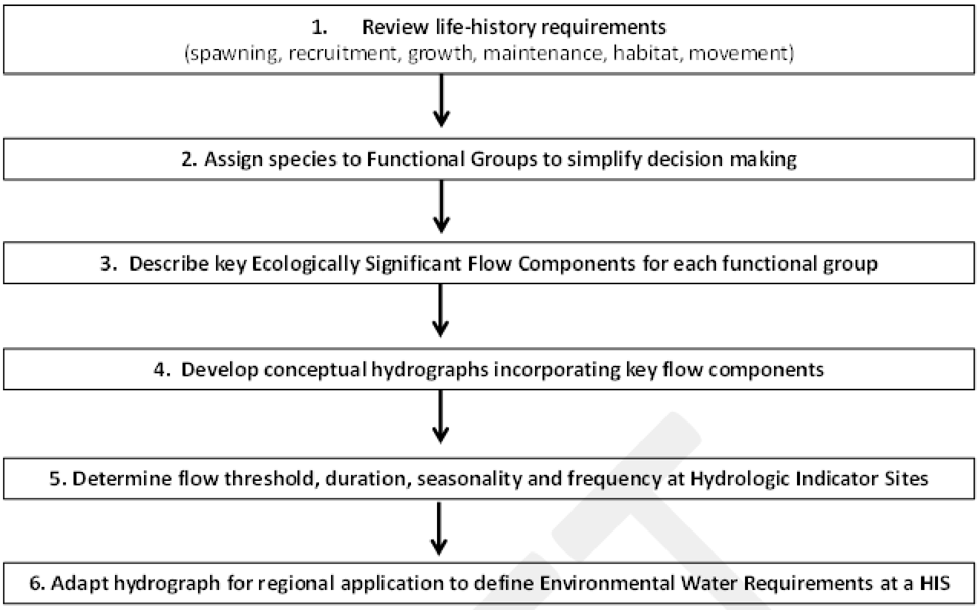

Figure 1. The Fish and Flows Management Framework produced to assist with the development of watering strategies that support native fish outcomes

Applying the Fish and Flows Management Framework:

1. Classify Southern MDB fish species into **Functional Groups** based on flow-related life history attributes (to simplify flow management planning when considering fish).
2. Describe **Ecologically Significant Components** of the in-stream flow regime required to support native fish (i.e. base flows, small and large within-channel 'fresh' flows, bank full and overbank flows).
3. Construct conceptual flow hydrographs based on generalised natural flow regimes for streams within the Southern MDB, which include ecologically significant flow components that will support the various functional groups of fishes (and life history stages within).

4. Determine Flow Thresholds Estimates for these ecologically significant flow components at representative Hydrologic Indicator Sites (HIS) throughout the Southern MDB.
5. Develop fish-specific EWRs to target fish outcomes in the rivers of the Southern Connected MDB.

EWRs are expressed as a set of flow indicators representing significant components of the flow regime relevant to the known biological requirements of fish. Flow Indicators are expressed as flow magnitude/volume, duration, seasonality and frequency. The indicator is expressed as a duration (number of days flow) that the proposed target threshold is maintained or exceeded, with rates of rise and fall around the peak should reflect natural rates of change for the sites and any operational requirements.

Since 2016, and throughout the development of this project, NSW DPI Fisheries managers have utilised the FFMF to inform planning of water for the environment, targeting native fish outcomes in various catchments in the Southern MDB.

Important Caveats

- For consistency with components of the Basin Plan being developed, we incorporate estimates for flow thresholds (Table 1), which were developed by Long Term Water Plan teams at the NSW Department of Planning, Industry and Environment (DPIE)- Environment, Energy and Science (EES). Where EES flow estimates were unavailable, corresponding values were derived by DPI Fisheries using similar methodology and collaboration with regional experts.
- The EWRs we present are not intended to be a comprehensive 'recipe', and the conceptual models are by no means prescriptive. It is anticipated the outputs of this project will assist agencies with water management responsibilities in implementing components of the Murray–Darling Basin Plan (e.g. the Basin-wide Watering Strategy and Long Term Water Plans).
- Responsible water management and the prioritisation of flow components within and between systems (both spatially and temporally) requires coordinated efforts by water managers across both the Southern and Northern MDB, and sustained consultation with expert fish ecologists, water managers and community groups.

Background: Fish and flow relationships in the Murray-Darling Basin

Water is fundamental to fish; however assuming any water will have positive outcomes for all fish is too simplistic. The interaction of the movement of water within and between waterbodies (i.e. flow) also has a major influence on their life history and population processes for fish (Mallen-Cooper and Zampatti 2018; Koehn et al 2020a). Flow produces hydrodynamic and hence habitat diversity, and therefore is a major factor structuring freshwater fish communities (Baumgartner et al. 2013). Flow variability promotes the exchange of nutrients and productivity in aquatic ecosystems and provides connectivity between aquatic habitats (e.g. rivers and floodplain habitats, valleys or reaches within a valley).

Essentially, flow and the physical characteristics of flowing water (hydraulics) influence fish life cycles and hence their survival and persistence.

