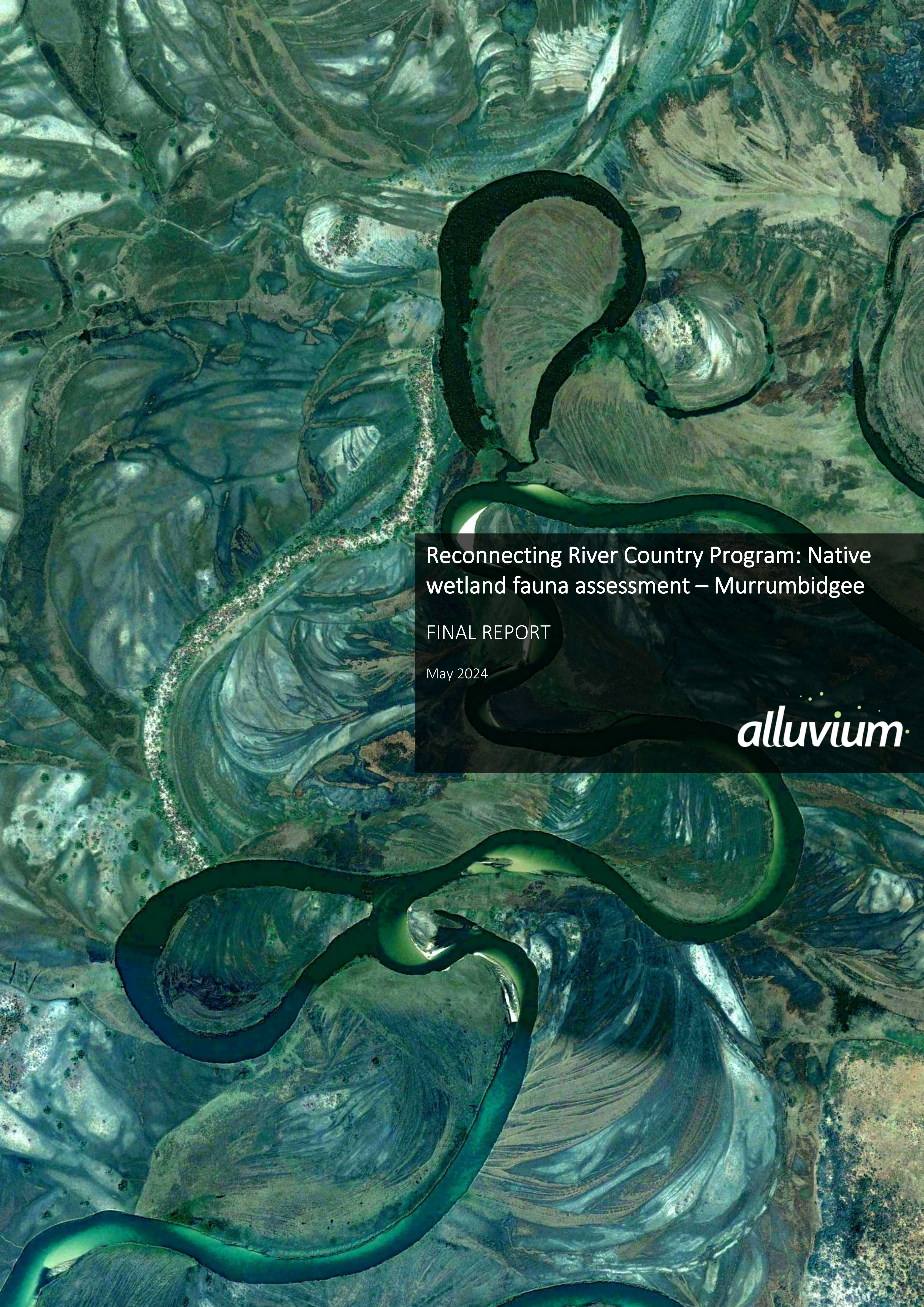

Reconnecting River Country Program: Native wetland fauna assessment – Murrumbidgee

FINAL REPORT

May 2024

alluvium

Alluvium recognises and acknowledges the unique relationship and deep connection to Country shared by Aboriginal and Torres Strait Islander people, as First Peoples and Traditional Owners of Australia. We pay our respects to their Cultures, Country, and Elders past and present.

Artwork by Melissa Barton. This piece was commissioned by Alluvium and tells our story of caring for Country, through different forms of waterbodies, from creeklines to coastlines. The artwork depicts people linked by journey lines, sharing stories, understanding, and learning to care for Country and the waterways within.

This report has been prepared by Alluvium Consulting Australia Pty Ltd for The NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) under the contract titled 'Reconnecting River Country Program: Native wetland fauna assessment – Murrumbidgee'.

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Executive Summary

Overview

The Reconnecting River Country Program (the program) aims to increase the frequency and extent rivers connect to wetlands and floodplains, to improve the health of Country in the Murray and Murrumbidgee River valleys. The program will achieve this goal by removing barriers, or constraints that impact the delivery of environmental water in the Murrumbidgee and Murray valleys (Figure 1). Should the program proceed to delivery, these options are expected to enable environmental flows to connect more wetlands and low-level floodplains more frequently than is currently possible, improving ecological outcomes across the Murray, Murrumbidgee River and Yanco Creek systems and their associated floodplains. This native wetland fauna assessment considers the Murrumbidgee and Yanco project areas only (hereafter referred to as the Murrumbidgee River system). The Murrumbidgee River system is home to a wide variety of ecosystem types that provide habitat for a large diversity of flora and fauna. For this study, we analysed the results of 4 flow scenarios, the base case flow limit and three higher flow limit options at Wagga Wagga, and the effects that we anticipate they would have on the system at large. The maximum operational flow rate for flow scenarios as measured at Wagga Wagga included:

- Base case: (22 GL/day flow limit)
- Option 1: (32 GL/day flow limit)
- Option 2: (36 GL/day flow limit)
- Option 3: (40 GL/day flow limit)

The assessment has been undertaken at the ecosystem and species levels. A summary of the hydrological and species-specific outcomes can be found in Table 1 and 2 below.

Table 1 Summary of inundation outcomes for flow limit options

	Base Case	Option 1 (32GL)	Option 2 (36GL)	Option 3 (40GL)
Percentage change to inundated area under each scenario (cumulative) [relative to base case]	NA	54%	30% [+100%]	16% [+220%]
Percentage of mapped Australian National Aquatic Ecosystem (ANAE) wetland types with >20% of total area inundated	32%	68%	84%	88%
Additional 32 GL flow events compared to base case occurring under each scenario	-	+10 events (+4 ext)	+19 events (+10 ext)	+19 events (+11 ext)
95th percentile inter event duration (years) for spells reaching 32 GL/day for at least 5 days (Wagga Wagga)	9	5.5	4	4
Proportion of total wetland areas deeper than 3m (Gundagai to Hay)	52%	67%	59%	67%
Increase in the area of wetlands inundated to depths >5m (by percentage when compared to the previous option)[relative to base case] (Gundagai to Hay). Numbers are proportional increase over each previous scenario, numbers in brackets are the increase relative to the base case.	-	7,296% [7,296%]	96% [14,396%]	66% [28,312%]

Method

Collating information on species' water requirements (SWR) was a five-step process.

1. Review of SWR in Long-Term Watering Plans and other relevant flow assessments.
2. Review of on-line databases to identify ecosystem types in which species had been observed.
3. Literature review of the function of key wetland flow characteristics on species life cycles.
4. Consideration of the known ecology of each species and its life history.
5. Review and input from an expert panel.

These lines of evidence enabled identification of four indicators that were both important to the life cycle of key floodplain species and that could be modelled for each scenario, specifically, the value of permanent wetlands, habitat preferences, the role of connectivity and species breeding or recruitment needs.

Hydrological modelling was used to assess potential environmental flow outcomes from the program over the long-term (DPE, 2022). Table 2 provides a summary of the flow scenarios assessed. Modelling was undertaken using the Source Murrumbidgee Model, a hydrological model developed by the NSW DCCEEW (formerly NSW DPE) (DPE, 2022). The model version used for this work represents current system operations, current environmental water recovery, and historical climate over the period 1 May 1890 to 28 March 2021 (130 years). This version of the model was further developed by the department to include the program flow scenarios and water delivery strategies described in DPE (2022). Flow series produced by the modelling were used as the basis for the assessment.

The model outputs were then compared to identified SWR to determine the outcomes of each scenario in terms of habitat availability, connectivity and recruitment needs.

Results

A summary of the results for key species are presented in Table 2. The first row for each species, provides a brief comment on the benefits, while the second row provides an assessment. For the Habitat assessment, the 3 boxes represent the percentage improvement in the area of habitat (ANAE derived) as you move from the base case flow limit to 32GL d^{-1} (Option 1), 36GL d^{-1} (Option 2), or 40GL d^{-1} (Option 3). The light blue boxes represent increases in core habitat, while dark blue boxes represent increases in habitats that become available during high flows. Grey boxes are an assessment of relative benefit from connectivity improvements with 1 representing little change and 5 representing significant improvement. Yellow boxes represent relative benefit to breeding and recruitment with 1 representing little change and 5 representing significant improvement. Question marks represent species that we felt were too uncertain to assess.

Table 2: Scorecard summary of flow limit options for representative species. A more comprehensive list of species is provided in the report. The Perm. column has a star for those species that are dependent on permanent wetlands. Only one score is provided for connectivity and breeding/recruitment across all scenarios due to the uncertainty associated with the rating.

Species	Perm.	Habitat	Connectivity	Breeding/ Recruitment
Freshwater catfish		Improved flow in smaller permanent and ephemeral streams	Uncertain – may move between wetlands and channel, but higher flow limits may not represent major improvement.	Influence of flow on breeding and recruitment remain uncertain.
	★	14 15 17	3	?
Murray River rainbow fish		Increase in permanent and ephemeral wetlands will increase available habitat.	Occupies a wide range of habitats and likely to move into new habitats, although there will be risks in colonising ephemeral habitats[1]	Improved vegetation
	★	17 18 21 14 16 16	5	4
Southern Bell frog		Increases in ephemeral wetlands will provide additional habitat during overbank flows	Improved vegetation condition and additional water in the landscape will support movements	
	★	15 16 18 14 15 16	5	4
Broad Shelled Turtle		Increases in depth and permanence of wetlands will provide addditional habitat.	Increased frequency of connection will facilitate dispersal between river and deep wetlands.	Influence of flow on breeding and recruitment remains uncertain.
	★	12 13 14	3	1
Platypus		Improved flow in smaller permanent streams and maintenance of permanent wetlands could improve available habitat	Ephemeral habitats and improved vegetation condition may reduce risks associated with juvenile dispersal	Platypus declines have coincided with regulation, but there may be risks to young during high flows, but little data.
	★	5 6 6 82 97 105	2	?

Floodplains represent a dynamic mosaic of habitat types driven by the flow regime, and this is believed to contribute to the number of species they can support. Higher flow limits increased the inundation of recognized ANAE types and in addition, higher levels of relaxation means that different areas of the same ANAE type can be subjected to different flow regimes. This heterogeneity is most likely to affect understory vegetation and through this, the habitat characteristics and food resources available to animals.

Broadly, there are four ways in which higher flow limits can benefit wetland fauna:

1. Increases in the frequency of inundation will improve species populations. Reducing the time between inundation events will reduce mortality during the dry periods and provide more frequent opportunities for breeding and dispersal.
2. For species that use ephemeral habitats, raising the flow limit will significantly increase the amount and frequency of habitat available. This applies to both species that specialise in ephemeral habitats, but also generalist species that use them opportunistically such as Murray River Rainbow fish and Eastern Long-necked turtles.
3. For species that exploit habitats across the floodplain (for example, Eastern Long-necked turtles), more regular inundation will both provide connectivity and improve vegetation condition that will also facilitate movements among elements of the dynamic mosaic.
4. Permanent wetlands will provide more reliable refuges with fewer and shorter dry periods. Increases in the number of refuges will help sustain species during droughts and promote resilience with the return of wet conditions. The benefit to permanent wetland habitats may be limited by the presence of invasive species such as gambusia and carp. The program has assessed the risk that higher flow limits will lead to an increase in carp populations in the short term (< 5 years). The carp study concluded that there would be negligible change (Wootton et al. 2023). It may be possible to manage the small number of deep wetlands (>5 m) to reduce invasive species numbers as a complementary measure to provide enduring refuge for native species, realising potential benefits from higher flow limits.

Conclusion

The assessment revealed that, at a landscape scale, higher flow limits have the potential to rehabilitate large areas of the Murrumbidgee River floodplain, and this will contribute to protecting a representative selection of ecosystem types. At the level of individual species, improvements in:

- The amount of available habitat
- Key ecosystem types, specifically permanent wetlands
- Connectivity restoration

These changes have the potential to help restore ecosystems so that they provide species with the resources they require, the connectivity will enable movement to either complete their life cycles or exploit food resources. Improvements in the depth and duration of wetland inundation will improve species resilience through provision of refuges and improved opportunities to recolonise disturbed habitats. Of the 15 species examined, all are expected to benefit to some extent from higher flow limits. These species are also likely to provide a good indication of the benefits for other species including bush birds and terrestrial reptiles such as the Grey snake. Outcomes for individual wetlands are difficult to forecast due to the suite of drivers that influence outcomes, however, at the landscape scale the assessment suggests that higher flow limits are likely to restore a more natural dynamic habitat mosaic.

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1 Introduction

1.1 Background

The Reconnecting River Country Program (the program) aims to increase the frequency and extent rivers connect to wetlands and floodplains, to improve the health of Country in the Murray and Murrumbidgee River valleys. The program will achieve this goal by removing barriers, or constraints that impact the delivery of environmental water in the Murrumbidgee and Murray valleys. This study focuses on the Murrumbidgee River system, with the goal to address constraints that currently limit the connection of water for the environment to wetlands and floodplains, thereby improving ecological outcomes. This involves studying the potential benefits and risks of changing flow limits through ecohydrological models and assessments in collaboration with experts (called the Environmental Benefits and Risks Assessment or EBRA – DPE, 2022. These studies use modelled river discharge time series that reflect potential flow regime changes, developed by the NSW DCCEEW, to simulate the impact of raising flow limits for water for the environment deliveries. The current flow limit and flow limit options being considered by the program are detailed in Table 3.

Table 3: Current and proposed flow limit options for the Murrumbidgee, and modelled flow scenario names.

Flow limit option	Modelled flow scenario name	Murrumbidgee Flow Limit (Wagga Wagga; ML day^{-1})
Current (base case)	W22	22,000
Option 1	W32	32,000
Option 2	W36	36,000
Option 3	W40	40,000

1.2 Project Area

The Murrumbidgee catchment, featuring diverse wetland ecosystems, is recognized for its ecological importance, with key areas like the Mid-Murrumbidgee River Wetlands and Lowbidgee Floodplain Wetlands listed in the Directory of Important Wetlands of Australia. The Mid-Murrumbidgee area is characterized by River Red Gum forests and a variety of lagoons and swamps, while the area below Hay includes the Lowbidgee Floodplain Wetlands, noted for a rich mix of aquatic habitats and plant species. The complex Redbank and the Gayini-Nimmie-Caira systems (part of the Lowbidgee) are also distinguished by their respective River Red Gum forests and extensive lignum shrubland, which provide vital waterbird habitats.

The Yanco Creek System is an effluent stream from the Murrumbidgee that travels over 800 km through the towns of Jerilderie, Conargo, Wanganella and Morundah before reaching Moulamein (Figure 1). It includes the creeks of Yanco, Colombo, Billabong and Forest creek amounting to over 800 kilometres of creek lines. Prior to European settlement, Yanco Creek was a high-level effluent creek and it is believed that the Murrumbidgee River only connected to the creek during flows of around 40,000 ML/day or greater. When flowing the Yanco Ck system links two the Murrumbidgee and Murray, through over 800 km of interconnected waterways. The Yanco Creek System includes a large number of wetlands that include large wetlands, smaller floodplain depressions and billabongs (Flow-MER 2022). It is home to a diversity of bird, vegetation, frog and native fish communities including iconic species such as Murray cod, golden perch, freshwater catfish and the threatened southern bell frog and trout cod.

In the late 1800s a cutting was made to provide flows at lower levels. The Yanco Weir on the Murrumbidgee River was built in 1928 and upgraded in 1981 to control and increase flows into the creek system. The Yanco Creek system now flows permanently and supports environmental and cultural values in addition to farming, town water supply and recreation (DPIE 2020).

Implementation of the Basin Plan has been associated with delivery of environmental flows into the Yanco Creek system (CEWO 2022). The system is also the subject of two sustainable diversion limit adjustment projects. These are the Reconnecting River Country Program and SDLAM works under their Yanco Creek Modernisation Project to improve water management.

For the EBRA projects, the Mid-Murrumbidgee is defined as the area between Burrinjuck Dam and Hay. This area, particularly between Gundagai and Hay, encompasses more than than 1,600 wetlands (Frazier and Page 2001) with varied habitats. These wetlands, crucial for native fauna, are increasingly impacted by river red gum sapling encroachment, largely due to reduced frequency of inundation events (OEH 2019).

