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Environmental outcomes of implementing the Floodplain Harvesting policy in the Gwydir Valley

Report

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Executive summary

Harvesting of water from floodplains reduces the volume, frequency, and duration of floods and changes the timing of these events, impacting on the health of floodplains and downstream waterways. To manage unconstrained harvesting, the NSW Government has introduced the NSW Floodplain Harvesting policy (the policy). The aim of the policy is to "manage floodplain water extractions more effectively in order to protect the environment and the reliability of water supply for downstream water users, ensure compliance with the requirements of the Water Management Act 2000 and meet the objectives of the National Water Initiative" (NSW Office of Water 2013). The policy is scheduled to be in place in the 5 Northern Murray-Darling Basin valleys of NSW Border Rivers, Gwydir, Namoi, Macquarie, and Barwon-Darling by July 2021. The policy includes licensing of floodplain harvesting to provide a more sustainable level of water diversions from the floodplain through returning water use to the long-term average annual extraction limit and curtailing future growth.

Using modelled long-term (1895 to 2016) changes to floodplain hydrology, this report provides an assessment of potential outcomes for the environment after implementing the policy in the Gwydir Valley. Key hydrological metrics and environmental water requirements (EWRs) were used to test and identify these outcomes for assets (e.g. a location) and values (e.g. species) including native fish, native vegetation, waterbirds, flow-dependent frogs and important ecosystem functions and wetlands.

Key findings

Our findings are based on the analysis of two river system model scenarios for the Gwydir Valley floodplain that simulate current conditions with and without the policy implemented. The results reported herein are therefore only indicative of potential outcomes under implementation of the policy. Based on the findings presented in this report, implementation of the policy should result in:

- An improvement in the environmental condition of the Gwydir Valley floodplain as most of the tested environmental water requirements are predicted to be achieved more frequently.
- Predicted changes to floodplain hydrology (volumes, durations, and timing of floods) will be primarily beneficial with some small negative outcomes at a few breakout zones[1].

A high-level summary of potential outcomes across the Gwydir Valley for waterbirds, native vegetation, native fish and water volumes is provided in map form in Figure 1.

The Gwydir/Gingham breakout zone which supports the internationally important Gwydir Wetlands is expected to receive the greatest outcomes. Modelling suggests that the environmental water requirements of native vegetation, native fish and waterbirds in this zone would be met more often, by an average of 82%, 97% and 142% respectively. Better outcomes for the Gwydir Wetlands would provide greater resilience for the diverse habitats and species it supports in the Gwydir Valley and the Northern Murray-Darling Basin more broadly.

Whilst the overall outcomes for the Gwydir Valley floodplain are predicted to be beneficial, stronger environmental outcomes could be achieved through additional reductions or changes in management of diversions between August and October. This is because late winter and spring is a key period for many environmental values (e.g. waterbirds and native fish). Modelling suggests there will be little change to flood durations in August and September, particularly in the Mehi River breakout which is predicted to have a 13% reduction in flood durations during September after implementation of the policy.

[1] As the water level rises from within the channel, the most common points through which inundation initially occurs are low areas where the stream can spill over onto its floodplain. These flow breakouts can extend across many properties, sometimes flowing along indistinct flow paths that can inundate large areas of the floodplain. Some breakout flow paths only get water flowing in very high flows, and others happen more frequently.

Hydrological outcomes

A range of ecologically relevant hydrological metrics were assessed, including flood magnitude (volume and flow rate), frequency of events, timing, and duration.

The majority of these metrics are predicted to improve once the policy is implemented. Outcomes vary with location on the floodplain; however, in general, **mean annual volume, seasonal volumes, duration of days with flow**, and **frequency of events** are predicted to increase, and **inter-event periods** are predicted to reduce. **Mean annual volumes** are predicted to increase by at least 11% in most breakout zones with the largest percentage change, a 22% improvement (2.2 GL) at Deadman/Biniguy and 19% improvement (16.5GL) in Mehi breakout zone. In consideration of all hydrological metrics, Gwydir/Gingham breakout zone is expected to have the greatest improvement with: an increase in mean annual volume of 13% (13 GL), an increase in number of events (109%), an increase in flood duration (51%) and reduced periods between floods (reduction in inter-event period) (-54%).