Different species of fish have differing habitat, food and lifecycle needs linked to the availability of water and the way it flows in the landscape. Different life history stages for a given species (i.e. eggs, larvae, juveniles, adults) may also have different flow related requirements. For example, survival of eggs and larvae may be dependent on flow to transport them to suitable nursery habitat, while floodplain habitats may support strong growth of juveniles. It follows that different species also respond uniquely to changes in flow regimes.

Multiple assessments concur that the native fish community status throughout significant stretches of rivers and creeks in the Southern MDB is in poor condition (Davies et al. 2012; NSW DPI 2016). This decline is attributed to cumulative threats and stressors including flow regulation, habitat degradation, poor water quality (cold-water pollution, sedimentation, blue-green algal impacts, hypoxic blackwater, salinity, pollutants etc.), barriers that impede fish passage, exploitation (commercial and recreational fishing), entrainment through irrigation diversions, competition and/or predation by non-native species, and disease (see Koehn et al 2020a).

Historically, diversity and variability in flowing conditions (particularly hydraulics) was a natural feature of the MDB to which fish and other aquatic biota are adapted (Mallen-Cooper and Zampatti 2018; 2020). Human influences and the exploitation of freshwater resources have substantially altered flow regimes throughout much of the MDB in less than 150 years (Thoms and Sheldon 2001; Gehrke and Harris 2001; Koehn et al 2020). These influences have contributed to a decline in the abundance and distribution of many native fish species in the MDB, with some now absent throughout much of their former range.

The impacts of river regulation and water use on native fish include:

- reduced flow variability and hydraulic complexity
- loss of extensive stretches of perennial flowing (lotic) habitat
- seasonal flow reversal
- reduced incidence and duration of small to medium floods
- permanent inundation of some areas
- altered connectivity both longitudinally and laterally between rivers and their floodplains
- prevention or impairment of the movements of fish
- cold water releases from larger dams severely impact the breeding cycles of native fish in downstream reaches.

Flow restoration

In recent years the process of restoring more natural flow regimes by augmenting regulated river flows with water for the environment (also referred to as ‘environmental flows’) has become a key aspect of ecosystem management in the MDB (Arthington 2012; Koehn et al. 2014). Effective flow restoration also requires an understanding of the relationships between hydrology, life history and population dynamics of river and floodplain biota, which then needs to be linked to management decisions. To manage native fish populations, it is important to understand the drivers that support healthy native fish populations and communities, as well as the threats and pressures that may impact them.

Complementary measures – adding value to flow remediation

Flow regulation and changes to the natural flow regime are only one of the threats implicated in the decline of native fish in the MDB. However, there are also a range of related influences that are not necessarily flow related that impact the health of rivers and wetlands and therefore the status of fish communities. These include:

- riparian and instream habitat degradation
- poor water quality
- barriers which impede fish movement
- loss of fish through irrigation diversions and pumping
- competition and/or predation by non-native species
- exploitation through fishing activities
- disease
- loss of genetic integrity and fitness
- climate change.

The potential for achieving long-term ecological outcomes through management of flow and water for the environment will be increased by undertaking parallel complementary measures such as habitat rehabilitation projects including revegetation, resnagging and fencing riverbanks, fixing fish passage, screening diversions, and mitigating cold water pollution that also address these additional influences.

Southern Basin MDB Functional Groups

The development of fish specific EWRs and flow related management actions can be simplified by allocating species of fish into functional groups based on similarities in reproductive strategies, movement capabilities and habitat requirements (see Ellis et al. 2016). A hybrid approach to fish functional groups was applied to the fish of the Southern MDB by combining elements of the reproductive spawning-movement and eco-hydraulic needs of species. Four (4) functional groups for obligate freshwater species in the Southern MDB were identified with an additional two (2) functional groups identified as occupying only the Lower Lakes-Coorong region at the terminus of the Murray River (not discussed further here).

Group 1 - Flow pulse specialists (e.g. Golden Perch, Silver Perch)

Flow pulses (within or overbank) coinciding with warmer water temperatures are generally required to generate a spawning response. The species move over large distances (e.g. flow induced spawning in the Barwon-Darling, drift of larvae hundreds of kilometres downstream as far as the Menindee Lakes nursery habitat). Golden Perch and Silver Perch spawned in the Darling River contribute substantially to populations in the Murray River system.

Group 2 - River specialists with either lotic or lentic preferences (e.g. Murray Cod, Macquarie Perch, Freshwater Catfish)

Adults may make short migrations to spawn in response to increased temperature. Moderately fecund, spawn in nests or have specific spawning substrate preferences, often with parental care. Unnatural drops in water level during nesting season could result in nest abandonment and breeding failure.

Group 3 - Floodplain specialists (e.g. Southern Pygmy Perch, Murray Hardyhead)

Adults may make short migrations to spawn in response to increased temperature, into or within lentic (or slow-flowing) off-channel habitats. Many species in this group are endangered because of habitat loss and fragmentation, with isolated populations often dependant on delivery of water for the environment.

Group 4 – Generalists, native and non-native (e.g. Australian Smelt, Carp)

Display flexible spawning strategies, but generally linked to increased temperature. Survive within-channel during low flows or on floodplains during overbank inundation. Adults may make short migrations to spawn in response to increased temperature. Generally highly fecund and may spawn multiple times in a year

Group 5 - Diadromous species

Movement between freshwater and marine environments is a fundamental to complete the lifecycle requirements of these species. Includes both catadromous species (i.e. adult freshwater residence and marine spawning, e.g. Congolli) and anadromous (i.e. adult marine residence and freshwater spawning, e.g. Short-headed Lamprey).