Many of these wetlands connect to the river via flood runners or small channels, but current flow limits (22 GL. d^{-1} Wagga Wagga) prevent environmental flows from reaching all of these areas. While pumping water into select wetlands is possible, it's costly and has limited overall benefit (Wassens et al 2021).

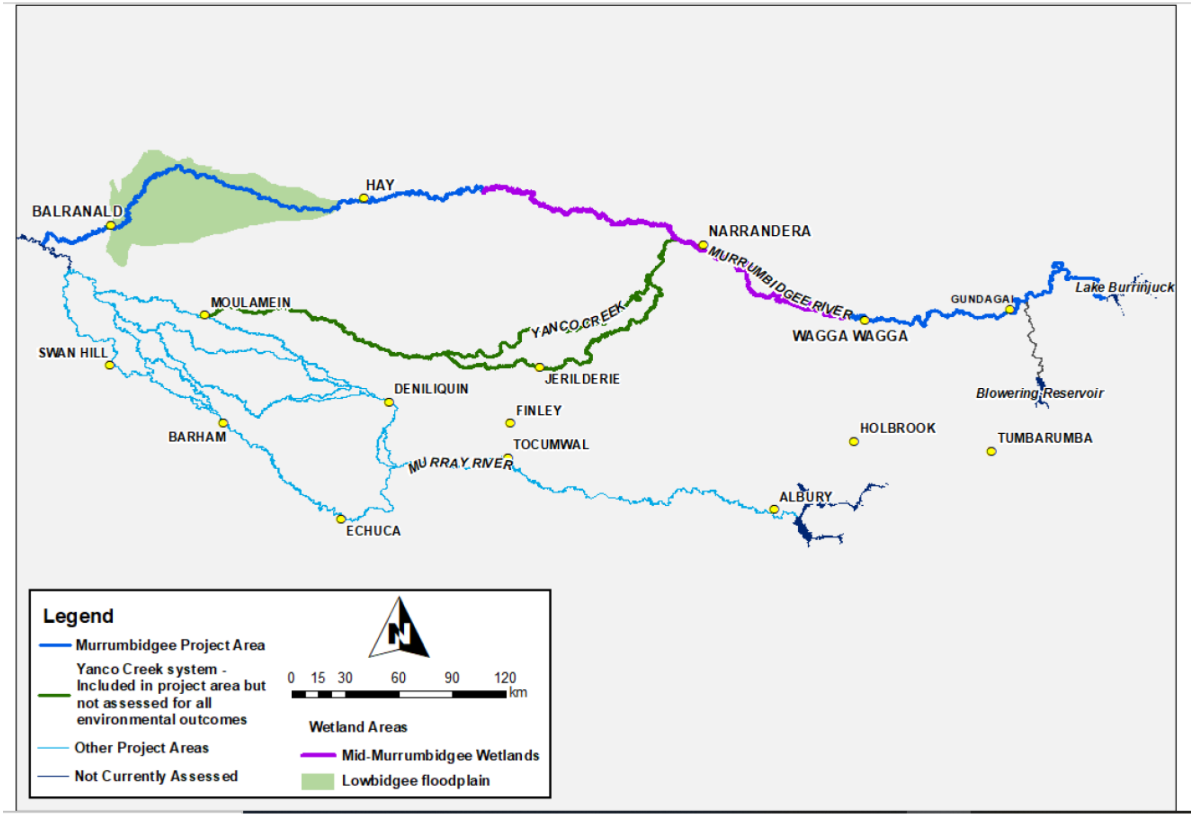

Figure 1 Riverine Zones in Murrumbidgee Selected Area (DPE, 2022)

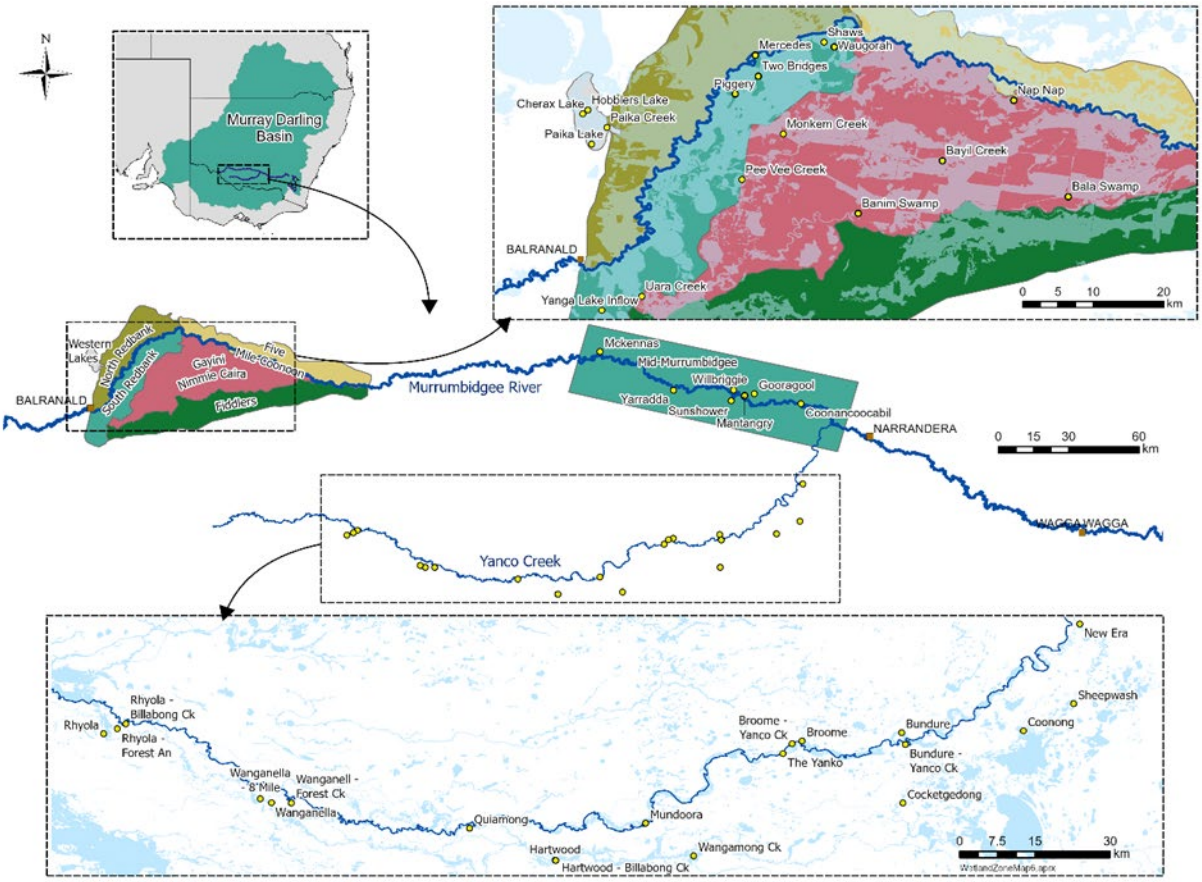

Figure 2 Wetland Zones in Murrumbidgee Area and Locations of Key Wetlands (Wassens et.al., 2017)

2 Methodology

2.1 Project Scope and Outcomes

The primary objective of this report is to provide an assessment of the likely outcomes for native wetland fauna from delivering water under a range of new flow limit options in the Murrumbidgee River. To achieve this aim, the NWFA project team:

1. Undertook a literature and data base review to identify the best available information on species environmental water requirements.
2. Consulted with a scientific expert committee
3. Used the outputs of DCCEEW NSW inundation modelling to identify the hydraulic outcomes of the base case and three flow limit option scenarios.
4. Integrated the hydraulic outcomes and SWR information to infer the potential outcomes for wetland fauna.

2.2 Review and Conceptualisation

2.1.1. Data

Information on species' water requirements (SWR), commenced with the collation of SWR in Long-Term Watering Plans and other relevant flow assessments. There was limited information for most of these characteristics in some cases because the relationship between flow characteristics and hydraulic outcomes varies among wetlands and also between events (Table 4).

Table 4. Species' water requirements are defined by a series of flow characteristics at a gauge. The hydraulic characteristics that influence species are modified by floodplain and wetland morphology. This table provides an overview of these relationships.

Characteristic	Modifying factors
Flow rate	Position on the floodplain, nature of connection, wetland depth
Timing	Species life history
Duration	Wetland depth, surrounding vegetation, connection to groundwater
Frequency	Wetland depth influences duration of inundation which may influence required frequency
Maximum inter-event period	Similar to frequency

A complementary search was undertaken of on-line databases to identify the ANAE ecosystem types in which each species had been observed. While useful, confidence in the results was reduced due to both known inaccuracies in ANAE mapping of ANAE wetland types, and also biases in the observations of species.

For analyses on wetland depth, duration and connection (Sections 3.3 and 3.4), mapped extents of wetlands were used, specifically Hall et al., (2023) for the mid-Murrumbidgee and DNR, (2007) for the Upper Yanco System. Note that the Hall et al., (2023) map of wetlands includes all wetlands larger than 1ha identified in Murray (2008) in the mid-Murrumbidgee, whilst all wetlands are mapped in the Upper Yanco System.

The review also considered what was known of the function or influence of key wetland flow characteristics on species life cycles. These are listed in Table 5. Obtaining certain estimates of species wetland flow characteristics did not produce all that much information. This is likely because persistence in wetlands requires that species have the capacity to adapt to a wide range of habitat conditions as the cycles of inundation and drying alter wetland habitat and connectivity characteristics.

Table 5. Key characteristics of wetland flow regimes and how their effects may vary among species.

Characteristic	Effect
Timing	The importance of flow timing varies among species
Depth	Depth is known to be important, but depth preferences vary as does species capacity to persist during periods when depth is not favourable.
Duration	Duration is important for species who require wetlands to complete a specific stage in their life cycle. Duration can vary in wetlands that are inundated to similar depths.
Frequency	Frequency will be influenced by duration and by the species' tolerance to the range of conditions experienced during the drying phase
Maximum inter-event period	Similar to frequency.

The final approach was to build on the information and then consider the known ecology of each species and its life history. From these lines of evidence, we were able to infer some additional species requirements. From this process we were able to identify four indicators (Table 6) that were both important to the life cycle of key floodplain species and that could be modelled for each scenario.

Throughout the process, we consulted with an expert panel who provided feedback on the information collated, provided advice on SWR and provided additional material for inclusion in the review process.

Table 6. Four key criteria derived from multiple lines of evidence that were used to infer the outcomes of changes to wetland flow regimes.

SWR	Description
Permanent wetlands	A range of species are dependent on permanent water if they are to survive cycles of flooding and drying.
Habitat	Using the wetland types observed to support species, the area of available habitat under each scenario could be estimated.
Connectivity	Two classes of connectivity were considered important. The first was connection between permanent wetlands and the river channel. The second was the connection between permanent wetlands and other types of wetland.
Breeding/Recruitment	This metric was based on several considerations. First was the extent to which wetlands required for breeding were inundated and inundated for long enough to support completion of that life cycle. The second was that cycles of wetting and drying are associated with improvements in vegetation condition which provides critical habitat for a range of species. Inundation and drying are also associated with increased productivity which is also important in growth and survival of juveniles.

2.1.2 Literature

Through a preliminary research process, we compiled a list of suitable species to reflect the effects of differing flow requirements. This included generalist and specialist species that have been found within the study area at present, or if significant historical records existed. This started as a preliminary list that was then reviewed by the expert panel to ensure that we were covering species of interest and relevance to the study area. The review included consideration of species habitat, connectivity and food requirements and also considered the life cycle of each species, including breeding and recruitment.

2.1.3. Expert Panel

Our process included an early review of methodology by an expert panel as assembled by NSW DCCEEW, which refined our species listing. During the methodology review, our initial approach to the conceptual models was also supplied to the panel. These models were then improved based on the information collected through data received from NSW DCCEEW, the literature review and the database search (Section 2.1.4).

Once the finalisation of our selected species was approved both by the NSW DCCEEW and their Expert Panel, the remaining species and information surrounding them were collated into a literature review report along with the coinciding conceptual models constructed. The expert panel then reviewed the draft report to ensure that selected species were adequately captured.

2.1.4. Data base search

Throughout the process of reviewing the literature, we found a lack of information surrounding depth and flow requirements for the species. To mitigate this, several databases were searched. These included databases constructed during previous Alluvium projects, MDBA databases and the Murrumbidgee LTWP. These databases were predominantly defined as Environmental Water Requirement Databases. Other databases reviewed were SPRAT (Species Profiles and Threats Database) profiles for all species listed (if available), and ICUN identification lists. During searches both the common and Latin names were used to ensure comprehensive results.

2.1.5. Limitations

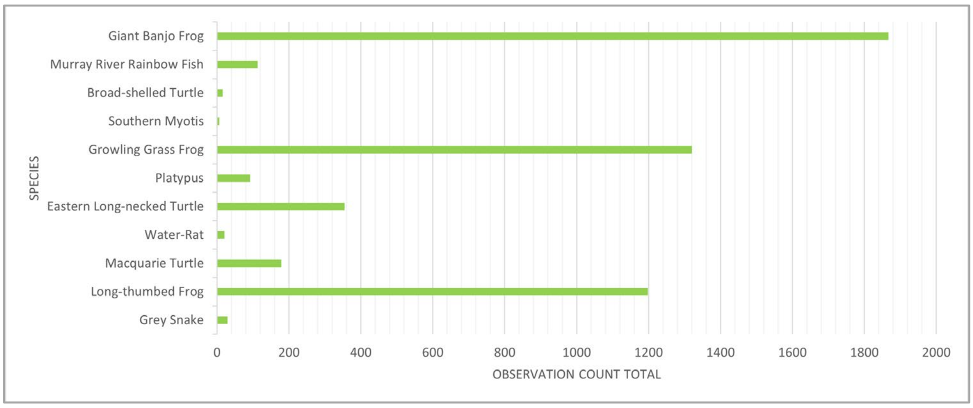

Figure 3 Combined Species Observation Counts under Study Area

The ANAE wetland classification and the sites of species observations were used to infer the types of wetlands that provided habitat for each species. The area of different ANAE wetland types were subsequently used to calculate the available habitat for each species, however it is acknowledged that there are errors in the ANAE mapping. Further uncertainties in the analysis are associated with site occupancy or variations in inundation between floods. One key assumption in our analysis is that species presence in an ANAE wetland type demonstrates the wetland type provides suitable habitat. Species information was dominated by frog species (Figures 3 & 4; see Appendix B for smaller ANAE types) and River Red Gum floodplains. There are likely to be a number of explanations for this do not relate to species distribution or habitat use. Potential explanations for the patterns include:

- River Red Gum floodplains occupy the largest area of any ecosystem type, and this will have a significant effect on the data.
- River Red Gum floodplains comprise the riparian vegetation for many ecosystem types, and this may bias observations.
- Frogs are largely identified using call count estimations as opposed to visual sightings, which may increase the number of observations.
- General lack of focus studies centred around turtle species as well as a shifting expectations of turtle abundance due to a variety of factors, including, but not limited to historical persecution of the species and lack of historical data.

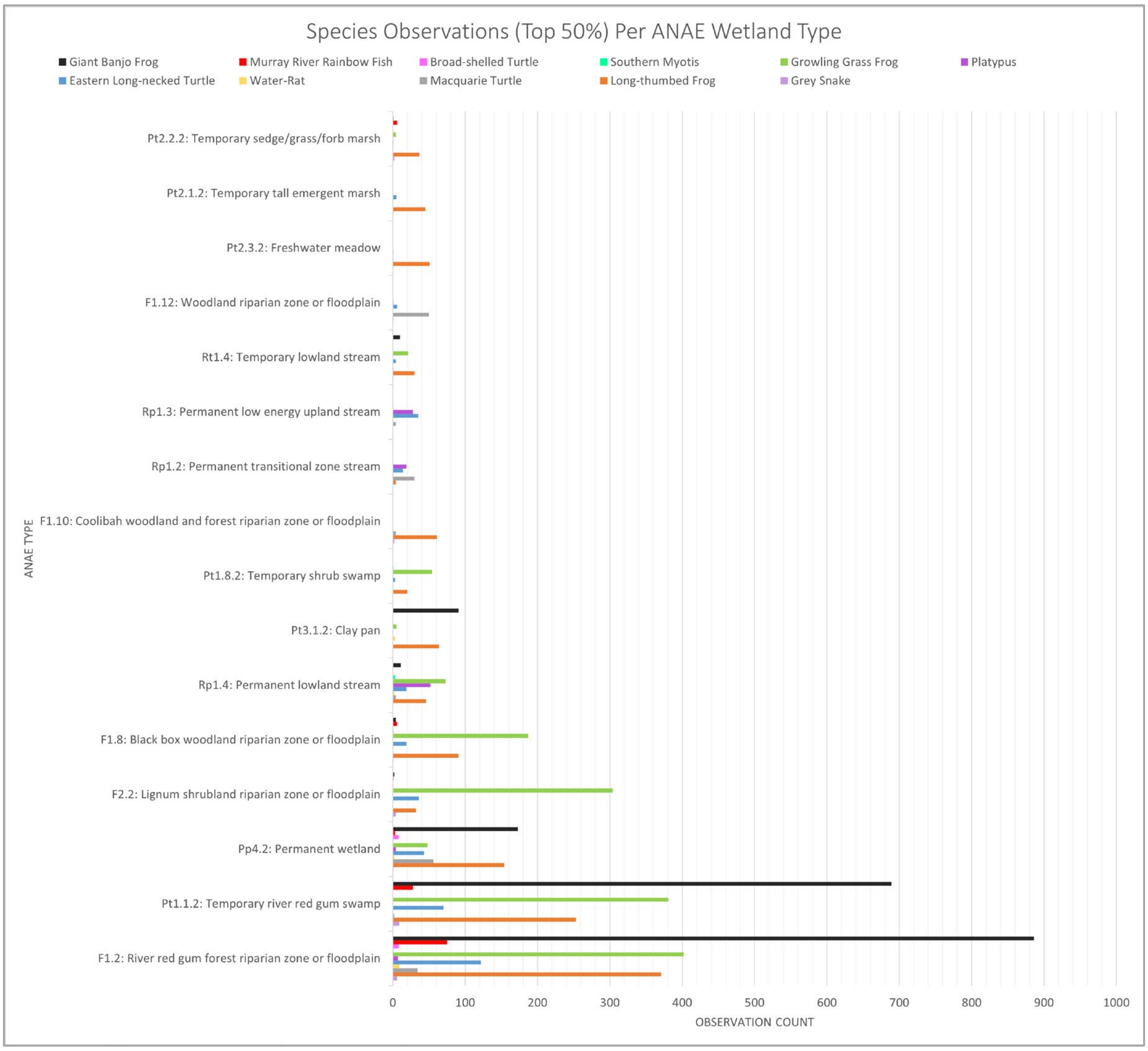

Figure 4 Top 50% of ANAE Wetland Types by species counts within the program area.