Based on the modelled scenarios, changes to hydrology will not be consistent across the breakout zones of the Gwydir Valley. Some zones, such as the Marshall breakout zone, are expected to have little to no change. The Deadman/Biniguy, Carole/Gil Gil Creek and Gil Gil/Carole Creek zones are predicted to have limited improvements to duration, frequency, and timing despite improvements in magnitude.

Upgraded modelling with floodplain return flows may identify additional benefits in the Gwydir Valley and into the Barwon-Darling.

Native fish

Water requirements of 11 native fish species in 4 guilds – flow dependent specialists (such as Golden Perch), generalist species (such as Bony Herring), short-moderate lived floodplain specialists (such as Southern Purple Spotted Gudgeon), and river specialists (such as Murray Cod) were used to assess outcomes for native fish under the policy.

Predicted outcomes are predominantly positive with anticipated improvements in the **number of flow days**, and **the frequency and timing (seasonality**) of events significantly benefitting reproduction opportunities and maintenance of adult individuals for all fish guilds. One exception is a small (2%) reduction in the timing of events in September and October, a critical spawning period for short-moderate floodplain specialists like the Olive Perchlet. Some of the best outcomes are expected for the Gwydir/Gingham breakout which includes the Gwydir Wetlands.

Waterbirds

There are 76 waterbird species comprising both colonial-nesting and non-colonial nesters recorded or predicted to occur across Gwydir Valley breakout zones.

Outcomes for waterbirds vary across the floodplain; however, on average, predicted improvements in the frequency and timing of floods under the policy should be beneficial for colonial-nesting and non-colonial nesting waterbirds. Flood duration is critical for waterbird breeding success and habitat maintenance. An increase in the **number of flow days** (used as substitution for flood duration) during waterbird breeding periods (August and May) is predicted for all months excluding August and October. These improvements are greatest in three breakout zones, with very little change expected in the other five breakout zones. The zones with the largest predicted increases in flood duration are the Gwydir/Gingham and Mehi River breakouts.