Group 6 - Estuarine dependant species. Species that either complete their lifecycle within estuarine environments (e.g. Black Bream) or spend large periods of their lifecycle in the marine environment but are dependent upon estuaries for a particular life stage (e.g. Mulloway).

Developing flows for fish

Managing river health through informed water delivery that targets the protection or re-instatement of natural flow regimes (or key components within natural flow regimes) is a good starting point when considering restoration of native fish populations. Higher flows and floods were generally experienced in late winter and spring in the Murray, Murrumbidgee, Lachlan and Goulburn River systems. Highest flows in the Darling River generally occur in summer-autumn resulting from summer monsoonal rain events but can also result from temperate winter storms.

Ecologically significant components of the flow regime

To be most effective, developing flow regimes that benefit native fish also necessitates an understanding of relationships between hydrology and life history, and the subsequent population dynamics. This can be done by considering specific components of a river's flow regime which may influence population outcomes such as spawning, recruitment and movement (e.g. migration). These are referred to here as Ecologically Significant Components (ESCs) of the flow regime (MDBA 2011b) and serve as a common reference to which flow management targets such as EWRs can be applied and gauged.

ESCs referred to in this report are summarised below. Currently, flow management efforts are generally constrained to targeting in channel ESCs "within channel"; that is base flows, small fresh, spring nesting flows, large fresh and in some cases bank full events (See Figures 2 and 3).

- Cease to Flow (CTF) – Periods of no flow occasionally occur in ephemeral, or non-perennial rivers, and for longer periods in some intermittent streams. During CTF events a series of disconnected pools may eventuate. CTF periods can play an important role in promoting growth of biofilms (i.e. through reduced scour) and productivity, although they can also be associated with poor body condition; particularly for species at lower trophic levels (Balcombe et al. 2012). High food availability for predatory species at higher trophic levels may occur initially during CTF periods given the limited refuge habitat for prey. However, during extended CTF periods, food supply and water quality can diminish water levels contract. Non-flowing pools can become thermally stratified in warmer climates and seasons, with a related potential for de-oxygenation of deeper water. Mixing of stratified pools, in response to small resumption flows or sudden weather events, can cause hypoxia throughout the pool with the risk of fish kills (e.g. see Ellis and Meredith 2004). In some cases CTF may restrict Carp breeding by limiting access to their preferred shallow submerged spawning substrate and habitat.
- Base Flows (BA) – Usually confined to deeper parts of the river channel, and would typically provide connectivity between pools and riffles, preventing CTF events. Occur on a near-ongoing basis in perennial systems maintaining longitudinal connectivity and associated dispersal opportunities. Base Flows may be important in maintaining drought refugia for fish, plants and invertebrates when low flow conditions prevail, and help maintain water quality (e.g. oxygenation through riffle habitats). Base Flows may also benefit small-bodied native species in terminal wetlands by maintaining aquatic habitat. Base Flows can enhance the condition of individuals and thereby contribute to sustaining a larger population carrying capacity for density dependant species during low flow periods. Base Flows also allow for the accumulation of allochthonous carbon and vegetation on dry river channel sediments and in-channel benches, which then contribute to ecosystem productivity during subsequent flow events. They also contribute to nutrient dilution during wet periods or after a flood event. Small variations in flow within the Base Flow band mimics natural variability and promote productivity during base flow periods.
- Small Fresh (SF) – Generally short increases in flow (10 days minimum) that promote longitudinal connectivity and may provide productivity benefits by replenishing soil water for riparian vegetation, inundating low-lying benches and cycling nutrients between different parts of the river channel. Small Freshes would generally be relatively slow flowing and are distinct from Large Freshes. They can contribute to the provision of suitable water quality and submerged habitat features such as snags and aquatic vegetation, which supports diverse heterotrophic

biofilm generation. The magnitude of Small Freshes can be informed by habitat mapping which identifies river heights at which within-channel features (e.g. benches and snags) are inundated. Small within-channel freshes would have generally occurred annually throughout the majority of the MDB (including most ephemeral streams), and potentially two to three times in a year for perennial (permanent or near permanently flowing) river and stream systems.