Due to the large dataset, a plot of the lowest 50% of ANAE wetlands by observational count is provided in Appendix B.

As displayed through Figures 3 and 4 above, there is a strong bias towards the counting of three of the selected frog species (Southern Bell Frog, Long-thumbed Frog, and Giant Banjo Frog) regardless of wetland types. In addition to their being numerically dominant in the studied wetlands, there could be miscounting or misidentification of species, geographical challenges when observing other species, or constraints in monitoring processes. As a listed species, it could be that results for Southern Bell Frog are uploaded preferentially. As the factors surrounding data biases is unknown, it is hard to evaluate absolute numbers in the study area. Consequently, this creates risks in correlating flow scenario modelling and observed species populations.

These uncertainties need to be considered in the interpretation of results. The species studied here, however, are used as indicators as we have good information on their life history and habitat requirements which can inform an assessment ecosystem types within the landscape.

2.3 Scenario Assessment

Hydrological modelling undertaken by NSW DCCEEW was used to assess potential environmental flow outcomes from the program over the long-term. Appendix C provides a summary of the flow scenarios assessed. The Source Murrumbidgee Model, a hydrological model developed by the NSW DCCEEW, was used to create these scenarios (DPE, 2022). It represents current system operations and environmental water recovery, with historical climate over the period 1 May 1890 to 28 March 2021 (130 years). Adjustments to the model were made by NSW DCCEEW to represent program flow options.

Inundation extent and depth was modelled using the Murrumbidgee H-FIM developed in 2023 – a model that predicts floodplain inundation extents and depths based on in-channel flow rates for the Murrumbidgee and Yanco catchments (NSW DCCEEW, unpublished).The Murrumbidgee H-FIM uses the Murrumbidgee hydraulic models developed for the program (see DPE (2022)) to model a typical flow hydrograph (peak duration and rates of rise and fall) for each modelled flow peak. The typical flow hydrograph design was based on analysis of spells of similar magnitude in the historical record.

Table 7. Environmental flow actions included as environmental orders at Wagga Wagga for each flow limit option modelled. (DPE, 2022)

Peak flow (ML/d)	Duration at peak flow (days)	Flow limit option			
		Base case 22,000	Option 1 32,000	Option 2 36,000	Option 3 40,000
22,000	5	✓	✓	✓	✓
28,000	5	×	✓	✓	✓
32,000	5	×	✓	✓	✓
36,000	5	×	×	✓	✓
40,000	5	×	×	×	✓

Inundation duration estimates are based on the modelled depth of each wetland and daily rates of pan evaporation at four sites; Yanco, Griffith, Maude and Balranald. For yearly estimates there was a difference of 16cm between the minimum (Yanco: 1685mm) and maximum values (Balranald: 1847mm; Table 9). These estimates were then used to determine the duration of inundation in wetlands of different depth.

Wetlands that hold water for the year after being inundated were identified. Additionally, it was assumed there was a minimum depth required to ensure species would not be exposed to predation or adverse water quality. This depth was set at 50cm as this is the minimum habitat depth for a number of small native fish. Any wetland that met these two requirements was considered permanent (Table 8).

Table 8. Estimates of depth required to inundate wetland for specified durations.

Type	Duration	Depth (m)
Permanent wetlands		2.5
Ephemeral wetlands	11 months	1.5
	6 months	1
	3 months	0.5
	1 month	0.3

For ephemeral wetlands the duration of inundation needs to be sufficient to support completion of critical life stages of species, such as egg and tadpoles for frogs. To estimate these values, and cover variation in timing of delivery, we calculated the average daily evaporation during each season. These values were then multiplied by 30 to estimate the duration of events delivered in spring. The estimates at the four sites for four different durations are provided in Table 9.

Table 9. Pan evaporation rates (mm) for 4 sites for different durations for flows delivered in late spring.

	Yanco	Griffith	Maude	Balranald
1 month	149	155	157	158
3 months	646	472	481	480
6 months	1116	908	931	931
11 months	1469	1406	1477	1462

3 Scenario outcomes

There are several characteristics of wetlands that influence their value to fauna. The most obvious of these is whether a wetland is inundated in any given event. Within this, the frequency, depth, and duration of inundation will influence habitat and productivity, while patterns of connectivity will influence species occupation.

3.1 Inundation

25 ANAE wetland or floodplain types are identified on the Murrumbidgee River system floodplain (Figure 5).

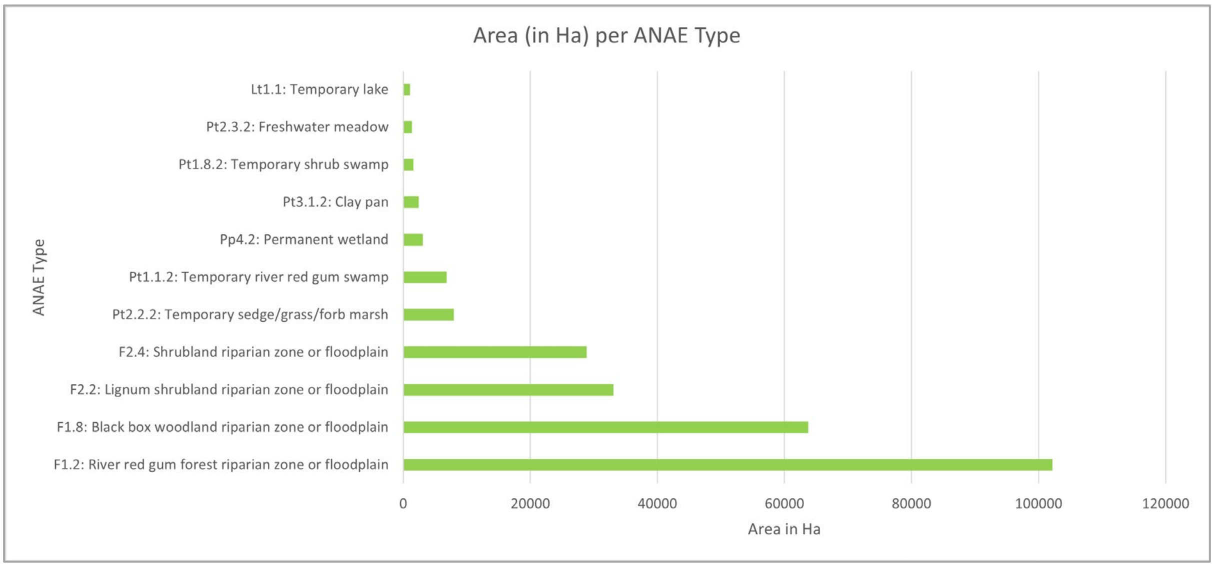

Figure 5 Area of the 11 most present ANAE Wetland Types on the Murrumbidgee floodplain.

In terms of area, four floodplain types dominate the floodplain each occupying more than 10,000 Ha (Figure 5).

- F1.2: River red gum forest riparian zone or floodplain
- F1.8: Black box woodland riparian zone or floodplain
- F2.2: Lignum shrubland riparian zone or floodplain
- F2.4: Shrubland riparian zone or floodplain

These four floodplain types were included in the assessment as observational data suggested that species of interest were in these ecosystem types. These ecosystem types also had the largest increases in inundated area in response to the scenarios (Figure 6).

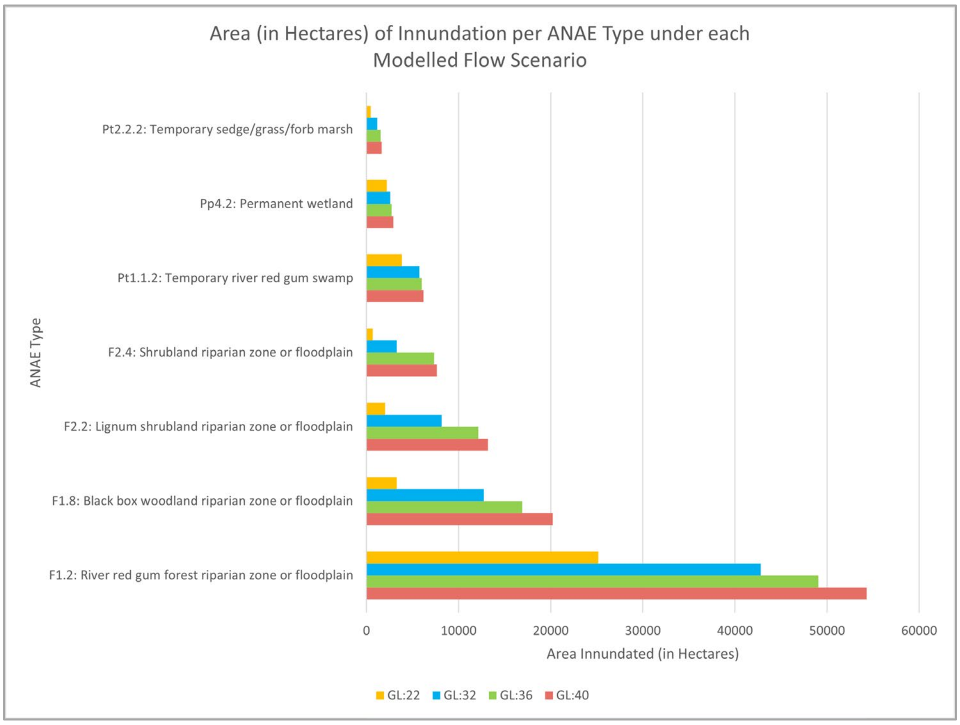

Figure 6 Area (Ha) of Selected ANAE Types under the Modelled Scenarios

At the other end, there were four wetland types with total areas equal or less than 20Ha, thirteen types with less than 10% of their area inundated. Of these thirteen, 5 types had less than 3% of their area inundated (Table 10). Two extremes help illustrate the range of variation; permanent sedge/grass/forb. There is only 6 Ha of permanent sedge/grass/forb marsh but nearly all of this wetland type (96.2%) is inundated under the base case. The second example is F2.4 Shribland riparian zone of which there is 28,855 Ha but only 693 Ha inundated under the base case. Under the highest flow limit option, this increases to 7,600Ha, or 26.4% of the ecosystem type.

This is likely due to the wetland type being low on the floodplain and regularly inundated to maintain the marsh vegetation. In this instance, higher flow limits only appeared to make a minor difference because most of the wetland type is already being inundated. In contrast, there are almost 29,000 Ha of Shrubland riparian zone or floodplain, however, only 2.4% of its area is inundated under the base case. The highest flow limit option (40 GL. d^{-1}) lead to a 20% increase in area inundated, however the change in area inundated was smaller than for other wetland types (Table 10), likely as it occurs higher up the floodplain.

Table 10. Wetland types that either occupy a small area of the Murrumbidgee floodplain or have substantial increases in inundation under flow limit options.

Wetland type	Total Area (Ha)	% inundated under base	% inundated 40GL. d^{-1}
F1.11: River Cooba woodland riparian zone or floodplain	20	7.2	81.2
Pp2.4.2: Permanent forb marsh	20	20.7	57.5
Pp2.2.2: Permanent sedge/grass/forb marsh	6	96.2	98.4
Pt4.2: Temporary wetland	43	0	88.6
F1.6: Black box forest riparian zone or floodplain	173	1.7	38.7
F2.4: Shrubland riparian zone or floodplain	28,855	2.4	26.4
Pt1.7.2: Temporary lignum swamp	81	2.6	63

Higher flow limits led to increases in the proportion inundated for all wetland types. Large increases in area were observed for River Red Gum Forest, Black Box woodland and lignum shrubland. The transition from base case to $32GL.d^{-1}$. produced proportional increases greater than 10% in 17 wetland types. For most wetland types the greatest proportional increase occurred in the transition from current to $32GL.d^{-1}$. The largest proportional increases were in:

- Pp2.2.2: Sedge/forb/grassland riparian zone or floodplain
- F1.11: River Cooba woodland riparian zone or floodplain
- Lt1.1: Temporary Lake

The largest proportional increase among any scenario was for Temporary wetlands that increased 62% from 32 to $36GL.d^{-1}$, although this represented a relatively minor increase in area of 27Ha. There were six other wetland types that also increased by more than 10% (Figure 7 below).

There were also several ANAE types that currently have only small proportions of their total area inundated under the base case flow limit. Table 10 provides an overview of these wetland types and the proportional increase in their area inundated under the 40 GL scenario

Table 10 shows diverse outcomes which are expected given the differing distributions of the wetlands on the floodplain. Importantly, in all wetland types, the inundation improved the area captured by at least 26%[1].

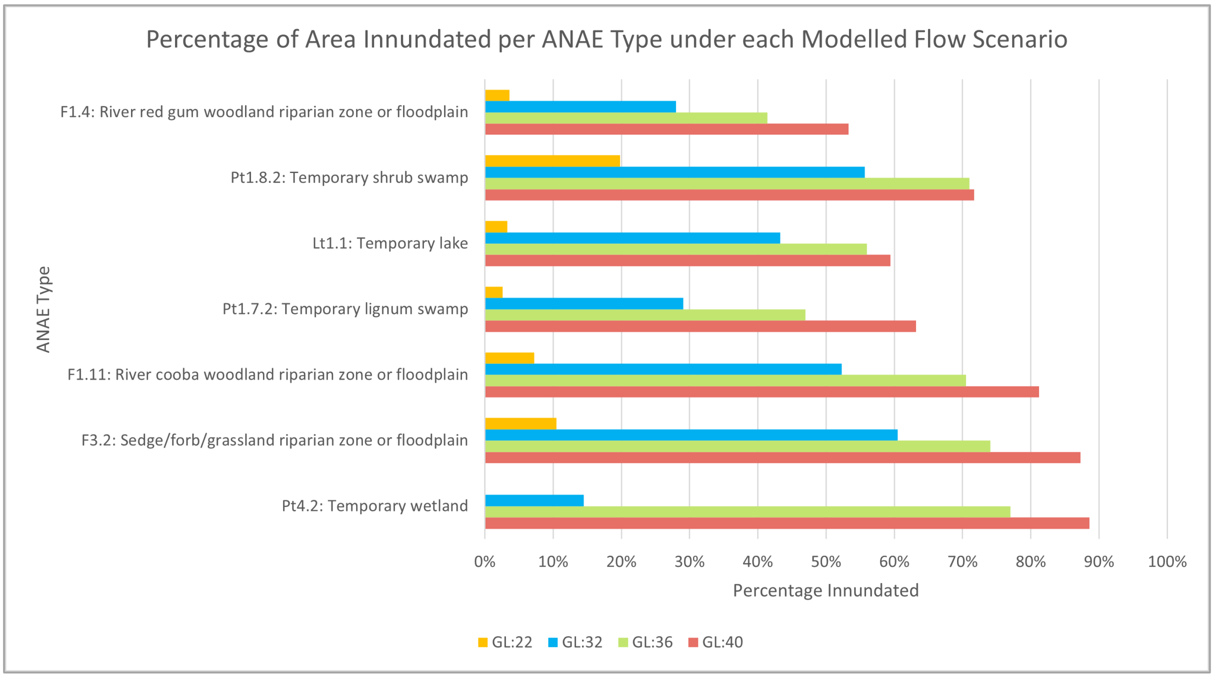

Figure 7 Percentage of Area Innundated under each Modelled Flow Scenario (Selected ANAE Types)

[1] Does not include Temporary salt marsh which was incorrectly mapped as being present in the region.

Table 11. Five ANAE wetland types and the areas that will be inundated under each of the flow limit options (in hectares).