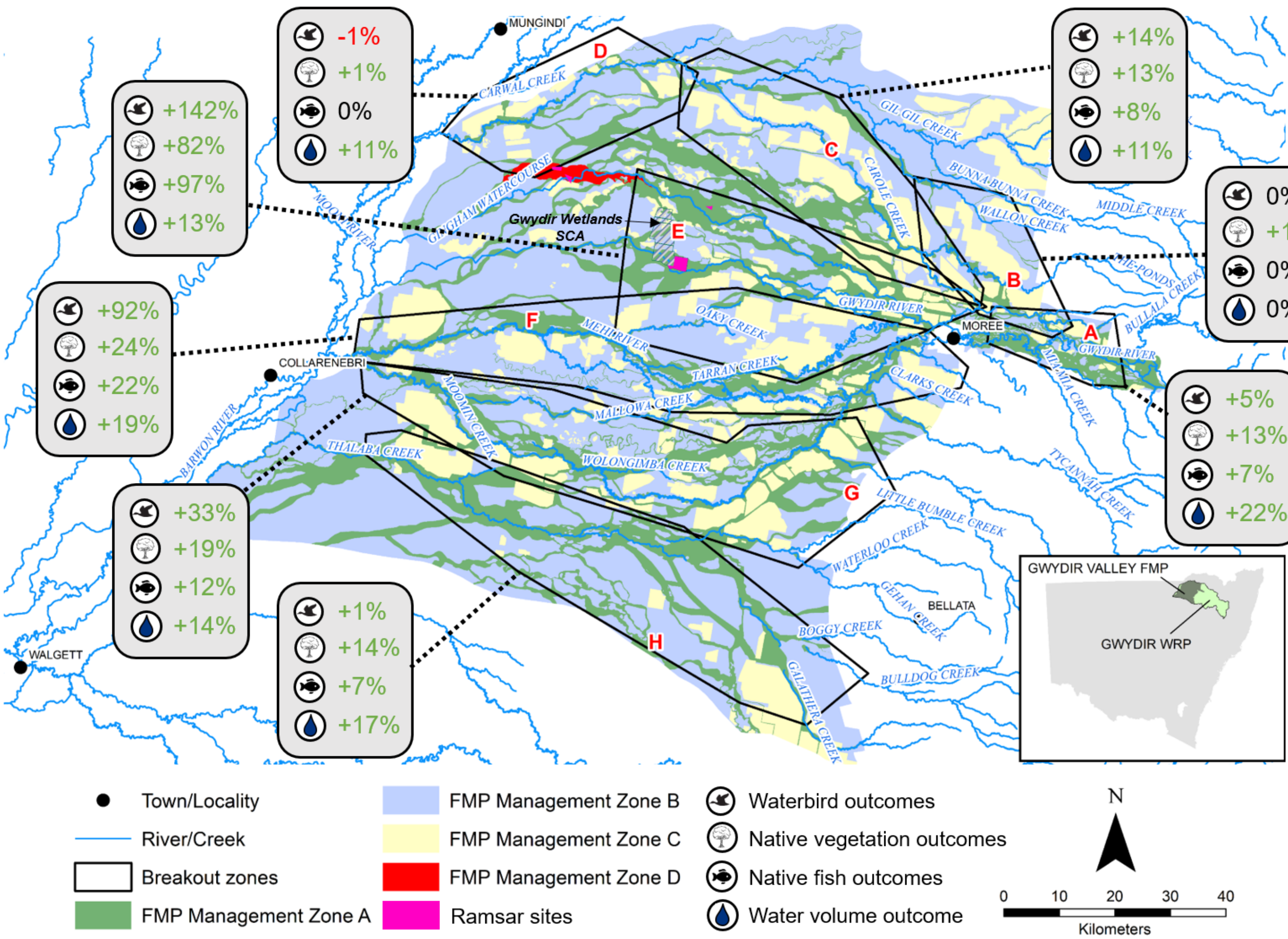

Figure 1 Mapped summary of predicted outcomes for waterbirds, native vegetation, native fish, and water volumes for the 8 breakout zones in the Gwydir Valley. Percent change values show the expected change from current (no policy) to current with policy implemented based on a 121-year simulation period. Values for waterbird, native vegetation and native fish outcomes are the average change in achieving key EWRs at each breakout zone (See Table 13). Water volume outcomes are the percentage change in mean annual volumes (See Table 4) during years with floods. FMP = Floodplain Management Plan. Breakout zones: A Deadman/Biniguy, B Marshall, C Carole/Gil Gil, D Gil Gil/Carole, E Gwydir/Gingham, F Mehi, G Moomin Creek, H Thalaba

The Gwydir Wetlands is a significant breeding area for colonial-nesting and non-colonial nesting waterbirds. The breakout zone which supports this wetland system is predicted to receive some of the largest improvements under the policy, with increased **frequency** and **timing of events,** and increased **number of flow days** in all months but July and October. For example, the frequency and timing of floods critical for colonial-nesting waterbird breeding events are expected to be achieved 60–163% more often. Additional improvements to flood volumes in this breakout zone should provide extra benefits to waterbirds in the Gwydir Wetlands.

Figure 2 The Australian pelican (*Pelecanus conspicillatus*), a colonial nesting waterbird often found in the Gwydir wetlands [Photo: Patrick Kavanagh]

The absence of spatial extent of floods in the river system model makes it difficult to estimate the duration of inundation and therefore test specific inundation durations (duration EWRs) important for waterbird breeding events.