- Spring nesting flows (SN) – a seasonal period of flow during which unnaturally rapid change in water levels are avoided during the predictable Spring breeding season for nesting River Specialists (e.g. Murray Cod, Freshwater Catfish), thus avoiding stranding or abandonment of nests. Minimum event duration of 14 days, during which changes in flow magnitude and stream height (particularly decreases) are maintained within natural rates of variability to allow eggs to hatch and for larvae to leave nest sites. Larger/longer duration for Spring nesting components (30-50 days from early October through to late November where and when possible) can enhance breeding outcomes by inundating additional spawning sites, increasing productivity, and dispersing drifting young to nursery habitats. Depending on location, nesting could be supported at flow ranging from Base Flow levels through to Large Fresh levels, although breeding success is likely to be higher in fast flowing within-channel habitats (e.g. velocity greater than 0.3m/s). A short increase in flow at the end of the Spring nesting component could be initiated (in managed flow situations) to inundate further enhance productivity and food generation for young fish (Sharpe and Stuart 2018).
- Large Fresh (LF) – Substantial increases in flow for short durations (5 days minimum) that provide inundation of within-channel features (e.g. benches) and promote hydraulic complexity. Generally provide fast flowing within-channel habitats (e.g. velocity greater than 0.3m/s) which may trigger spawning in some species of Flow Pulse Specialists (e.g. Golden Perch, Silver Perch), although in highly regulated reaches concurrent lowering of weirs may be required to increase flow velocity and hydraulic complexity. Large within-channel freshes enhance productivity and nutrient exchange and promote dispersal and recruitment. In some reaches Large Freshes may contribute to minimising geomorphological impacts of regulation (e.g. sedimentation). Maintaining natural rates of change in water level may be important when Large Freshes overlap with predictable Spring breeding season of key nesting River Specialists (e.g. Murray Cod, Freshwater Catfish) as rapid change in water levels may lead to nest abandonment. Hence the recession of a Large Fresh may be protracted. Large Freshes may connect low lying backwaters and wetlands with low commence to flow thresholds in some river reaches. Large within-channel freshes would have generally occurred annually across most of the Southern MDB, and up to two to three times a year in some systems.
- Bank full (BF) – For the purposes of this project, Bank full flows are flow magnitudes at which inundation of ephemeral floodplain habitats with low commence to flow levels adjacent to river and stream channels may occur (such as wetlands, creeks and anabranches). These events generally provide fast flowing within-channel habitats (e.g. velocity greater than 0.3m/s). Currently managed flow events are unlikely to exceed Bank full levels in most situations due to system constraints and potential third-party impacts.
- Overbank flows (OB) – Overbank flows can inundate large areas of floodplain habitat. Overbank events can enhance breeding opportunities for many species by creating additional spawning habitat and floodplain productivity benefits which contribute to increased condition and recruitment. These events are generally unregulated, although there may be scenarios where environmental water activities could augment within-channel flows to create small overbank events or prolong floods to assist with maintenance of suitable water quality. These cases should ideally reflect the natural rates of flow increase or decrease corresponding to position in the catchment. Overbank events generally would have occurred every 1-25 years (depending on the magnitude of the event) for both intermittent and perennial systems.

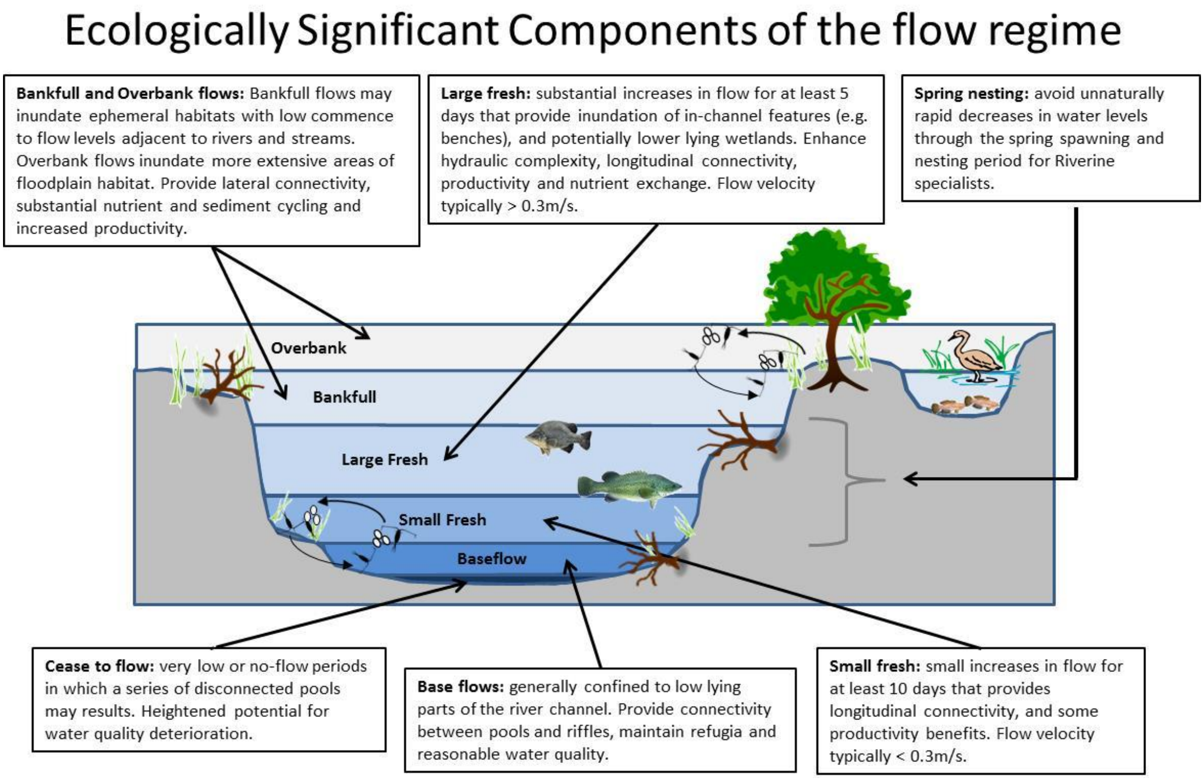

Figure 2. Ecologically significant components of the within-channel flow regime (including Cease to flow, Base Flows, Small Fresh, Large Fresh, Spring nesting component, Bank full and Overbank flows).