Ecosystem Type	Base case	Option 1	Option 2	Option 3
Pt1.1.2: Temporary River red gum swamp	3860	5739	6020	6178
Pp4.2: Permanent wetland	2216	2596	2745	2910
F2.2: Lignum shrubland riparian zone or floodplain	2025	8147	12141	13192
Pt2.3.2: Freshwater meadow	144	157	202	218
Pt1.2.2: Temporary black box swamp	47	106	137	153

3.2 Frequency of Inundation

NSW DCCEEW examined the frequency with which flows at Wagga Wagga achieved 22, 32, 36, and 40 GL. d^{-1}. They also examined the effects of higher flow limits on the number of years at which these flows were not achieved, the average duration of these spells and the length of the longest period without the flow being achieved.

The number of years in which high flows occurred increased with higher flow limits for all considered flows (Figure 8; Appendix C). Additional high flow events are achieved for each of the flow levels with the largest increase in events being for 32 GL. d^{-1} (up to +19; Option 3) and increases in higher flow rates up to 40 GL. d^{-1} occurring under the higher flow limit options (Table 12).

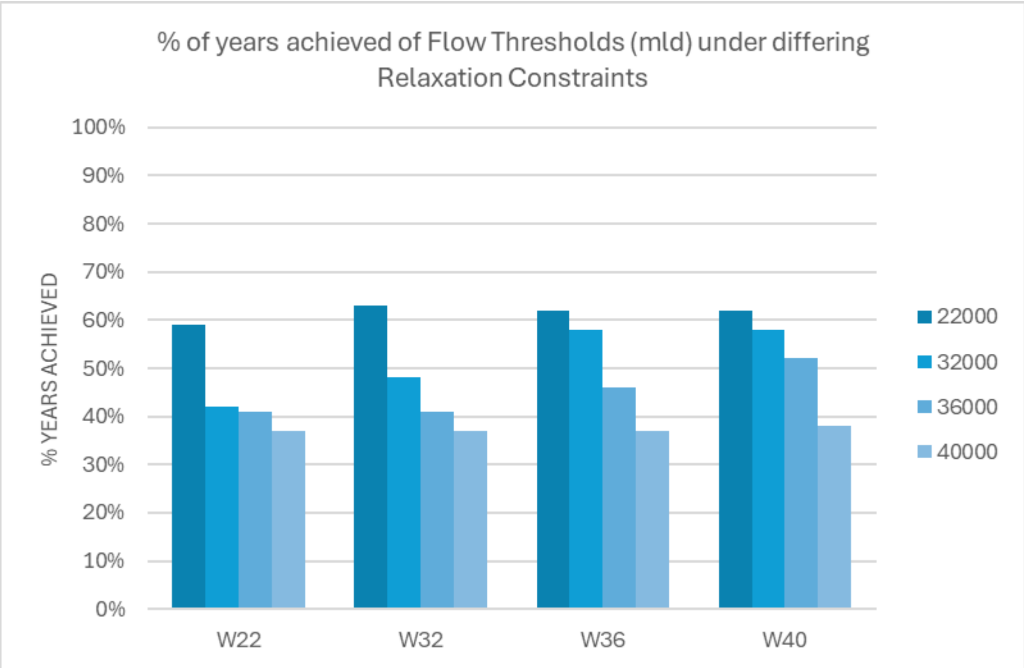

Figure 8. The percentage of years where each scenario had a peak flow of or in excess of the flow limit option flow thresholds W22=Base case, W32=Option 1, W36=Option 2, or W40=Option 3 at Wagga Wagga. Different coloured columns represent different flow rates (source; NSW DCCEEW)

The average duration of extended inter event spells (periods that flow levels were not reached) decreased in response to raising flow limits (Figure 9). For flows of 40 GL. d^{-1} this was only 20% of a year (Option 3), but at 36 GL. D^{-1} the Option 3 scenario reduced the 95th percentile of inter event period durations from 9 years (base case) to 5, and the median inter event duration from 2 (base case) to 1 (Wagga gauge; Appendix C). Similar results are observed in the Yanco, where the Option 3 scenario reduced the 95th percentile of inter event period durations from 9 years (base case) to 5 (at 3.5 GL. d^{-1}), and the median inter event duration from 2 (base case) to 1 (Yanco offtake gauge; Appendix C). In the modelled scenarios, the longest inter event durations occurred during the Millennium Drought with an inter event spell durations for 13 years for flows at or above 40 GL. d^{-1} and 9 years for flows at or above 36 GL. d^{-1}, and 32 GL. d^{-1}. Under the Option 2 and 3 scenarios, the dry spell was interrupted in 2005 by flows of 32 GL. d^{-1}, substantially shortening the inter event period for habitats reached by flows at this level.

Table 12 Change in Annual Flow Event Frequency (and flow peak duration extension) relative to the base case scenario at Wagga Wagga; 5 day flow peak duration.

Flow event magnitude	W32 scenario	W36 scenario	W40 scenario
22 GL/day	+4 events (+22 ext)	+4 events (+29 ext)	+3 events (+28 ext)
32 GL/day	+10 events (+4 ext)	+19 events (+10 ext)	+19 events (+11 ext)
36 GL/day	+0 events (0 ext)	+8 events (+ 3 ext)	+15 events (+4 ext)
40 GL/day	-1 events (0 ext)	0 events (+1 ext)	+3 events (+1 ext)

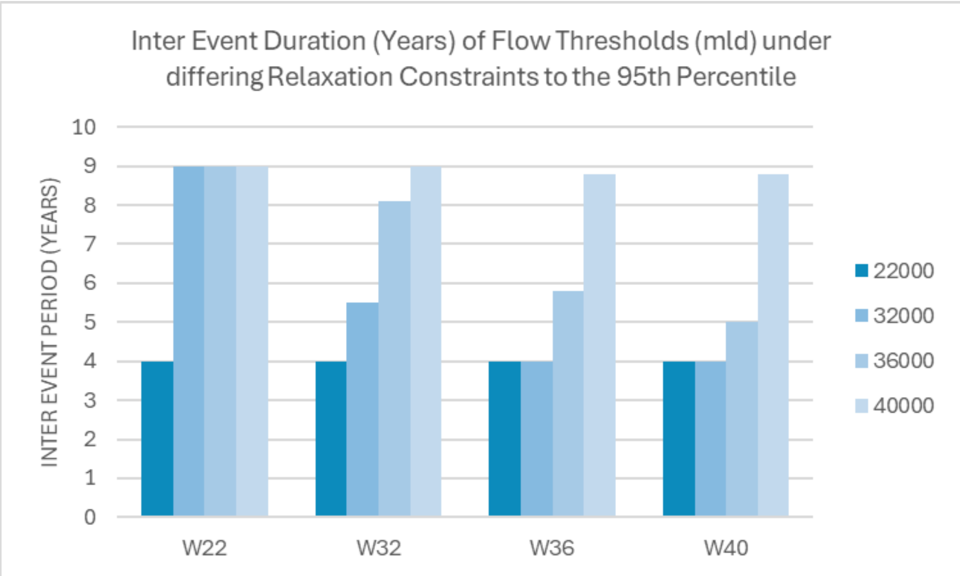

Figure 9. 95th percentile inter event period durations (years) for four flow peak magnitudes under each of the four flow limit option scenarios (at Wagga Wagga; source NSW DCCEEW).

Longer periods between inundation events have two consequences. The first is that the wetland is more likely to dry which at a landscape scale will reduce available habitat. This means that species' response to the next inundation event will have to respond from a lower base i.e. recolonising from fewer refuges and multiplying from fewer adults. Longer dry periods may also affect the viability of seeds and eggs laying dormant in wetland sediments. Seeds and eggs losing viability may affect the system's response to the next inundation with fewer species germinating or emerging or fewer numbers able to respond.

For the landscape, changes to the frequency of inundation and drying will mean that similar ecosystem types will be subjected to different flow regimes. From first principles, this should provide two benefits. First, it will introduce heterogeneity across ecosystem types. Second, specific hydraulic conditions will both occur in different places and at different times during or as overbank flows recede.

Overall, higher flow limits will restore the frequency of inundation in ways that will be ecologically significant. The effects on individual fauna are discussed in Section 4. From a landscape and ecosystem perspective, the frequency of inundation is likely to benefit native vegetation (McPhan et al., 2022) and contribute to maintaining a dynamic mosaic of habitats on the floodplain.

3.3 Depth and Duration

Inundation depth and duration are both key habitat characteristics for wetland fauna. Depth influences water quality and the relative effectiveness of fish and avian predators. Duration is important as it determines the time available to complete key life stages and for water dependent species it will determine persistence in the wetland.

The first pattern identified was that under a base case flow delivery, most wetlands were not inundated (0-10%), but the second most common category was 90-100% filled (Figure 10; W22 facet). These two categories remained the most common under all options with the number of filled wetlands exceeding unfilled wetlands under Option 2 (36 GL d^{-1}) flows. The relatively low numbers of wetlands that only partially filled suggests that a typical flow peak duration (~5 days at Wagga Wagga) is sufficient to fill most wetlands.

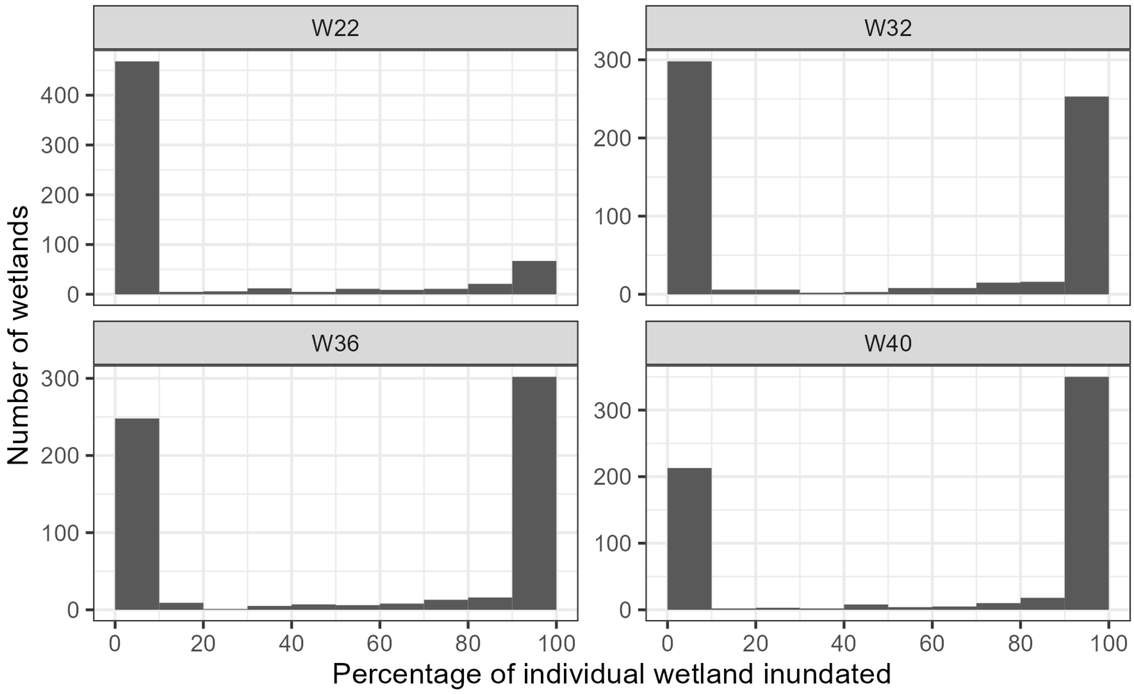

Figure 10. Comparison of the proportional inundation of individual wetlands inundated under raised flow limit deliveries in the mid-Murrumbidgee. There is a marked increase in the number of wetlands fully inundated under raised flow limit deliveries. There are also only a small number of wetlands partially filled, indicating that wetlands fill rapidly once connected (source; NSW DCCEEW).

When evaluating depth, two variables were considered: area of inundation of specific depths, and the number of wetlands that reached a certain maximum depth. The area provides an indication of available habitat for species at a point in time. For example, wading birds require shallow water to forage with the specific depth varying among species. The number of wetlands is important as it informs the legacy of the inundation, both in terms of the duration of inundation, but the habitat characteristics that will emerge during the drying phase.

Under higher flow limit deliveries, we see an increase in the area of all wetland depths between 0.5 and 5 m, with greater increases to deeper areas (>2m; Figure 11, Figure 12). Higher flow limits made relatively little difference to the area inundated to a depth of up to 50cm (Table 13). In contrast the proportional increase in wetlands deeper than 5m was over 7000% due in part to there only being 0.1 Ha over 5m in the base case. With higher flow limits, wetlands of 1 to 1.5m depth became the most abundant depth under Option 1 (32GL d^{-1}) and this remained the case for the other two options (Figure 12).

Table 13. Percentage change to the median wetland depth and area of four wetland depths ranges (cumulative between flow limit options). Here we see that under higher flow limits, the largest increases are to the area of deeper wetlands.

Flow limit	Median	0 to 0.5	1 to 1.5	2 to 3	>5
32	76	6	101	158	7296
36	9	8	7	24	96
40	10	-6	11	14	66

In terms of the number of wetlands, raising the flow limit was associated with increases in the number of wetlands within each depth category. The proportional increase (change to the distribution of wetland depths) grew larger across the options for wetlands 2 to 3m category and >5m category. In contrast the proportional increase decreased in the 0.5 to 1m and 4 to 5m categories (Figure 11).

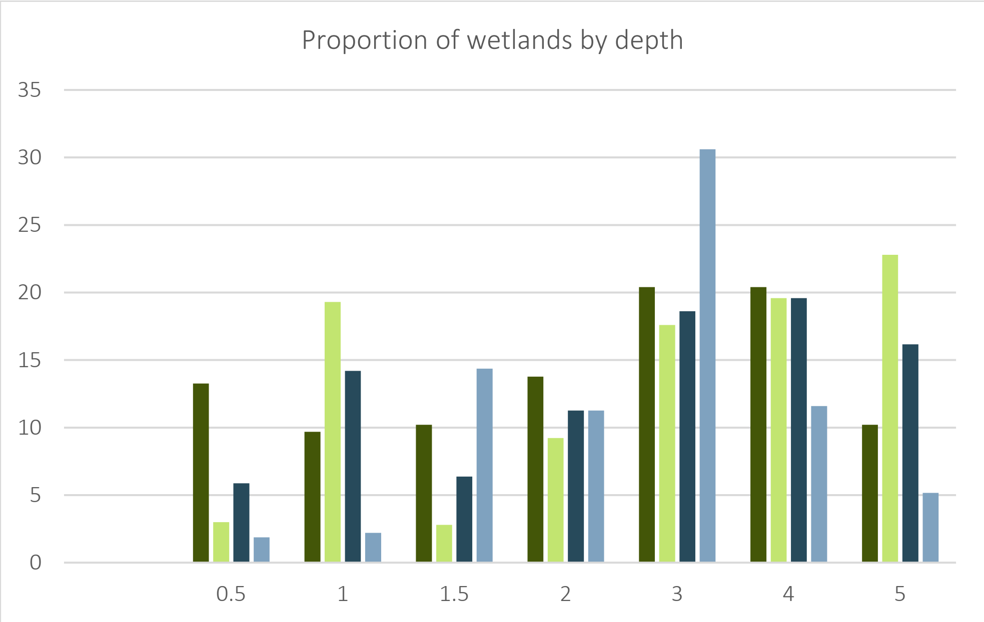

Figure 11. Proportion of wetlands inundated to different depths under deliveries at the base case flow limit (W22) and three flow limit options (W32 , W36 , W40).