Native vegetation

As for native fish and waterbirds, the policy is predicted to improve the **number of flow days** (used as substitute for duration), frequency and timing of floods, with benefits for many of the floodplain's dominant vegetation species. This includes lignum, coolabah, river cooba, river red gum, blackbox, marsh club-rush, cumbungi, and water couch. Other predicted benefits are **improved timing (seasonality)** for mature plant maintenance, seed dispersal and seedling establishment in several species, including river red gum. As with the other environmental values assessed in this report, changes and the size of those changes varied across the floodplain.

Summer is a critical period for maintenance, regeneration and reproduction for most vegetation values including river red gum, lignum, coolabah, blackbox, water couch and cumbungi – the **number of flow days during summer and autumn** are predicted to substantially improve in three breakout zones. Fewer winter events in the Gil Gil/Carole breakout zone may influence potential lignum seed dispersal that occurs in August to November.

The Gwydir Wetlands which includes the Gwydir Wetland State Conservation Area (SCA) (Figure 3) and Ramsar subsites is predicted to have some of the best outcomes for native vegetation under the policy. This breakout zone has high native vegetation diversity, with 7 of the 8 species assessed in this report occurring in the associated breakout zone (Gwydir/Gingham). As an example, cumbungi was only present in Gwydir/Gingham breakout zone and has the largest predicted increases in the frequency (74-88%) and timing (99%) of its EWRs. Over a two-fold increase in meeting the **flood frequency requirement for maintenance** of marsh club-rush is predicted, alongside **improved flood timing (seasons) for maintenance** and **flood frequency for seedling establishment**. This rush is a key species of a critically endangered community under the *NSW Biodiversity Conservation Act 2016*. These same 3 EWRs for marsh club-rush are also predicted to increase within the Moomin Creek breakout zone, although by lower amounts.

Figure 3 Satellite image showing Gingham Watercourse, part of the Gwydir Wetlands State Conservation Area (SCA)during a severe drought on 2 February 2020. This area is part of a nationally significant wetland which provides critical refugia for water-dependent ecosystems. [Image sourced from the Sentinel Playground (https://www.sentinel-hub.com/explore/eobrowser), Sinergise Ltd]

Ecosystem functions and flow-dependent frogs

The ecosystem functions assessed in this report include EWRs which relate to productivity (generation of biomass), nutrient supply and hypoxic blackwater event prevention.

More frequent flood events are likely to provide better outcomes for these ecosystem functions. The predicted increase in flood events occurring in the warmer summer months (**improved timing**) should benefit the floodplain ecosystem by providing longer floods during periods of higher biological activity. Improved flood frequency is also likely to reduce the build-up of carbon on the floodplain and lower the risk of blackwater events. The modelled hydrological changes of implementing the policy are predicted to improve the frequency of longer **flood durations** (greater than 2 weeks) by 11% on average across the Gwydir Valley floodplain. These longer events are expected to provide the best outcomes for primary production that enhance the abundance of aquatic insects and increase dissolved organic carbon supply.

The Gwydir floodplain is home to six flow-dependent frog species. The predicted increase in flood frequency and timing of flood events should benefit these species. In addition, larger flood volumes and more days with flow on the floodplain may increase the flood inundation area and provide more habitat for flow-dependent frogs. The policy is predicted to improve all six frog EWRs assessed in this report, with the Gwydir/Gingham breakout zone receive the greatest benefit.

Overall, the flood requirements (timing and frequency) for flow-dependent frogs should improve by at least 15% on the floodplain with the policy implemented.

Wetlands

The Gwydir Valley floodplain supports a number of wetlands. Key wetlands include the Gwydir Wetlands which incorporates the Gwydir Wetlands State Conservation Area (SCA) and the 4 Ramsar listed subsites (Goddard's Lease, Old Dromana, Windella and Crinolyn) which are all located in the Gingham Watercourse and Lower Gwydir area. The breakout zone which supports the SCA and Ramsar subsites is the Gwydir/Gingham breakout. The Windella and Crinolyn subsites are directly downstream of this breakout and should experience similar changes to the sites within the breakout zone as there are no additional floodplain harvesting properties with access to water below the Gwydir/Gingham breakout.