Conceptual hydrographs

Conceptual flow hydrographs are useful tools to assist with environmental water planning processes. Conceptual hydrographs incorporating the ESCs presented above were developed for rivers in the Southern MDB (Figure 3). These conceptual hydrographs provide a visual representation of flow components under three (3) different water resource availability scenarios (High, Moderate, and Low water availability), and suggested timing for each ESC in relation to the seasonal requirements for functional groups of Southern MDB fishes. Larger flow components will be less achievable in periods of limited water availability.

If flow threshold magnitudes are determined for each flow component at a given HIS, fish-specific EWRs can then be developed for that site expressed as flow magnitude/volume, duration, seasonality and frequency. These EWRs provide a useful starting point in the annual and longer-term planning of flow deliveries targeting fish outcomes.

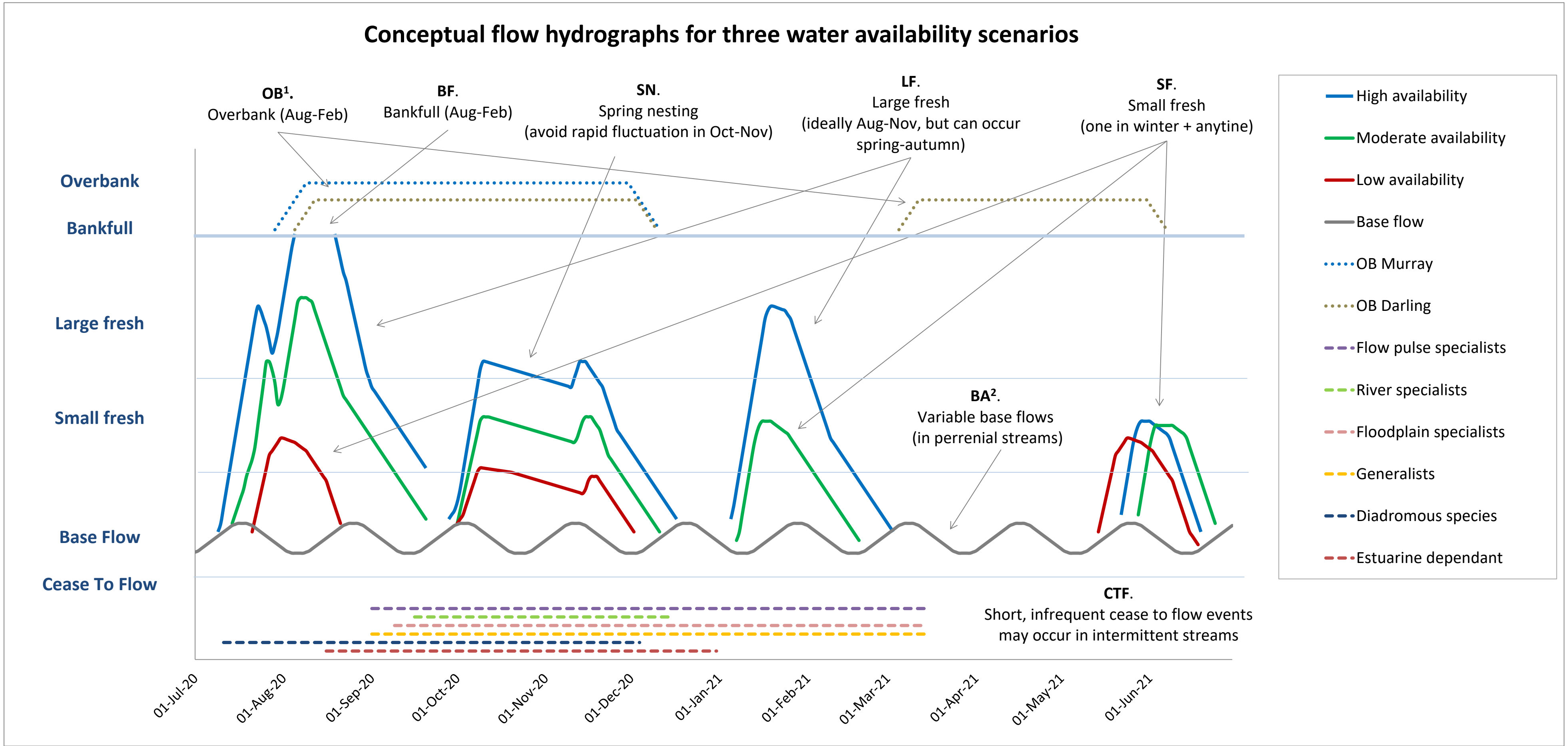

Figure 3. Conceptual flow hydrographs for three water availability scenarios (High, Moderate, and Low). Breeding season windows for each functional group of Southern MDB fishes are identified by dashed lines. Ecologically significant flow components which may promote key life history elements for fish (such as movement, spawning and condition) are labelled Bank full (BF), Overbank (OB), Large Fresh (LF), Spring nesting component (SN), Small Fresh (SF), Base flow (BA) and Cease-to-flow (CTF).