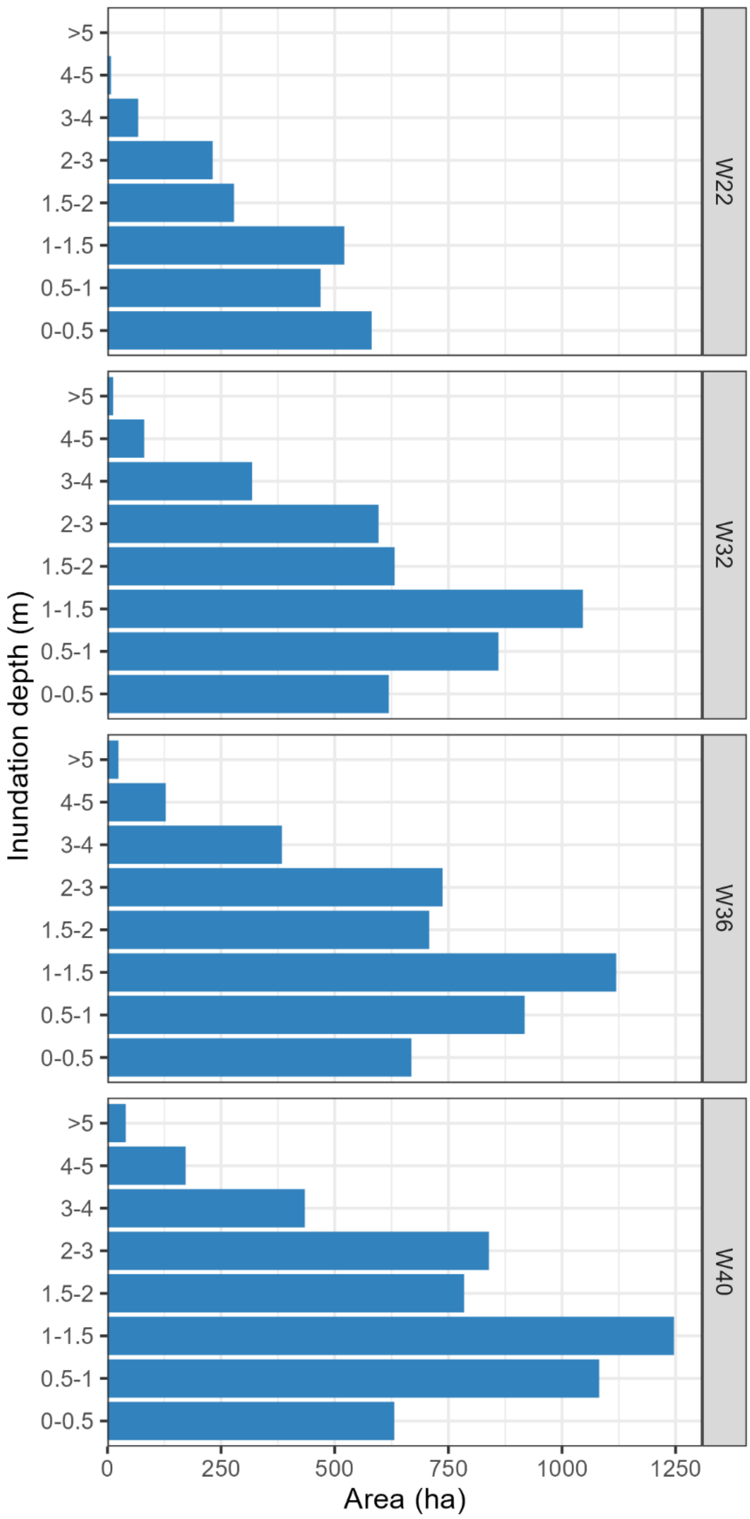

Figure 12. Area of wetland depth under a water for the environment delivery at the maximum flow limit for the 4 scenarios (source NSW DCCEEW).

3.4 Connection

Some of the key issues around connectivity are covered in the discussion of frequency of inundation (Section 3.2), but this section discusses the number and area of wetlands connected under the three options. Up to 120 mapped wetlands are inundated under a flow at the base case flow limit in the mid-Murrumbidgee (Hall et al., 2023; Appendix C, Source NSW DCCEEW), but this increases to 242 under Option 1, with more gradual increases in the transition to Option 2 (300) and Option 3 (345). In the Upper Yanco system, up to 246 mapped wetlands are inundated under a flow at the base case flow limit, which increases to 257 under Option 1, 289 under Option 2 and 302 under Option 3 (DNR, 2007; Appendix C). For permanent wetlands (Figure 13), there was little improvement in the area inundated under higher flow limits which contrasted with the depth assessment (Section 3.3) likely because ANAE is based on current permanent wetlands but the number of permanent wetlands may expand under program flows. In terms of connection, this suggests that higher flow limits will increase connections between permanent wetlands and other ecosystem types located further up the floodplain. The importance of the types of wetlands connected will vary among species.

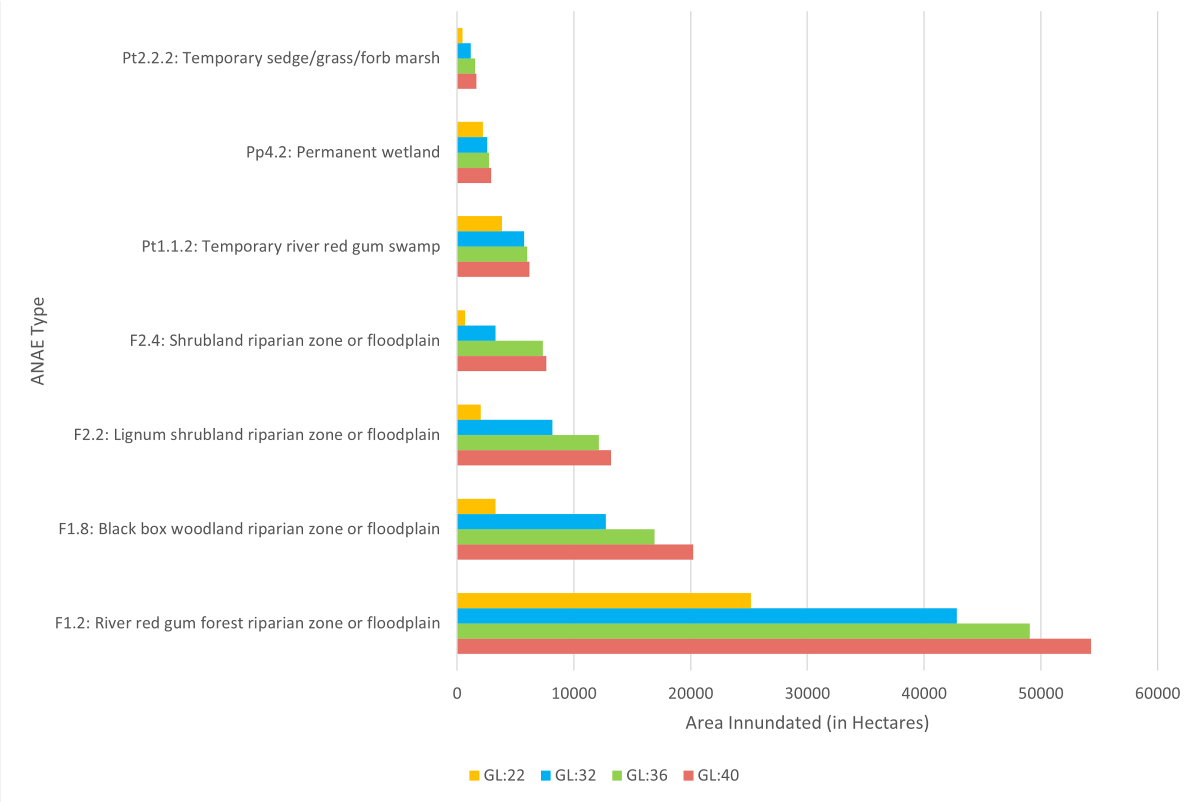

Figure 13. Area under each of the 4 scenarios, with the largest increase occurring between W22 and W32.

4 Species' outcomes

To assess the potential outcomes of higher flow limits for native wetland fauna, the information collated around habitat requirements was compared to changes in the area of habitat available under each flow scenario. We considered several criteria:

1. Core habitat. Core habitat would be expected to support populations through wetting and drying sequences. They were usually comprised of the ANAE types where the species was most often recorded.
2. Boom habitat. Boom habitat would provide opportunities for species during periods of significant overbank flows through the provision of habitat for additional food resources. There were several species where movement to these habitats during floods is uncertain, although accidental transport may occur. Both the habitat assessments could use the percentage increase in available habitat as an appropriate metric to inform the assessment.
3. Connectivity. Here we refer to the lateral connection of flow with floodplain habitat as connectivity. The assessment does not have access to detailed information on patterns of connectivity, however, we used our understanding of species life-cycles to provide a relative rating of the likelihood that improved patterns of connectivity expected under the program would provide benefits.
4. Breeding. We considered the increased opportunity for species to breed. Some species of small native fish are dependent on aquatic vegetation to provide a substrate on which to lay eggs and then provide both food and refuge for larval fish. We considered the impact higher flow limits would have on wetland vegetation while recognising that plants are subject to multiple threats. The other threat to small native fish is that invasive species consume eggs and larvae. Within this context, we believed that species likely to move into more ephemeral habitats would face risks associated with drying but may also benefit from lower numbers of invasive species.

Results of the assessment are summarised in Table 14. Raising flow limits was associated with increases in the amount of both core and productive habitat available. The patterns of increases to the area of inundated habitat with higher flow deliveries varied by habitat type, although the step from 22 to 40GL was the greatest (Figure 6; Section 3.1). 22 to 32GL was associated with a larger proportional increase compared to 32GL to 36GL, or 36GL to 40GL. Under higher flow limits species that utilise ephemeral habitats stand to benefit more substantially, with the majority of increases to inundated area being to ephemeral habitats. Species found exclusively in permanent wetlands will likely benefit from increases in the frequency of inundation and associated shorter dry spells. This is important for wetland fauna because permanent wetlands function as refuges between floods. They are also subject to several threats that affect their value as habitat for native vegetation, fish and waterbirds.

The other pattern was that there was a large proportional increase in the area of ephemeral streams connected under higher flow limit deliveries. We predict that these would represent boom habitats for purple spotted gudgeon, southern pygmy perch and platypus, on the basis that they would be productive and accessible, however no research has been undertaken to-date demonstrating these as important habitats.

More detailed assessments of the individual species are provided in the following sections.

Table 14. Overview of the results of the assessment on individual species for Permanent wetlands (Perm.), Habitat, Connectivity and Breeding.

The first row for each species provides a brief comment on the benefits, while the second row provides an assessment. A star within the Perm. Column indicates that the species is dependent on permenant wetlands and will benefit from increasing area and greater permenance of these habitats. For the Habitat assessment, the 3 boxes represent the percentage improvement in the area of habitat as you move from the base case flow limit to 32GL (Option 1), 36GL (Option 2), or 40GL (Option 3). The light blue boxes represent increases in core habitat, while dark blue boxes represent increases in habitats that become available during high flows. Grey boxes are an assessment of relative benefit from connectivity improvements with 1 representing little change and 5 representing significant improvement. There is only 1 assessment of connectivity and breeding/recruitment, rather than one for each flow option, due to the uncertainty in the assessment and to minimise the risk that the assessment would be able to discriminate between scenarios. Yellow boxes represent relative benefit to breeding and recruitment with 1 representing little change and 5 representing significant improvement. Question marks represent species that we felt were too uncertain to assess.

Species	Perm.	Habitat	Connectivity	Breeding/ Recruitment
Freshwater catfish		Improved flow in smaller permanent and ephemeral streams	Uncertain – may move between wetlands and channel, but raising flow limits may not realise major improvement.	Influence of flow on breeding and recruitment remain uncertain.
	★	14 15 17	3	?
Murray River rainbow fish		Increase in permanent and ephemeral wetlands will increase available habitat.	Occupies a wide range of habitats and likely to move into new habitats, although there will be risks in colonising ephemeral habitats[1]	Improved vegetation
	★	17 18 21 / 14 16 16	5	4
Purple-spotted gudgeon		Improved flow in smaller permanent streams and wetlands	Improved access to ephemeral habitats may improve condition. Little known about their movements.	Vulnerable to flow variability – more natural flows may lead to improvements
	★	5 5 5 / 82 97 105	?	3

Species	Perm.	Habitat	Connectivity	Breeding/ Recruitment
Olive perchlet		Increase in permanent wetlands, depth and frequency of connection will all support improvements.	Increased distribution and resilience	
	★	12 13 14	3	2
Southern pygmy perch		Improved flow regime and vegetation in small streams	Reducing fragmentation would be expected to lead to improvements, but little known about movements	Improves with vegetation which is subject to multiple threats.
	★	5 5 5 82 97 105	?	2
Southern Bell frog		Increases in ephemeral wetlands will provide additional habitat during overbank flows	Improved vegetation condition and additional water in the landscape will support GGF movements	
	★	15 16 18 14 15 16	5	4
Long-thumbed frog		Increases in the number of suitable wetlands and improvement in vegetation condition	Some ephemeral wetlands will exclude fish, providing benefit to tadpoles	Deeper wetlands will provide breeding opportunities in the year following inundation.
		16 17 19 16 17 19	5	4
Sloane's froglet		Improved vegetation in Temporary grass marsh and freshwater meadows will increase available habitat.	Increased inundation will provide opportunities to disperse.	Potential increase in emergent vegetation will improve breeding habitat.
		16 17 19	4	2

Species	Perm.	Habitat	Connectivity	Breeding/ Recruitment
Eastern Long-necked turtle		Increased ephemeral habitats will provide additional foraging habitat.	Increased inundation and improved vegetation will support movements.	Influence of flow on breeding and recruitment remains uncertain.
		14 15 17 12 13 14	5	1
Macquarie Turtle		Increases in depths and frequency of inundation will improve habitat availability through time.	Movement during floods will be improved through increases in frequency of inundation and connectivity between wetlands.	Influence of flow on breeding and recruitment remains uncertain.
		12 13 14	2	1
Broad Shelled Turtle		Improvments in depth and permanence of wetlands will provide addditional habitat.	Increased frequency of connection will facilitate dispersal between river and deep wetlands.	Influence of flow on breeding and recruitment remains uncertain.
		12 13 14	3	1
Grey Snake		Improvements in frog populations will ensure food availability and increased habitat avalibale to the species.	Movement requirements remain uncertain.	Food resources and changes in predator pressure may improve recruitment.
		15 16 18	?	?
Platypus		Improved flow in smaller permanent streams and maintenance of permanent wetlands could improve available habitat.	Ephemeral habitats and improved vegetation condition may reduce risks associated with juvenile dispersal.	Platypus declines have coincided with regulation, but there may be risks to young during high flows, but little data.

Species	Perm.	Habitat	Connectivity	Breeding/ Recruitment
	★	5 6 6 82 97 105	2	?
Rakali		Dependent on permenant habitat which will be more available with higher flow limits.	Utlising habitats created during floods may be facilitated, but unlikely to be a major influence.	Wetland productivity and improvements in vegetation will support reproduction.
	★	12 13 14	2	?
Fishing Bat		Dependent on permanent wetlands and increases in depth and increased frequency of inundation will ensure habitat.	Maintaining permanent wetlands close to roosts will improve access to foraging habitat.	Wetland proudctivity associated with inundation will improve food supply.
	★	12 13 14	4	?

4.1 Fish

4.1.1 Freshwater catfish (*Tandanus tandanus*)

Freshwater catfish were once widespread across the Murray Darling Basin (MDB) and were found to occur in higher abundance in some areas than others. Their range included rivers draining the Western slopes of the Great Dividing Range to the Darling River in the west of the MDB. To survive in this range of systems suggests that they are tolerant of a wide range of habitats and that nesting habitat preferences may also vary.

There are several indicators that suggest that higher flow limits will benefit Freshwater catfish:

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% of years with the 95th percentile inter event duration (years) between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include:
    - Enhanced vegetation communities which represents improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources for Freshwater catfish. If the Freshwater catfish are breeding in wetlands, then this productivity boost will be important for juvenile growth and survival.

The extent to which these responses will support improvements in Freshwater catfish populations is less certain, in part because the response of vegetation communities in permanent wetlands may be muted and the extent of wetland use by Freshwater catfish along the river is poorly understood.

Table 15. Flow requirements for Freshwater catfish.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth/duration (m)	Ephemeral wetland depth/duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
slow to still			33	100	2.5				Both

Table 16. Summary of Freshwater catfish characteristics

Characteristic	Detail
Guild	River specialist – Associated with permanent off-channel lentic habitat
Diet	Insects, molluscs, worms, shrimps, yabbies and small fish
Movement	Individuals may move between wetlands and the main channel

4.1.2 Murray River rainbowfish (*Melanotaenia fluviatilis*)

There are several indicators that suggest that higher flow limits will benefit Murray River rainbowfish:

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The area of ephemeral wetlands known to be used by rainbowfish (Figure 14) will increase by up to 14,800 Ha. The frequency of these connections will also increase by 7 and 15%.
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% with the 95th percentile inter event duration (years) between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include:
    - Enhanced vegetation communities which represent improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources for rainbowfish.

The extent to which these responses will support improvements in Murray River rainbowfish remains uncertain, in part because the timing of Murray River Rainbowfish and availability of resources in connected wetlands are not well understood.

Table 17. Flow requirements for Murray River rainbowfish

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
slow to still	0.5		50	100	2.5	0.5			Both

Table 18 Summary of Murray River rainbowfish characteristics

Characteristic	Detail
Guild	Generalists– Occupy a range of streams and waterbodies. Can persist within-channel during extended low flow conditions.
Diet	Omnivores – feed on aquatic and terrestrial invertebrates and some filamentous algae
Movement	Adults move short distances over a wide range of hydrological conditions to spawn

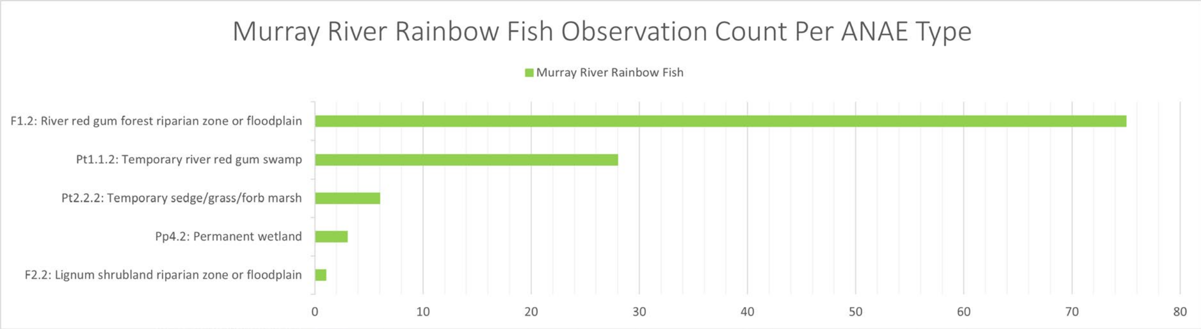

Figure 14 Observations of Murray River Rainbow Fish in different ecosystem types.