The Gwydir Wetlands is predicted to receive some of the largest hydrological improvements in the Gwydir Valley. **Mean annual volumes** are predicted to be boosted by increased summer flow volumes and flood events. Achievement of all of the environmental water requirements tested for the Gwydir Wetlands are predicted to improve by between 60 and 221% depending on the tested metric. The number of flow days are expected to increase in all months except July for the Gwydir Wetlands. An increase in the **total number of flow days** in the modelled period during summer months is predicted: December (171 more days or +95%), January (230 more days or +53%) and February (282 more days or +71%). These metrics indicate that implementation of the policy would enhance the flooding regime to this significant wetland. This should provide increased resilience for the diverse habitats and species it supports in the Gwydir Valley and the Northern Murray-Darling Basin more broadly.

Improving assessment of environmental outcomes

The results presented in this report are based on the best available simulation modelling, using locally specific information where available, else inferred from the literature or from similar environments in NSW. However, building understanding of the likely effects of floodplain harvesting on floodplain condition requires further investment, including to:

- improve the underlying river system models. Return flows are rarely included in the river system models. Along with major floodplain flows, these need to be measured and represented in the models. This will allow cumulative downstream impacts to be estimated. At present, little to no environmental benefit is detectable in some downstream floodplain breakouts. It is unclear if this is due to the inability of the models to incorporate return flows and thus cumulative downstream impacts, or if this is a real outcome predicted after implementation of the policy.
- incorporate modelling of additional flow thresholds with the flood inundation models to quantify changes to flood inundation extent and duration across a wider range of flows. Hybrid hydrological/hydraulic models may enable changes to flood inundation duration and extent to be modelled based on modelled changes to hydrology. This would enable a more robust assessment of environmental water requirements (inundation frequency, duration, and timing) and policy changes.
- implement long-term environmental monitoring, evaluation, and reporting (MER) programs for floodplain environmental assets and values to complement existing long-term MER programs run by other agencies such as the NSW Department of Planning, Industry and Environment – Environment, Energy and Science. This is critical to be able to measure real-world outcomes of the policy.

Incorporating these recommendations into the implementation of the policy would reduce uncertainties in the current modelling and improve confidence in predicted outcomes.

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1 Introduction

1.1 Background

In 2013, the NSW Government introduced the NSW Floodplain Harvesting policy (the policy). The policy is scheduled to be in place by July 2021. The purpose of the policy is to

> ‘manage floodplain water extractions more effectively in order to protect the environment and the reliability of water supply for downstream water users, ensure compliance with the requirements of the Water Management Act 2000 and meet the objectives of the National Water Initiative’ (NSW Office of Water 2013).

The policy aligns with the objectives of the National Water Initiative, an intergovernmental commitment made by the Council of Australian Governments in 2004 to increase the efficiency of Australia’s water use. The policy aims to manage unconstrained floodplain harvesting by bringing it into a licensing framework. The NSW Government is currently implementing the policy in the designated floodplains of five inland northern NSW valleys – Border Rivers, Gwydir, Macquarie, Namoi and Barwon-Darling.

Improved environmental outcomes for floodplains is one of the key outcomes sought through implementation of the policy. Unconstrained harvesting of water from floodplains reduces the amount of water available to meet wetland and floodplain needs and to ensure downstream river health. Floodplain harvesting can also affect connectivity between a river and its local floodplain wetlands by reducing flow volume and redirecting flood flows (DPIE Water 2019a).

1.2 Report purpose

This report considers the predicted environmental outcomes (i.e. ecological responses) to changed floodplain harvesting volumes in the Gwydir Valley after implementing the policy. It includes identification of floodplain water-dependent environmental assets (e.g. locations) and values (e.g. species), modelled hydrological changes and predicted outcomes for floodplain ecosystems with and without implementation of the policy. This assessment has a targeted focus on areas of the floodplain where floodplain harvesting occurs.