Southern MDB Indicator sites

Hydrologic Indicator Sites (HIS) in major streams across the Southern MDB were used in this project for application of the FFMF and development of fish-specific EWRs (see Figure 4). Representative gauging locations for each HIS are generally consistent with those originally used in the development of the Basin Plan.

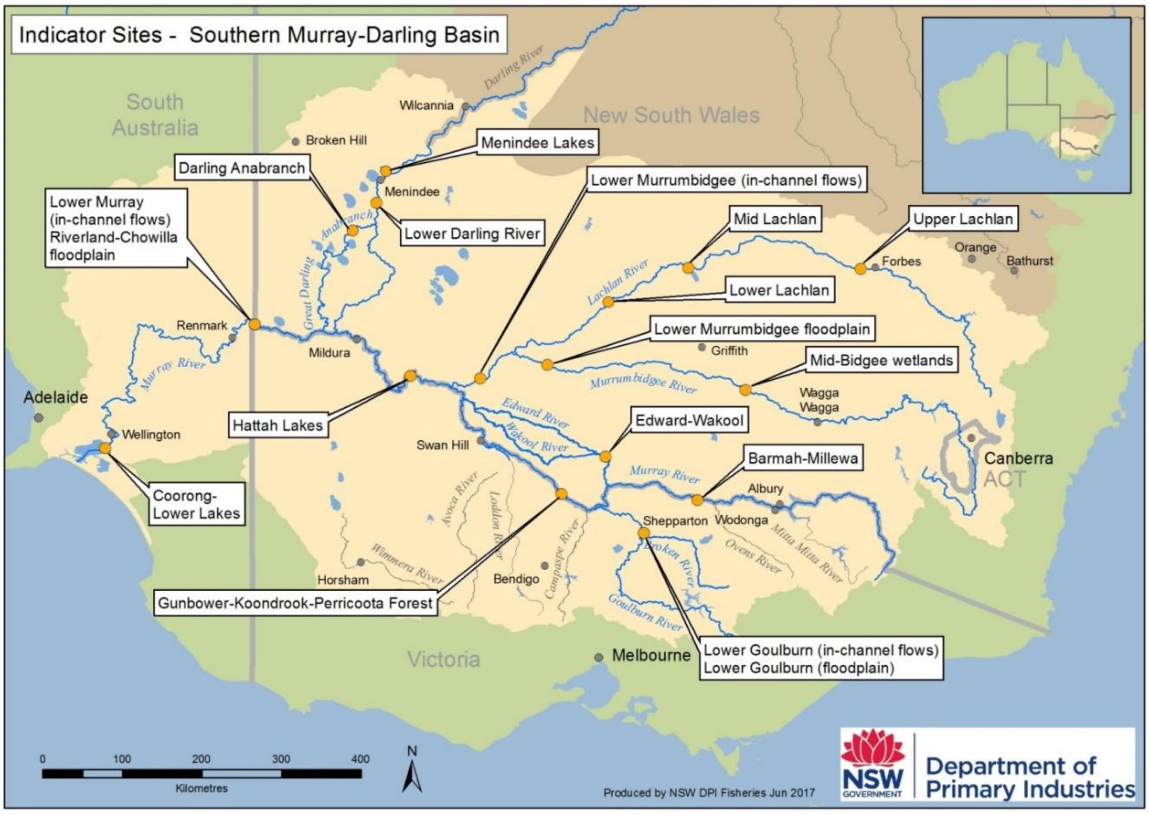

Figure 4. Major streams in the Southern MDB and location of flow gauging points for Hydrologic Indicator Sites and additional steams discussed in this report.

Flow Threshold Estimates

Hydrological analyses were undertaken to develop estimates for flow thresholds (discharge rates) that distinguish ESCs of the within-channel flow regime at sixteen selected HIS in the Southern MDB (Table 1). We have endeavoured to provide consistency between for flow thresholds presented here and those developed by the EES in Long Term Water Plans for NSW[1]. Where EES flow estimates were unavailable, corresponding values were derived by DPI Fisheries using similar methodology and collaboration with regional experts. Spring nesting component flow bands generally extend from the base flow thresholds to mid-range Large Fresh thresholds provided HIS, however regional expertise (i.e. River operators, water managers and fish ecologists) also informed the development of Spring nesting magnitudes.

[1] https://www.environment.nsw.gov.au/topics/water/water-for-the-environment/planning-and-reporting/long-term-water-plans

Table 1. Flow thresholds estimates (ML/day) for the Ecologically Significant Components of the in-stream flow regime at included sites in the Southern MDB.