4.1.3 Purple spotted gudgeon (*Mogurnda adspersa*)

Populations of Purple spotted gudgeons declined through the 1980s due to a variety of factors including flow regulation, reduced food availability, loss of breeding habitats and invasive species. If reintroduced to the Murrumbidgee, higher flow limits would likely improve their likelihood of persisting.

There are several indicators that suggest that higher flow limits will benefit Purple Spotted Gudgeon:

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The area of permanent streams will increase by between 4.6% (Option 2) and 7.7% (option 3).
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% with the longest interval between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include:
  - Enhanced vegetation communities which are critical to the breeding of Purple Spotted Gudgeon.
  - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources for Purple Spotted Gudgeon.

The extent to which these responses will support improvements in Purple Spotted Gudgeon remains uncertain, due to limited information on its life history and habitat requirements.

Table 19. Flow requirements for purple spotted gudgeon.

Determined by other factors (e.g. vegetation) Not relevant Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
slow to still	0.5				2.5				Both

Table 20 Summary of purple spotted gudgeon characteristics

Characteristic	Detail
Habitat	Permanent water bodies including slow-flowing streams and wetlands.
Diet	Ambush predators of a range of prey including invertebrates, small fish, tadpoles, and small yabbies.
Movement	There is little known about the movements of purple spotted gudgeon.

4.1.4 Olive perchlet (*Ambassis agassizii*)

Olive perchlet may colonise ephemeral wetlands, however, these wetlands will not support populations over the long term. Olive Perchlett no longer exist in the Murrumbidgee River but do occur thoroughout the Lower Lachlan and have been known to expand their reach when flooding events occur. Olive perchlet will require permanent wetlands with aquatic vegetation. Higher flow limits will have the following benefits for Olive perchlet:

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% with the 95th percentile inter event duration (years) between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include:
  - Enhanced vegetation communities which represent improvements in habitat quality.
  - There may be some wetlands with barriers to connectivity that may reduce the threats posed by carp, gambusia and Red-Fin Perch.

Higher flow limits will significantly improve habitat availability for Olive perchlet; however, dry periods lasting 4 years will represent a threat to a short-lived wetland specialist. The benefits of higher flow limits may also be undermined by the ongoing threats from introduced species and their effects on vegetation, water quality, food availability and successful recruitment. Complementary measures will likely be required to promote survival of reintroduced Olive perchlets.

Table 21. Flow requirements for olive perchlet

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
Slow to still	0.4		100		2.5		1	2	

Table 22 Summary of olive perchlet characteristics

Characteristic	Detail
Habitat	Rivers, creeks, ponds, and swamps with slow-flowing or still waters. They are commonly found in sheltered areas such as overhanging vegetation, aquatic macrophyte beds, logs, dead branches, and boulders during the day, dispersing to feed during the night
Diet	Zooplankton and aquatic and terrestrial insects
Movement	Thought to be relatively sedentary

4.1.5 Southern pygmy perch (*Nannoperca australis*)

Southern pygmy perch have declined due to a combination of invasive alien fish species (e.g. gambusia, european carp), habitat fragmentation and destruction. Habitat preferences are generally for still to slow-flowing water, with abundant aquatic vegetation cover. Increases in the area of permanent streams along the Murrumbidgee River, and increases to inundation frequency at higher flow rates, suggests that higher flow limits will increase the amount of available habitat for pygmy perch.

As with the olive perchlet, southern pygmy perch face several other threats including declines in aquatic vegetation due to a variety of threats may continue to limit populations. Higher flow limits may help reduce habitat fragmentation, but this may be a secondary issue compared to the loss of vegetation.

Table 23. Flow requirements for southern pygmy perch.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
Slow to still	0.4		100		2.5		1	2	

Table 24 Summary of southern pygmy perch characteristics

Characteristic	Detail
Habitat	low-gradient waterways and floodplains with slow-flowing or still water and aquatic macrophyte cover or wood at shallow depths
Diet	small invertebrates, zooplankton moving onto larger insects as they grow.
Movement	Relatively sedentary and males are territorial during breeding season.

4.2 Frogs

4.2.1 Southern bell frog (*Litoria raniformis*)

The Southern bell frog (SBF) (also known as Growling Grass Frog) is classed as Endangered in NSW under the Biodiversity Conservation Act 2016 (BC Act; DCCEEW, 2023) and vulnerable under the commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Breeding occurs in permanent wetlands with tadpoles maturing over 2 to 15 months. Southern Bell Frog have been found in a wide variety of habitats (Figure 15). A tracking study found individuals remained in permanent waterbodies in November but had abandoned these areas in favour of flooded ephemeral waterbodies by January. As the ephemeral waterbodies dried, individuals moved back into permanent waterbodies (Wassens et.al., 2017).

There are several indicators that higher flow limits will be beneficial for SBF.

- There will be a significant increase in habitat available to SBF. Across all ecosystem types in which SBF, have been observed there will be an increase in area between 32% (Option 1) and 57% (Option 3).
- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The deepening of wetlands and increases in the range of depths will provide enduring resources for SBF.
- The number of years in which permanent wetlands will be connected to ephemeral wetlands will increase between 7.7% (Option 1) and 14.6% (Option 3). This would be expected to improve the distribution and resilience of SBF.
- Indirect influences of these changes in flow would include:
    - Enhanced vegetation communities which represent improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources for SBF.
    - The movements of individuals between permanent and ephemeral wetlands will be facilitated by improvements in vegetation and increases in the number and area of ephemeral wetlands.

The species characteristics table includes a flow duration of 4 months (Table 26), which is substantially longer than the 5 day flow peak duration targeted by the program. While the peak flows in the river that connect with the floodplain may only extend for 5 days, it is anticipated that water within the permanent wetlands will persist.

Table 25. Flow requirements for southern bell frog

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
Slow or Still	>0.5		50	100	2.5		1	1.5	Wetland

Table 26. Summary of southern bell frog characteristics

Characteristic	Detail
Habitat	Flow events should occur for a duration of a minimum of 4 months, ideally 6 months or more. These events should occur every 1 to 2 years with a maximum inter-event period of 18 months. This species is found mostly amongst emergent vegetation
Diet	Variety of invertebrates as well as other small frogs
Movement	Adults move between permanent and temporary wetlands.

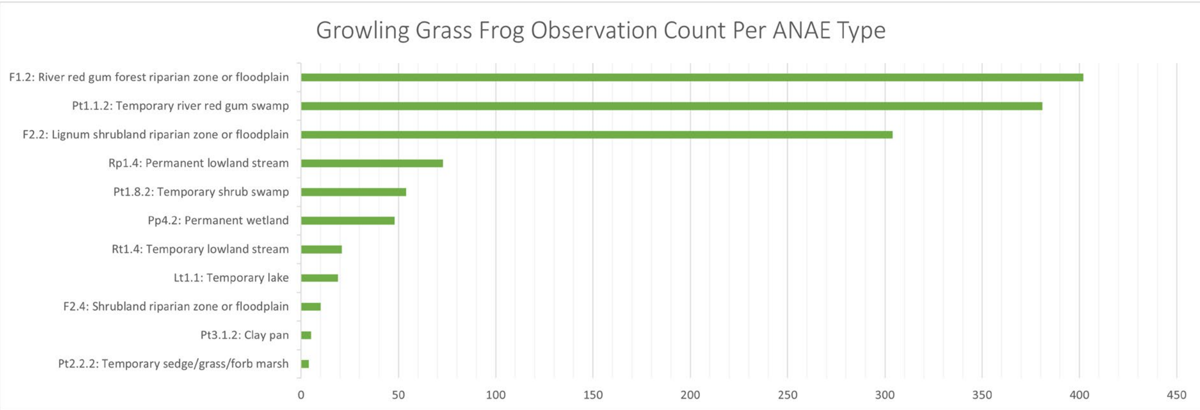

Figure 15 Observations of southern bell frog in different ecosystem types.

4.2.2 Long-thumbed frog (*Limnodynastes fletcheri*)

This species inhabits woodlands and river floodplains close to water. It is often associated with inundated grassland, around ponds, and along creek lines. Breeding is varied; in wetter areas, it breeds from October to March, in drier areas it breeds after heavy rains. Males call from floating vegetation. Eggs hatch after one day and metamorphose after 1–2 months.

There are a number of lines of evidence that suggest that higher flow limits will benefit long-thumbed frogs, including:

- Increases in the area and numbers of ephemeral wetlands by between 16% (Option 1) to 36% (Option 3).
- The increase in deep wetlands may provide breeding opportunities in the year following inundation.
- The number of years in which ephemeral wetlands will be connected will increase between 7.7% (Option 1) and 14.6% (Option 3). This increase will support frog movements and increase resilience.
- Indirect influences of these changes in flow would include:
    - Increased likelihood of ephemeral wetlands without fish which would improve recruitment.
    - Enhanced vegetation communities which represent improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources.

Higher flow limits will likely improve outcomes for Long-thumbed frogs, however, the longest dry phase will be 4 years for all options which will represent a threat to populations.

Table 27. Flow requirements for long-thumbed frog.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
still			50	100		0.5	1.5		Wetland

Table 28. Summary of long-thumbed frog characteristics

Characteristic	Detail
Habitat	Every 7 in ten years with no dry phase longer than 2 years
Diet	Feeds on a wide variety of insects.
Movement	Flooding has a major influence on frog movements

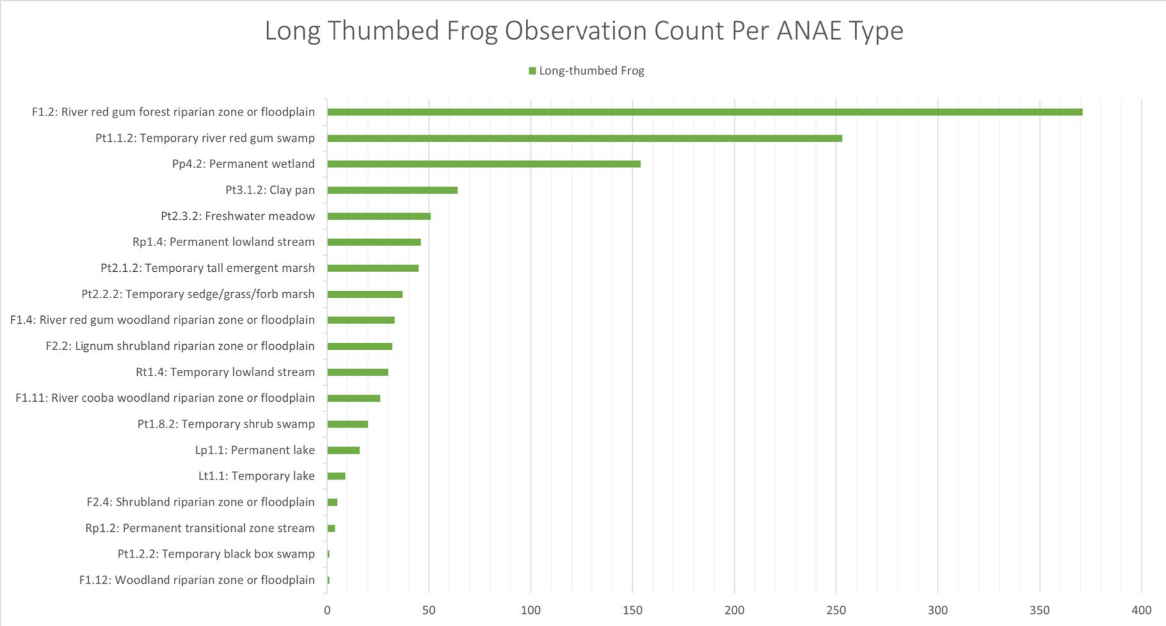

Figure 16 Observations of long-thumbed frog in different ecosystem types.

4.2.3 Sloane's froglet (*Crinia sloanei*)

This species is classified as endangered both on a commonwealth level (EPBC Act) and a state (BC Act) level throughout NSW. The ecology of the froglet remains poorly known and so any assessment of the impact of changes in flow will also be uncertain. Sloane's froglet is found in wetlands, swamps, inundated depressions, and flooded grasslands. The breeding habitat include large areas of emergent vegetation. It can persist in ephemeral wetlands as long as there are appropriate refuges. From the description of habitat requirements, their preferred habitat of flooded grasslands is currently relatively uncommon on the Murrumbidgee floodplain. The two ANAE types with the largest areas are Temporary sedge/grass/forb marsh (7957 Ha) and Freshwater meadow (1369 Ha) and all others being less than 200 Ha.

Our understanding of Sloane's froglet population dynamics and environmental water requirements remains uncertain which affects the confidence with which the outcomes of higher flow limits can be forecast. The following indicators suggest that higher flow limits will be beneficial for Sloane's froglet.

- Increases in the area and numbers of ephemeral wetlands by between 16 (Option 1) to 36% (Option 3).
- The increase in deep wetlands may provide refuge habitat.
- The number of years in which ephemeral wetlands will be connected will increase between 7.7% (Option 1) and 14.6% (Option 3). This increase will support frog movements and increase resilience.
- There will also be additional wetlands that have an inter-event period of less than 18 months.
- Indirect influences of these changes in flow would include:
  - Increased likelihood of ephemeral wetlands without fish which would improve survival and recruitment.
  - Enhanced vegetation communities which represent improvements in habitat quality. Improved vegetation may also broaden the depth of wetlands in which the froglet may be able to survive.
  - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources.

There will remain a number of challenges for Sloane's froglet, including the period between inundation events and habitat modification. This gap may interact with the distribution of fish in deeper wetlands that will prey on the froglet and its tadpoles.

Table 29. Flow requirements for Sloane's froglet.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
still			50	100		1	1.5		Wetland

Table 30. Summary of Sloane's froglet characteristics

Characteristic	Detail
Habitat	Flow events should occur for a duration of a minimum of 4 months, ideally 6 months or more to support frog species occurring in these habitats. These events should occur every 1 to 2 years with a maximum inter-event period of 18 months
Breeding	Winter and spring breeding species that attaches eggs to vegetation in flooded grasslands and wetlands. These eggs hatch after 10 to 21 days and usually metamorphosis about 11 weeks later.
Movement	Froglet is a dynamic species that moves between waterbodies within and between seasons.

4.3 Turtles

4.3.1 Eastern long-necked turtle (*Chelodina longicollis*)

The eastern long-Necked turtle (ELNT) has been observed in 26 different wetland types illustrating their willingness to move around in search of food. Their mobility (for a turtle) suggests that landscape patterns will be important in determining the condition of the adult population. The following outcomes are expected to support improvements in ELNT populations.

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The area of ephemeral wetlands known to be used by ELNT (Figure 17) will increase by up to 45,600 Ha.
- The frequency of connections will also increase by 7.7 (Option 1) to 14.6% (Option 3).
- Indirect influences of these changes in flow would include:
    - Enhanced vegetation communities which represent improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources

There are risks around nest inundation if high flows occur after nesting, however, for a long-lived species, the greatest threat they face is nest predation by foxes. Whether flows could be used to reduce fox predation has not been investigated, but is possible through the creation of islands that might hide nesting areas from foxes.

Higher flow limits would appear to favour ELNTs. The increase in the area and types of wetlands make it more likely that food will be located while also reducing the distances needed to travel between wetlands. In addition, patterns of wetting and drying will be associated with increases in productivity that will boost macroinvertebrate abundance in wetlands.

Table 31. Flow requirements for eastern long-necked turtle.

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
moderate to still					2.5				Both

Table 32. Summary of eastern long-necked turtle characteristics

Characteristic	Detail
Habitat	Preference for shallow, transient wetlands that are more remote from permanent rivers. They are predominately found in anabranches, swamps, and oxbow lakes.
Breeding	Lays eggs between October and December with eggs hatching after 120-150 days. Hatchlings may stay in the nest for up to 1 year after hatching.
Movement	If needed, these turtles can migrate over land to find suitable habitat
Diet	An opportunistic carnivore whose diet is largely macro-invertebrates, small vertebrates, tadpoles, and carrion.