1.3 Assessment approach

The choice of assessment approach and selection of assessment metrics was dictated by the availability of data and access to a river system model that was capable of simulating the flow of water overbank and onto floodplains over a long-term period and under different management practices (as would occur under implementation of the policy). The three components of the approach are shown in Figure 4. Identification of values (such as native fish species) and assets (such as wetlands) is described in Chapter 3. The hydrological assessment (of ecologically relevant flow statistics) is described in Chapter 4. Relating the results of the hydrological assessment with the water requirements of key environmental values and assets is described in Chapter 5.

The values were selected to represent the range of biotic flow requirements for assessing environmental responses to changes in flow. The intent was to cover the spectrum of flow dependencies. The approach compares the influence of flow only, all other influences being equal.

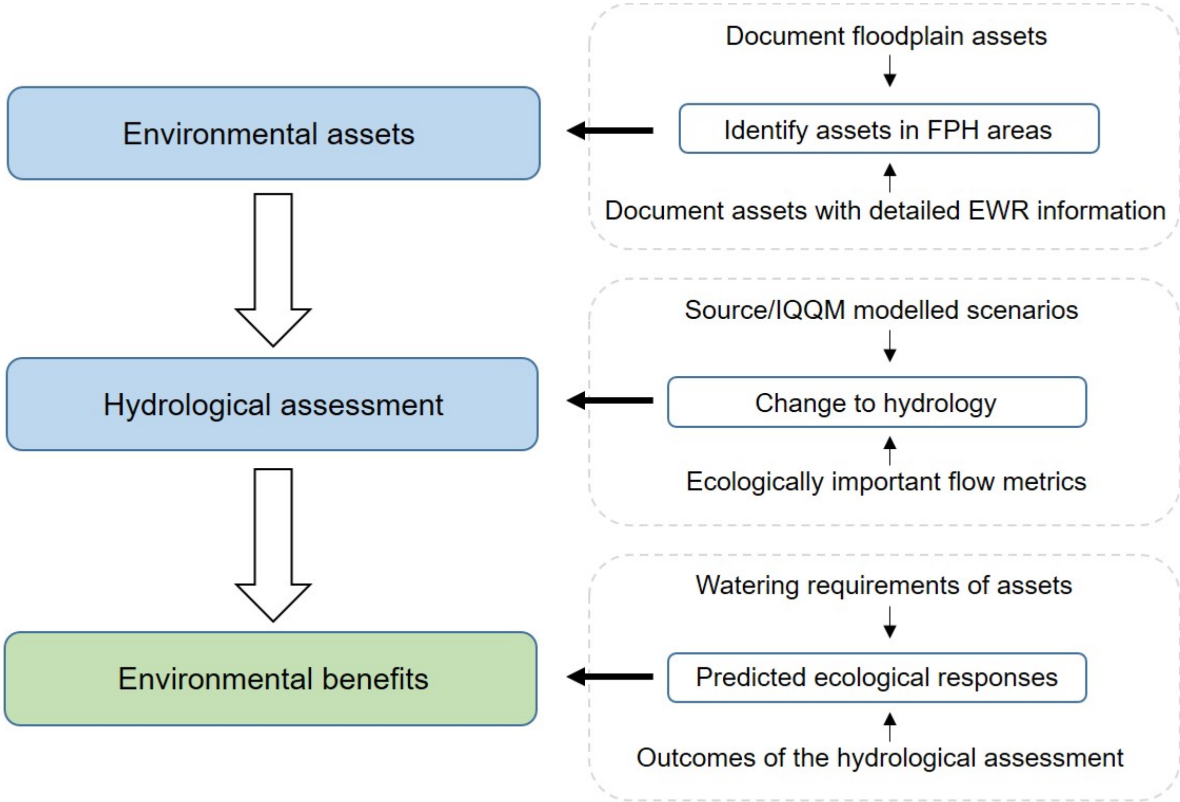

Figure 4 Summary of the approach adopted to identify the environmental outcomes of implementing the NSW Floodplain Harvesting *p*olicy (FPH = floodplain harvesting; Source/IQQM are river system/hydrological models)

1.4 Companion reports

This report is one of a suite of 3 reports that are prepared for each of the 5 NSW northern Murray-Darling Basin valleys. This report describes an assessment of the predicted environmental outcomes from implementing the policy.