Hydrological Indicator Site	Gauge location	Base flow	Small Fresh	Nesting Flow	Large Fresh	Bank full	Small Overbank	Large Overbank
Barmah-Millewa forest	Murray downstream of Yarrawonga	1,800-7,000	7,000-12,000	4,000-12,000	12,000-29,000	29,000	>30,000	>50000
Edward-Wakool system	Edward River downstream Stevens Weir	170-1,600	1,600-2,600	300-1,600	2,600-6,000	6,000	>8,000	>10000
Gunbower–Koondrook–Perricoota forests	Murray downstream of Torrumbarry	2,000-7,000	7,000-1,2000	4,500-12,000	12,000-22,000	22,000	>25,000	>40000
Hattah Lakes	Murray downstream of Euston	2,500-14,000	14,000-20,000	5,000-10,000 [2]	20,000-38,000 [2]	38,000	>50,000	>80000
NSW Lower Murray River Locks 10-7	Murray downstream of Lock 9	3,500-14,000	14,000-20,000	5,000-14,000 [2]	20,000-40,000 [2]	40,000	>55,000	>80000
S.A. Murray Lock 1-6 & Riverland-Chowilla Floodplain	Murray River at NSW-SA border	3,500-14,000	14,000-20,000	5,000-14,000 [2]	20,000-40,000 [2]	40,000	>55,000	>80000
Coorong, Lower Lakes and Murray Mouth [1]	Murray at Barrages and NSW-SA border(combined)	4,000 - 14,000	14,000 - 25,000	4,000 - 35,000 [2]	25,000 - 60,000 [2]	60,000	>64,000	>80,000
Lower Darling River	Darling River upstream of Weir 32	150-2,000	2,000-7,000	250-7,000	7,000-10,000 [3]	10,000	>15000	>25000
Darling Anabranch	Darling Anabranch at Wycott Station	NA	NA	800-1,500	800-2,000 [4]	2,000	>3000	>8000
Mid-Murrumbidgee Wetlands	Murrumbidgee downstream of Narrandera	230-4,000	4,000-14,000	1,000-14,000	14,000-38,000	38,000	>38000	
Lower Murrumbidgee floodplain	Murrumbidgee downstream of Maude	170-2,500	2,500-6,000	600-6,000	6,000-1,300	13,000	>15,000	>22,000
Lower Murrumbidgee in-channel	Murrumbidgee downstream of Balranald	170-2,500	2,500-6,000	500-6,000	6,000-8,900	8,900	>10,500	>20,000
Lower Goulburn River and Floodplain	Goulburn downstream of Shepparton	500 - 2,000	2,000 - 5,600	1,500 - 6,000	5,600 - 15,000	15,000	>15,000	>40,000
Upper Lachlan	Lachlan downstream of Cottons Weir	50-600	600-8,500	200-8,000	8,500-13,000	13,000	>13900	>45000
Mid Lachlan	Lachlan at Hillston	20-280	280-1,600	100-1,600	1,600-4,000	4,000	>5000	>7000
Lower Lachlan	Lachlan at Booligal	10-200	200-650	100-650	650-2,000	2,000	>2500	>4000

Application

Environmental Water Requirements (EWRs)

By taking the conceptual hydrographs produced using the FFMF, and the flow thresholds above (Table 1) we developed a suite of fish-specific EWRs at sixteen selected HIS across the Southern MDB. A thorough presentation and description and rationale for recommended EWRs at each HIS is available in the full report (Ellis et al. 2022). The fish-specific EWRs are recommended to support the management or water such that the needs of native fish are considered. EWRs are expressed as a set of flow indicators representing significant components of the flow regime relevant to the known biological requirements of fish (flow magnitude/threshold or volume, duration, seasonality and frequency). Water managers can refer to the recommended EWRs when planning and prioritising water delivery to achieve (or generate) hydrograph components that enhance native fish outcomes.

Prioritising hydrograph components

The prioritisation of ESCs in a stream hydrograph in any given season will be guided by the required return frequency of each flow component. Flow components that are not met within the recommended return frequency will inform prioritisation and planning in subsequent years. Recommended annual return period (ARI; years), duration (days) and maximum period between ESCs relative to each functional group of fish are included in the full report.

Whilst Overbank flood events are vital for the long-term ecological health of the MDB, currently they are not considered achievable using water for the environment reserves due to the large volumes required and system constraints. We refer to Overbank floods in this report but do not propose these can be achieved through water for the environment alone.

Comprehensive monitoring covering the appropriate spatial and temporal time periods for the ecological outcomes or impacts resulting from the delivery of one or more flow components is critical to allow for evaluation, future adaptation and optimisation of this process.

Coordinated management

The fish-specific flow indicators we present should also be read in conjunction with information regarding the holistic EWRs of a site (i.e. to achieve multiple ecological targets for the HIS). Most of the HIS in the Southern MDB are hydrologically connected and therefore interdependent. To be most effective, manipulation of the flow regime to target fish objectives should aim to achieve cumulative benefits within and across catchments. The FFMF is intended to be applied with consideration of adjoining sites, reaches and streams by using information about the fish communities present within each catchment.

Prior to completion of this project, DPI Fisheries have been using the FFMF to assist state and Commonwealth environmental water managers in planning annual priorities and flow deliveries. These efforts are reflected in positive native fish outcomes linked to targeted deliveries of water for the environment in the Murray, Lower Darling, Murrumbidgee and Lachlan rivers since 2016. For example, in the Lower Darling Baaka River environmental water has been used in conjunction with managed operational flows to achieve EWRs that support Murray cod spawning and recruitment, and dispersal of the flow pulse specialist Golden perch (Stuart and Sharpe 2021).

Overlap with cultural and recreational fishing values

During completion of this project accompanying consultation with water managers and Aboriginal Traditional Owner groups identified that the achievement of fish outcomes through environmental water delivery would in many cases also achieve certain cultural outcomes for Aboriginal peoples.