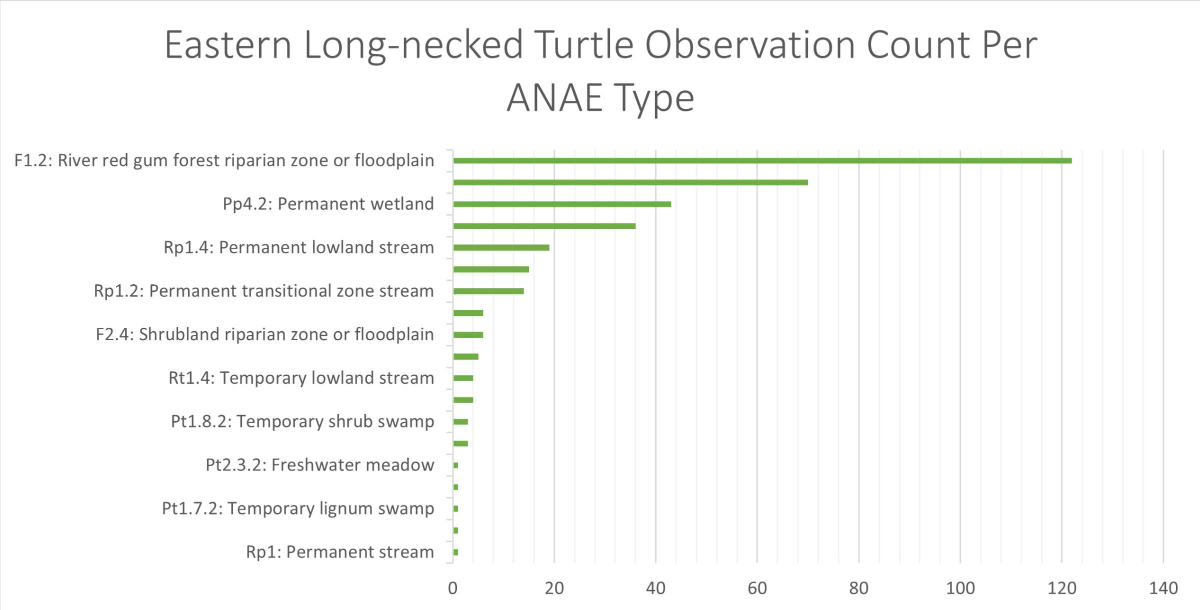

Figure 17 Observations of the eastern long-necked turtle in different ecosystem types.

4.3.2 Macquarie Turtle (*Emydura macquarii*)

The macquarie turtle is a wide-ranging species, commonly associated with rivers but also known to move into wetlands. The Macquarie turtle has a broad diet that may facilitate a less mobile life that the ELNT as well as serving as a risk mitigation for desiccation (Chessman, 1985). This species has recently been marked as critically endangered through Victoria and is identified as vulnerable throughout South Australia. Macquarie Turtles also breed in spring but a relatively short egg incubation period.

The following outcomes are expected to support improvements in Macquarie turtle populations.

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a rise from 4 to 23 (Option 3) wetlands with a maximum depth >5m that will remain wet for 2 years.
- The area of permanent wetlands known to be used by Macquarie turtle (Figure 18) will increase by up to 31,000 Ha.
- The frequency of connections will also increase by 6 (Option 1) to 16% (Option 3). This will support dispersal and resilience of Macquarie turtles who depend on aquatic connections.
- Indirect influences of these changes in flow would include:
    - Enhanced vegetation communities which represent improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources.

There are risks around nest inundation if high flows occur after nesting, however, for a long-lived species, the greatest threat they face is nest predation by foxes. Whether flows could be used to reduce fox predation has not been investigated.

Table 33. Flow requirements for Macquarie turtle.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
moderate to still					2.5	1			Both

Table 34 Summary of Macquarie turtle characteristics

Characteristic	Detail
Habitat	This species prefers river pools and fast flowing rivers between 2-3m deep throughout coastal populations. However on more inland systems, they have a tendency to remain close to the larger local rivers throughout the surrounding wetlands. They will also move into shallow wetlands with partially submerged logs as places in which they can bask.
Breeding	Mating season is between September and October and nests from October to early January. The female will lay between two or three clutches of eggs. The eggs incubate for approximately 45-70 days before hatching. Nesting tends to occur further from the water's edge than most turtle species (Petrov et. al., 2018)
Diet	Feeds on filamentous algae, macrophytes, invertebrates, small vertebrates, and carrion
Movement	Connectivity between river and wetlands likely to be important.

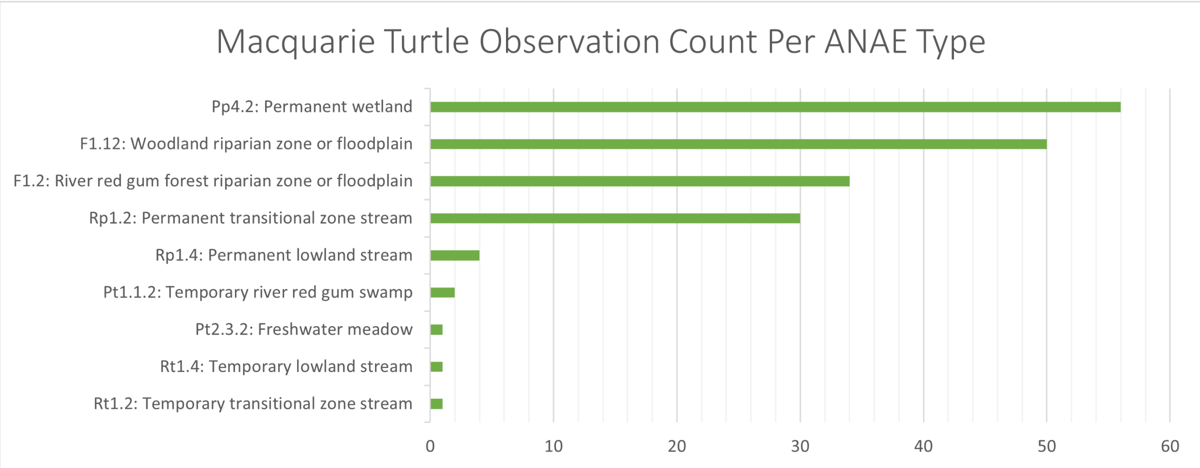

Figure 18 Observations of Macquarie turtle in different ecosystem types.

4.3.3 Broad-shelled turtle (*Chelodina expansa*)

The broad-shelled turtle is a large turtle species that is classified as endangered in South Australia and Victoria. Their habitat preference is for deep permanent wetlands close to the river. Within this context, higher flow limits are expected to support improvements in broad-shelled turtle populations.

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The area of permanent wetlands known to be used by the broad-shelled turtle will increase by up to 690Ha.
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% with the longest interval between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include:
    - Enhanced vegetation communities which represent improvements in habitat quality.
    - Flow restoration would be expected to boost production of wetland invertebrate communities and thereby provide additional food resources

There are risks around nest inundation are high given the species long incubation period. It is possible that nest sites are adapted to site flow conditions, in which case, more frequent high flows may help reduce this risk. Also, they nest further from the water's edge than other species (Petrov et al., 2018). The greatest threat they face remains nest predation by foxes. The 4 year maximum interval between inundation may represent a threat to broad-shelled turtles in permanent wetlands, however, the more frequent connection of permanent wetlands to the river may promote resilience of populations.

Table 35. Flow requirements for broad-shelled turtle.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
moderate to still		3			3				River

Table 36 Summary of broad-shelled turtle characteristics

Criteria	Result
Habitat	The broad-shelled turtle depends on permanent water bodies that are usually deeper than 3m. They show a strong preference for habitats that have a variety of submerged structures such as dead trees, logs, and tree roots.
Breeding	Broad-shelled turtles can nest more than 500 meters from the river and tend to breed during autumn. This species nests in autumn and lays approximately 20 eggs in a shallow hole that is above flood-level. Their egg incubation time is quite long, with periods usually exceeding 1 year. Hatchlings can stay in the nest throughout the winter and emerge in spring. This appears to be influenced by rainfall events and can result in hatchlings staying in the nests for an extended period of time.
Diet	A carnivorous species, that feed on large aquatic insects, shrimp, and fish. They also have been known to eat carrion.

4.4 Other Species

4.4.1 Grey Snake (*Hemiaspis damelii*)

This relatively small but venomous snake feeds primarily on frogs. The grey snake tends to favour forests and woodlands near wetlands. It shelters under rocks, logs, debris, and cracks in the soil. This species is classified as endangered in both NSW (BC Act) and nationally (EPBC Act). Being essentially a terrestrial species, yet still associated with wetlands (Michael et.al., 2023), most of the benefits to the grey snake are expected to be indirect benefits to habitat and food availability:

- Flow restoration would be expected to improve frog populations on which the snake feeds.
- Enhanced vegetation communities which, over time, will lead to increases in logs, debris and soil cracks that will provide shelter for the snake and its food.

Table 37. Flow requirements for grey snake.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
NA					2.5	0.5			Wetland

Table 38. Summary of grey snake characteristics

Criteria	Result
Habitat	Dry sclerophyll forests and woodlands close to wetlands. It requires physical habitat such as rocks, logs, debris, or cracks in the soil to provide shelter.
Breeding	Breeding occurs from January to March. Adult females' ovarian follicles increase in size during Spring. Litter sizes range from 4-16 live young that take around 12 months to mature.
Diet	Frogs and occasionally skinks

4.4.2 Platypus (*Ornithorhynchus anatinus*)

The status of platypus in the lowland reaches of the Murrumbidgee is uncertain. Platypus ranked seventh in terms of observations. The effects of flow regulation also remain uncertain although the most significant declines in populations have been associated with river regulation. Concerns have been raised about the risks of environmental flows inundating burrows while they contain young, but there is limited evidence to support this hypothesis. Platypus can occupy a wide range of habitats, but their diet is limited to aquatic invertebrates and so they need water with a productive invertebrate community to survive. The data identified 11 wetland types in which platypus had been sighted, most of which were permanent streams or wetlands. The exceptions were River red gum floodplain, temporary stream, woodland floodplain, and temporary wetland. It is unlikely that these latter wetland types provided enduring habitat for platypus, however, it is possible that there were used by dispersing juveniles.

Higher flow limits are unlikely to benefit river dwelling Platypus. It is possible that changes in flow in terms of more frequent inundation and shorter dry spells may improve the habitat quality of permanent wetlands.

Table 39. Flow requirements for platypus.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
still					2.5				
flowing to still		1	100	100	2.5				River

Table 40 Summary of platypus characteristics

Characteristic	Detail
Habitat	Streams and suitable freshwater bodies, including some shallow water storage lakes and ponds
Breeding	Breeding season is October to March when the female will produce one to three eggs annually, but usually two. Young are to be kept in the burrow for 3-4 months after hatching which involves a 10-day incubation period. Young emerge from the burrow at the end of the summer. Females produce
Diet	benthic macroinvertebrates
Movement	Adults move through their territory in the water. Juvenile dispersal is believed to be important and may be across land.

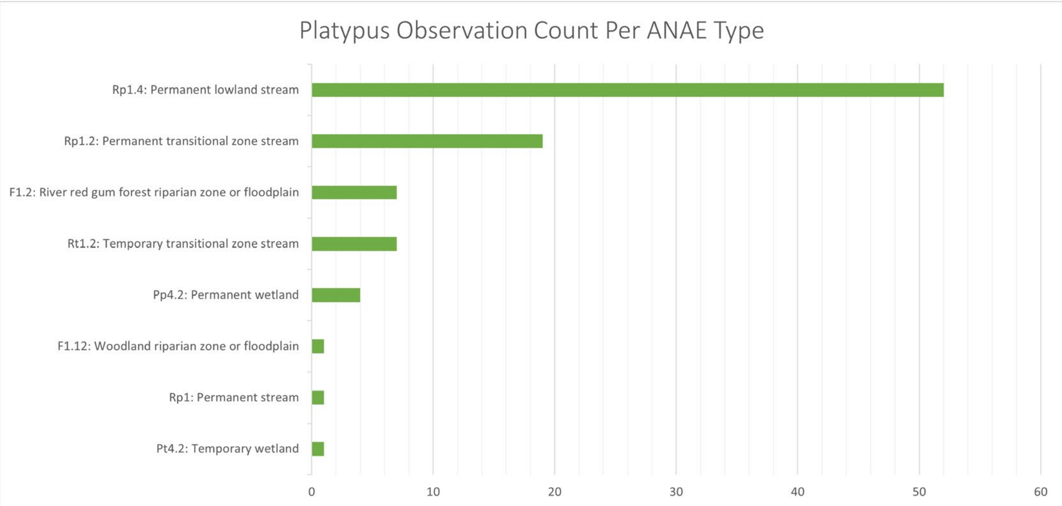

Figure 19 Observations of the platypus in different ecosystem types.

4.4.3 Rakali (*Hydromys chrysogaster*)

The Rakali is a native rodent that inhabits areas near permanent bodies of water. They are not considered to be endangered, with the greatest threats to this species including larger carnivores and loss of suitable wetland/waterbody habitat. Higher flow limits are expected to have the following outcomes:

- The number of permanent wetlands are predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years.
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% with the 95th percentile inter event duration (years) between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include:
    - Greater variation in wetland depth will enhance vegetation communities which may improve recruitment success.
    - Increased wetland productivity including fish and invertebrate communities that provide additional food resources.

Rakali are classified as being of "least concern" and so there are no significant obstacles to prevent Rakali populations benefiting from increases in habitat and food associated with higher flow limits .

Table 41. Flow requirements for Rakali.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
slow to still					2.5				River

Table 42 Summary of Rakali characteristics

Characteristic	Detail
Habitat	Rakali inhabit a wide range of habitats including rivers, coast habitats, estuaries, creeks lakes and reservoirs (natural or man-made), irrigation channels, wetlands, and morasses. Populations expand during floods and then contract as the landscape dries.
Breeding	This species main breeding season is between September-March. The gestational period is approximately 35 days, and the juveniles reach maturity at around 240 days old. Rakali construct burrows in river banks and build nests within sunken logs and dense riparian vegetation for cover from predators.
Diet	Rakali are nocturnal hunters that primarily prey on small fish, crustaceans, molluscs, and invertebrates. Additionally, they have been observed consuming frogs, small water birds, bird eggs, and even other small mammals This is dependent on the season and availability of the food sources.
Movement	Rakali are territorial and solitary animals that typically occupy a 1-4 kilometre range. They exhibit localized movement around nesting sites and foraging areas.

4.4.4 Fishing bat (*Myotis macropus*)

Myotis macropus are small bats that use echolocation to detect ripples in the surfaces of the waterbodies and prey on small fish and invertebrates. This species is listed as vulnerable within NSW (BC Act). The species is found foraging on large streams at the lower end of the catchment and permanent wetlands. Given their high metabolic requirements, they are likely vulnerable to loss of foraging habitat within 500m of their roost (Campbell 2011). Raising the flow limit is expected to have the following outcomes:

- The number of permanent wetlands is predicted to increase from 81 to 191. This includes a number of wetlands that will fill to >5m (31 in Option 3) that will remain wet for 2 years. This will increase the amount of core habitat for *Myotis macropus.*
- The frequency of connection between the river and permanent wetlands will increase by between 8 and 15% with the longest interval between connections decreasing from 9 to 4 years under Options 2 & 3.
- Indirect influences of these changes in flow would include increased wetland productivity including fish and invertebrate communities that provide additional food resources.

Myotis macropus are classified as being vulnerable due to wetland degradation and access to roosting sites. In some areas, contaminants and bioaccumulation have also been found to be an issue. Restoration of permanent wetlands and the river they are connected to would be expected to lead to improve the reliability of food resources. If roost site availability is an obstacle, *M. macropus* has proven adaptable, utilising bridges and other structures. There would also be an expectation that over time, vegetation condition would improve and with it potential roosting sites.

Table 43. Flow requirements for Fishing bat.

Determined by other factors (e.g. vegetation) | Not relevant | Knowledge gap

Current	Depth (m): Min	Depth (m): Max	Flow Freq. (%): Min	Flow Freq. (%): Max	Permanent wetland depth / duration (m)	Ephemeral wetland depth / duration (m)	Inter-Event Period: Min	Inter-Event Period: Max	Connect
Still			50	100	2.5				

Table 44 Summary of Fishing Bat characteristics.

Criteria	Result
Habitat	They roost within tree hollows, culverts, bridges, and caves near waterways and live in a harem social structure. Waterbodies provide critical foraging habitat.
Food Sources	This species feeds on a variety of prey including aquatic insects, some small fish and crustaceans.
Breeding	This species has multiple breeding seasons a year - many of the copulations occurring in early spring. Some individuals can have up to two or three litters of single pups per breeding season. Individuals mature after around 9 months and then live for around 6 years.
Movement	Foraging and roosting sites need to be within 500m of each other. There is no information on the movements of *M. Macropus* to loss of foraging habitat.

5 Discussion

5.1 Species overview

Raising the current flow limit to the assessed options, while holding the accountable environmental water-holdings constant, was associated with improvements in environmental outcomes. A summary of outcomes is provided in Table 45. The key outcomes are:

- The condition of water-dependent ecosystems will improve supporting the life cycles of many native wetland fauna, including listed threatened species or listed threatened ecological communities.
- The frequency of connection increases which both improves wetland flow regimes and ensures that rivers and creeks are regularly connected to their floodplains.
- Wetland depth increases extending the duration of inundation in wetlands and contributing to a dynamic floodplain mosaic.
- Increases in the area and frequency of inundation will increase productivity across the system contributing to episodically high ecological productivity and its ecological dispersal.