Similarly, recreational fishing leaders and managers confirmed that achieving positive outcomes for native fish populations would in the long term contribute to the large recreational fishing industry across the MDB. Ongoing exploration of these overlapping outcomes is recommended to ensure shared outcomes can be achieved through the management and delivery of water for consumptive needs and the environment.

Discussion and next steps

The ***Fish and Flows in the Southern Basin*** project presents a synthesis of knowledge and conceptual understanding of how flow may be managed to benefit fish. The framework and conceptual models presented are not prescriptive. Due to the natural variation in flow characteristics both spatially and temporally within the Southern MDB, responsible application of the framework presented here in water management must consider regionally specific details (such as the timing of breeding seasons, channel capacity and discharge values for which various levels of inundation of critical habitat features occurs). The framework and concepts outlined in this report need to be adapted to suit different geographic locations based on these considerations.

Importantly, the outputs presented in this report can be updated as additional information comes to hand. Targeted research and robust monitoring of the ecological outcomes or impacts resulting from application of the FFMF will be critical to allow future adaptation and optimisation of the process of delivering flow for targeted fish outcomes. As knowledge gaps are addressed our understanding will increase and management options will be refined.

Again, we note that the delivery of water is only one step in the process of achieving environmental outcomes for native fish. Due to the extent of water and land use in the MDB, in some cases the achievement of meaningful outcomes for fish will require strategies in addition to the delivery of proposed flow regimes (i.e. complementary actions) (Koehn 202ab). These actions may include re-snagging programs, mitigating cold water pollution (Lugg and Copeland 2014), weir pool manipulations, improvements to fish passage (Baumgartner et al. 2014), conservation stocking or translocations (Whiterod et al. 2019), screening of irrigation pump offtakes to minimise fish entrainment (Baumgartner et al. 2009; Baumgartner and Boys 2012), pest fish control (e.g. wetland screening or removal programs), riparian restoration and coordinated watering strategies (between States, jurisdictions and sites).

References

Arthington, A. (2012). Environmental Flows: Saving Rivers for the Third Millennium. University of California Press.

Davies, P., Stewardson, M., Hillman, T., Roberts, J. and Thoms, M. (2012). Sustainable Rivers Audit 2: The ecological health of rivers in the Murray – Darling Basin at the end of the Millennium Drought (2008-2010) Volume 2. Canberra, ACT. Prepared by the Independent Sustainable Rivers Audit Group for the Murray– Darling Basin Ministerial Council.

Ellis, I., Cheshire, K., Townsend, A., Copeland, C., Danaher, K. and Webb, L. (2016). Fish and flows in the Murray catchment – a review of environmental water requirements for native fish in the Murray River catchment. NSW Department of Primary Industries, Queanbeyan.

Ellis, I., Cheshire, K., Townsend, A., Danaher, K., Lone, R. (2022). Fish and Flows in the Southern Murray-Darling Basin: Developing environmental water requirements for native fish outcomes. NSW Department of Primary Industries, Buronga.

Gehrke, P. C. and Harris, J.H (2001). Regional-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. Regulated Rivers: Research and Management 17, 369-391.

Koehn, J. D., Raymond, S. M., Stuart, I., Todd, C. R., Balcombe, S. R., Zampatti, B. P., Bamford, H., Ingram, B. A., Bice, C. M., Burndred, K., Butler, G., Baumgartner, L., Clunie, P., Ellis, I., Forbes, J. P., Hutchison, M., Koster, W. M., Lintermans, M., Lyon, J. P., Mallen-Cooper, M., McLellan, M., Pearce, L., Ryall, J., Sharpe, C., Stoessel, D. J., Thiem, J. D., Tonkin, Z., Townsend, A. and Ye, Q. (2020a) A compendium of ecological knowledge for restoration of freshwater fishes in Australia's Murray–Darling Basin. Marine and Freshwater Research, 71 (11). pp. 1391-1463.

Koehn, J., Balcombe, S., Baumgartner, L. J., Bice, C. M., Burndred, K., Ellis, I., Koster, W., Lintermans, M., Pearce, L., Sharpe, C., Stuart, I. G., & Todd, C. (2020b.) What is needed to restore native fishes in Australia's Murray-Darling Basin? Marine and Freshwater Research, 71(11), 1464-1468.

Mallen-Cooper, M. and. Zampatti, B. (2018). History, hydrology and hydraulics: Rethinking the ecological management of large rivers. Ecohydrology. 2018; e1965.

Mallen-Cooper, M. and. Zampatti, B. (2020). Hi Restoring the ecological integrity of a dryland river: Why low flows in the Barwon–Darling River must flow. Ecological Managemnet & Restoration. 2020.

NSW DPI (2016a). Fish communities and threatened species distributions of NSW. Report prepared for the Commonwealth Government. NSW Department of Primary Industries, Wollongbar.

Stuart and Sharpe (2021) "An eco-hydraulic model for designing environmental flows supports recovery of imperilled Murray cod (Maccullochella peelii) in the lower Darling/Baaka River following catastrophic fish kills" Marine and Freshwater Research. https://www.publish.csiro.au/MF/justaccepted/MF20377

Thoms, M.C. and Sheldon, F. (2000). Water resource development and hydrological change in a large dryland river: the Barwon-Darling River, Australia. Journal of Hydrology 228, 10-21