Table 45: Summary of outcomes for wetland species by flow scenario

Flow Scenario	Potential benefits and risks
Option 1 – W32	The area of available habitat increased under this option by 17% for permanent and 14% for ephemeral wetlands. In addition to the increased area, wetland depth also increased with 61 (+8 compared to base case) wetlands deeper than 3m which means they would last for over 12 months. The number of wetlands that would persist for 2 years (>5m) doubled from 2 to 4 with a 7,400% increase in area of deep-water habitat. • Increased in the extent and duration of ephemeral wetlands would be expected to benefit frog species including the Long-thumbed frog and Sloan's froglet. • Habitat used by southern bell frogs increased by 16%. • The increased depth and duration are likely to favour small native fish such as Murray River rainbowfish. Wetland connectivity will improve with permanent wetland connectivity increasing by 6% and the 95th percentile inter-event duration of 36,000 $GL.d^{-1}$ flows dropping from 9 to 8 years. Improved connectivity will both reduce the frequency of permanent wetland drying and also facilitate movement of species such as Macquarie turtle. • Increased connectivity is also expected to favour southern bell frogs and eastern long-necked turtles that are known to move across the floodplain

Option 2 – W36	The area of available habitat increased under this option, with a large increase in the area of ephemeral wetlands. In addition to the increased area, increases in wetland depth also increased the number of wetlands that would persist for 2 years (>5m); doubling from 4 to 8 which was associated with a 14,400% increase in area of deep-water habitat over the base case. In contrast there was only a small increase in the number of wetlands >3m. • Increased in the extent and duration of ephemeral wetlands would again be expected to benefit all frog species. • The increased depth and duration are likely to favour small native fish such as Murray River rainbowfish. • The large increase in the area of permanent wetlands will be beneficial to fishing bats, southern bell frogs and turtles Connectivity of permanent wetlands increased from 10% to 16%. The probability of a 36,000 GL.d^{-1} flow increased to 0.46 while the 95th percentile inter-event duration of dropped to 5.8 years. The improved connectivity will both reduce the frequency of permanent wetland drying and facilitate movement of species such as eastern long-necked turtles. The greater area of deep wetlands is also likely to build ecosystem resilience by providing more refuges and providing a larger population base on which to build when wet conditions return. Increases in ephemeral wetlands and their beneficial influence on frog populations are likely to support grey snake populations.
Option 3 – W40	The area of ephemeral habitat increased by 89% and the area of wetlands >5m increased by 24,000% compared to the base case. These progressive improvements in available habitat will provide benefits seen in Options 1 and 2, however, additional habitat will increase the likelihood of population gains as variations among wetlands and the larger mosaic provide greater chances of survival and recruitment. • For southern bell frogs, there would be an additional 18% more habitat compared to the base case. Frequency of connection to Permanent wetlands remained stable at 16% increase on the base case. The likelihood of a 36 GL.d^{-1} flow improved to 0.52 (events per year) while the 95th % inter event duration for 36 GL.d^{-1} decreased to 5 (down from 5.8 in Option 2). The improvements in connectivity would be expected to: • Facilitate movement of catfish between permanent wetlands and the river to breed and complete their life cycle. • Increase opportunities for southern bell frog and eastern long-necked turtles to disperse and utilise ephemeral wetlands. • As well as supporting the same benefits seen in Option 1 and 2.

5.2 System overview

At the system scale, higher flow limits are likely to increase the number of wetland species supported on the Murrumbidgee floodplain. Several outcomes of this report are key factors that inform this judgement, including:

- The area of floodplain engaged by water for the environment is increased considerably. The species-area relationship is a consistent ecological relationship that forecasts that with an increase in area will come an increase in the species richness in that area.
- Higher flow limits are associated with an increase in habitat heterogeneity through three pathways:
  1. The area of rarer ecosystem types inundated increases.
  2. Within ecosystem types there is greater variation in flow regime.
  3. Through time, variations in depth and subsequent duration are likely to contribute to heterogeneity.
- Raising the flow limit increases connection frequency between the river and all floodplain habitats, especially permanent wetlands, and their secondary connection with diverse wetlands higher on the floodplain. This will increase the exchange of energy and nutrients between the river and its floodplain and facilitate the movement of biota to either complete their life cycle or persist in the face of water-related disturbances.
- Higher flow limit deliveries yield wetlands of increased depths inundated more frequently, which will have significant impacts on the wider ecosystem by providing habitat for species that require deep habitats. Perhaps more importantly, increases in the inundated depth of wetlands will mean:
  - Water will remain in the landscape for longer to support aquatic, amphibious and terrestrial biota.
  - There will be more refuges for animals to persist through dry spells and thereby increasing their resilience with the return of wet conditions.

5.3 Knowledge gaps, risks and moving forward

Outcomes for specific species are more variable and, in some instances, more uncertain. There are three sources of uncertainty:

1. Limited understanding of species flow requirements
2. Limited understanding of the multiple pathways by which flow may influence species (vegetation, habitat, connectivity, food, predation)
3. The influence of other threats to species. This issue lies out of scope for this assessment as conceptually, non-flow threats impact the species directly regardless of improvements to flow regimes.

There are clearly species that will benefit from a higher flow limit including ELNT, Murray River rainbow fish and southern bell frogs all of whom have broad habitat requirements and will move among wetlands to exploit opportunities. There are other species for whom outcomes are less certain, including freshwater catfish, Sloane's froglet and platypus. For freshwater catfish and platypus this uncertainty comes from our poor understanding of the extent to which they would benefit from increased connectivity to permanent wetlands and increased frequency of inundation of permanent wetlands. The uncertainty around Sloane's froglet is associated with our limited understanding of influences on its persistence within landscapes. Regardless of the uncertainty around some of the forecasts, the assessment found no risks that higher flow limits would further deplete species' populations.

Issues have also been identified within permanent wetland areas and habitats, particularly with carp and gambusia populations that may limit potential benefits from higher flow limits. Assessment of the risks of higher flow limits found that carp numbers will remain relatively constant (Wootton et al. 2023). This means that the threat currently posed by carp in wetlands will not change, which in turn, may affect the outcomes of flow regime restoration.

The assessment of connectivity focussed on the frequency of connection but did not consider the nature of the connection and ways in which this may facilitate or impact movement of sediments, nutrients, and other biota among wetlands. Across the floodplain, however, it is likely that inundation of a greater diversity of wetlands will be associated with greater variety in the way wetlands are connected. Connection will be important for small native fish and their capacity to exploit the opportunities associated with inundation of ephemeral wetlands will depend on how wetlands are connected. Eastern long-necked turtles and southern bell frogs will both benefit from increases in the availability of ephemeral wetlands. There may also be benefits to small native fish (e.g. olive perchlet) and frogs (e.g. Sloane's froglet) in the inundation of wetlands with restricted connections that may prevent colonisation by invasive fish (e.g. carp). Connectivity may also be important for the dispersal of juvenile platypus, but little is known about the influence of water in the landscape on their dispersal.

Further investigation of the effects of higher flow limits on duration would improve the assessment by identifying the extent to which the duration of inundation would support breeding and recruitment by frogs and small native fish. The preliminary assessment found that the distribution of inundated wetland depths would vary between high flow magnitudes. This variation is likely to contribute to habitat heterogeneity across the floodplain which would be expected to support species richness. The variation in depth may also mean that the locations of successful recruitment may vary from one event to the next. If this is the case, then increasing the inundation of different wetland types will improve the likelihood that there will be some successful recruitment. It also reinforces the importance of connectivity for population restoration in wetlands that won't support recruitment during the next inundation i.e. it is important the individuals can disperse to improve the population's chances of recruitment during the next event.

The dynamic nature of floodplains, variation in wetland depths and the importance of connectivity (both hydrological and biotic) all underline the importance of landscape configuration in determining the potential benefits for native wetland fauna from higher flows.

6 Conclusions

The assessment revealed that, at a landscape scale, increasing the flow limit from the current level has the potential to rehabilitate large areas of the Murrumbidgee River floodplain, and this will contribute to protecting a representative selection of ecosystem types. At the level of individual species, this will lead to improvements in:

- The amount of available habitat
- Key ecosystem types, specifically permanent wetlands
- Connectivity restoration

A brief outcome summary of each scenario is provided in Table 45. It is expected that ecosystem restoration at this scale will better provide species with the resources they require, and the connectivity will enable movement to either complete their life cycles or exploit food resources. Improvements in the depth and duration of wetland inundation will improve species resilience through provision of refuges and improved opportunities to recolonise disturbed habitats. Of the 15 species examined, all are expected to benefit to some extent through raising the flow limit. These species are also likely to provide a good indication of the benefits for other groups including bush birds, koalas and terrestrial reptiles. Outcomes for individual wetlands are difficult to forecast due to the suite of drivers that influence outcomes, however, at the landscape scale the assessment suggests that raising the flow limit is likely to restore a more natural, dynamic habitat mosaic.

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Appendices

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Appendix B: Bottom 50% of ANAE Wetlands by Species Observational Counts

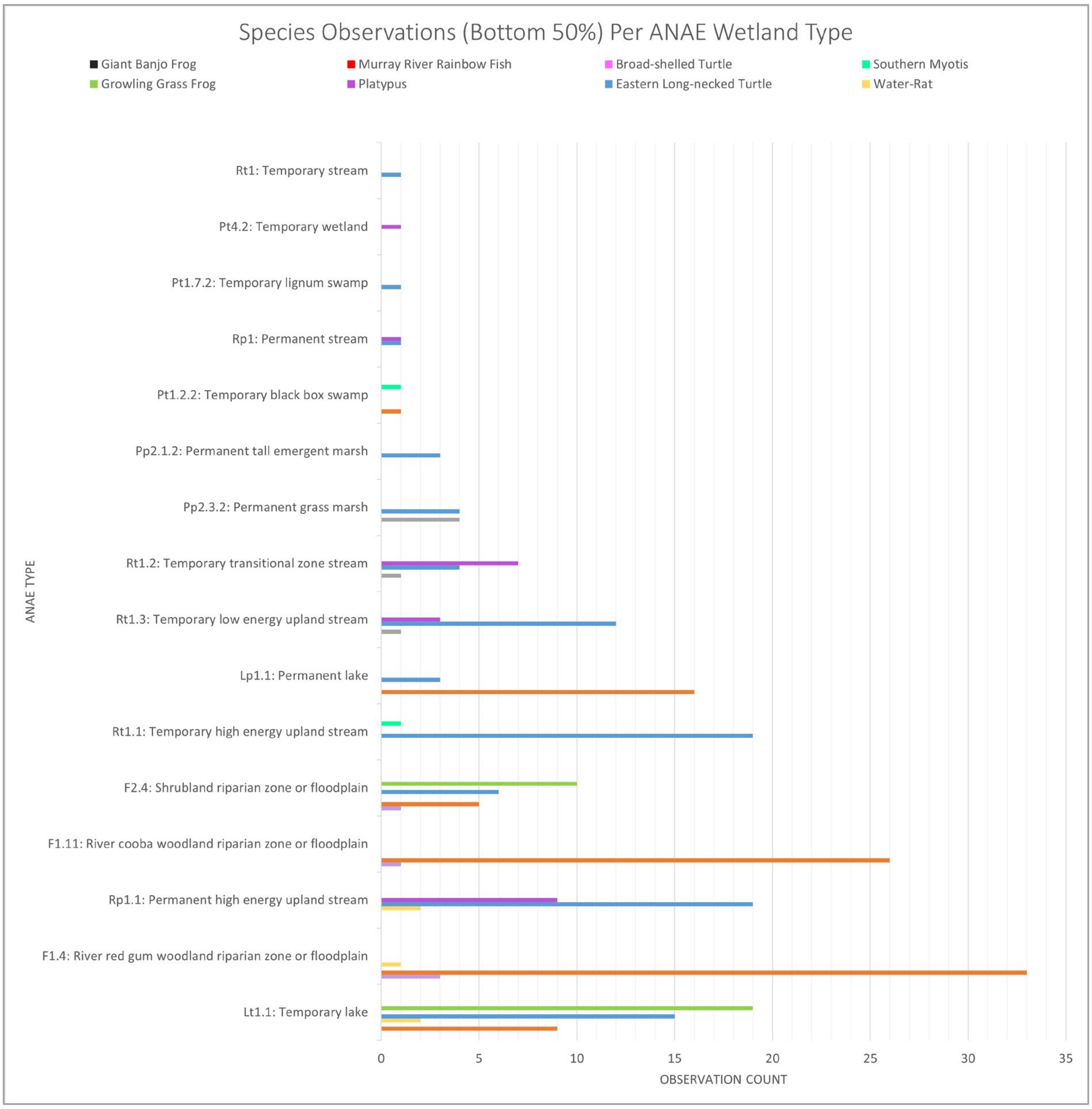

Figure 20: Count of species observed within uncommon ANAE wetland types.

Appendix C: Flow and inundation statistics for the Murrumbidgee River system (from NSW DCCEEW)

Table 46: Flow recurrence and wetland inundation statistics – Gundagai to Hay Weir (Wagga gauge). Assumes a 5 day duration of flow peak, 5 day “spell gap tolerance”. Wetland area results determined using Hall et al., (2023) mapped extents.

Flow threshold (ML. d^{-1})	% years achieved in flow scenario W22	% years achieved in flow scenario W32	% years achieved in flow scenario W36	% years achieved in flow scenario W40	Area floodplain and wetlands inundated (ha)	Area of major wetlands inundated (ha)	# major wetlands connected	# wetlands connected (max depth >2.5m)	# wetlands connected (max depth >1m)	# wetlands connected (max depth >0.5m)	Area (ha) wetlands connected (max depth >2.5m)	Area (ha) wetlands connected (max depth >1m)	Area (ha) wetlands connected (max depth >0.5m)
16000	80	77	78	76									
20000	75	72	72	71	2095	1068	68	35	62	64	504	797	900
22000	59	63	62	62									
24000	52	60	60	60	4904	2149	119	62	108	115	1303	1829	1960
28000	50	59	60	60	6624	2444	175	91	160	169	1307	2033	2134
32000	42	48	58	58	10530	3333	242	139	218	228	1981	2923	2992
36000	41	41	46	52	15400	4151	300	181	263	288	2922	3822	3944
40000	37	37	37	38	19741	4673	345	216	306	333	3388	4253	4417
44000	34	34	32	31	24699	5217	387	248	353	374	3901	4941	5008
48000	32	31	29	29									
52000	29	26	28	28									

Table 47: P95 and median inter event period durations – Gundagai to Hay Weir (Wagga gauge)

Flow threshold (ML. d^{-1})	95th percentile inter event duration (years) W22	95th percentile inter event duration (years) W32	95th percentile inter event duration (years) W36	95th percentile inter event duration (years) W40	Median inter event duration (years) W22	Median inter event duration (years) W32	Median inter event duration (years) W36	Median inter event duration (years) W40
16000	2	2	2	2	1	1	1	1
20000	2	2	2	2	1	1	1	1
22000	4	4	4	4	1	1	1	1
24000	5.9	4	4	4	2	1	1	1
28000	8	4	4	4	1	1	1	1
32000	9	5.5	4	4	1.5	1	1	1
36000	9	8.1	5.8	5	2	2	2	1
40000	9	9	8.8	8.8	2	2	2	2
44000	9	9	9	9	2	2	3	3
48000	9	10.5	9	9	2	2	3	3
52000	9	10.8	9	9	3	3	3	3

Table 48: Flow recurrence and wetland inundation statistics – Yanco System (Yanco offtake gauge). Assumes a 5 day duration of flow peak, 5 day “spell gap tolerance”. Wetland area results determined using DNR (2007) mapped extents.

Flow threshold (ML. d^{-1})	% years achieved W22	% years achieved W32	% years achieved W36	% years achieved W40	Area floodplain and wetlands inundated	Area of major wetlands inundated (ha)	# wetlands connected	# wetlands connected (max depth >2.5m)	# wetlands connected (max depth >1m)	# wetlands connected (max depth >0.5m)	Area (ha) wetlands connected (max depth >2.5m)	Area (ha) wetlands connected (max depth >1m)	Area (ha) wetlands connected (max depth >0.5m)
1000	82	78	79	78	1307	734	208	9	128	192	61	336	519
1500	68	68	68	67	1782	1072	256	13	147	210	124	474	671
1750	62	65	65	64									
2000	55	59	59	59	2333	1132	246	20	164	227	180	819	1033
2500	52	60	60	60	2930	1273	257	29	177	237	238	943	1165
3000	48	52	57	59	3557	1481	289	42	189	249	275	1095	1232
3500	42	45	48	53	4341	1564	302	56	215	271	336	1230	1364
4000	38	39	38	43	5114	1633	310	65	232	283	361	1290	1427
4500	35	35	33	32									
5000	34	32	30	31									
5500	29	28	26	26									

Table 49: P95 and median inter event period durations – Yanco System (Yanco offtake gauge).

Flow threshold (ML. d^{-1})	95th percentile inter event period duration (years) W22	95th percentile inter event period duration (years) W32	95th percentile inter event period duration (years) W36	95th percentile inter event period duration (years) W40	Median inter event period duration (years) W22	Median inter event period duration (years) W32	Median inter event period duration (years) W36	Median inter event period duration (years) W40
1000	2	2	2	2	1	1	1	1
1500	3	3	3	3	1	1	1	1
1750	4	4	4	4	2	1	1	1
2000	5	4	4	4	1	1	1	1
2500	6	4	4	4	2	1	1	1
3000	6	5	4	4	1	1	1	1
3500	9	8	6	5	2	2	2	1
4000	9	9	9	6	2	2	2	2
4500	9	9	9	9	2	2	2	3
5000	9	9	9	9	2	2	3	3
5500	9	9	9	9	3	3	3	3