This assessment relies on having access to a detailed river system model of the valley, which represents the physical movements of water onto, through and exiting the valley and the regulations, policies and practices in place to equitably manage that water for all water users. Those models have been extended or rebuilt for each valley. The build of the Gwydir Valley model is described in *Building the Gwydir Valley river system model* (DPIE Water 2021a).

Modelling scenarios have been developed which use the river system model, with alternate parameter settings that describe the current condition and condition with the policy implemented. How these have been built and used to assign floodplain harvesting entitlements is described in *Floodplain Harvesting Entitlements for the Gwydir Valley – Scenarios* (DPIE Water 2021b).

The three reports together serve to describe how the modelling meets the objectives of the policy.

2 Floodplain harvesting in the Gwydir Valley

The Gwydir Valley floodplain is within the Gwydir River catchment. The most upstream or eastern boundary of the designated Gwydir Valley floodplain begins around Biniguy and spreads towards Moree and then out to the south and north west towards the Barwon River. The main waterways in the floodplain are the Gwydir River, Mehi River, Carole Creek, Moomin Creek and Gingham Watercourse. The Gwydir Valley floodplain is flat with slow flow velocities. This causes floodwaters to distribute in a delta like drainage pattern to the northwest via Carole Creek, to the west through the Gingham Watercourse and to the southwest via the Mehi River. The Mehi River is the largest effluent stream on the floodplain followed by Carole Creek. The Gwydir River is considered a terminal or closed system however large floods can connect the floodplain to the Barwon River (DPI Water 2015).

The Gwydir Valley is regulated by Copeton Dam and other instream structures further downstream, including weirs that divert irrigation water from the Gwydir River into the Mehi River, Carole Creek and Moomin Creek. In addition to these regulating structures there is the Gwydir Raft, which is formed by a large obstruction of timber and debris and forms a dam like structure. This is a unique feature of the Gwydir Valley floodplain which disrupts flow in the Gwydir River causing water to split at Tyreel Weir into the Gingham and lower Gwydir channels (DPI Water 2015).

These large regulating structures capture headwater flows and divert flows which reduces the magnitude, frequency, and timing of downstream overbank flooding (Leigh and Sheldon 2008). Larger uncontrolled floods that make it to the floodplain can be constrained by other localised floodplain regulating structures. Extensive floodplain development exists on the Gwydir Valley floodplain including levee banks, earthworks, banks, and water supply channels. Works such as these, which affect the distribution of floodwaters, are referred to as flood works. Approximately 191,000 hectares of the floodplain are enclosed by flood works in the Gwydir Valley floodplain (DPI Water 2015). Flood works create considerable disconnection of the original floodplain by blocking surface flows (both laterally and longitudinally) and causing artificial inundation in off-river storages (Steinfeld and Kingsford 2013). In addition, the modifications of deepening and widening of channels in the Gwydir River, Mehi River, Moomin Creek and Carole Creek for improved supply of allocated water has altered the carrying capacity and the natural flood regime.

A key part of the Healthy Floodplains Project involves the development of valley-based floodplain management plans for designated floodplains in the NSW Border Rivers, Gwydir, Namoi, Macquarie, and Barwon-Darling valleys. These floodplain management plans establish management zones and set rules for new flood works and amendments to existing flood works that are designed to protect the passage of floodwater, whilst minimising the risk to life and property.

The Floodplain Management Plan for the Gwydir Valley Floodplain 2016 commenced on 12 August 2016 and is due for extension/replacement on 12 August 2026 (DPI Water 2015).

The other key component of the Healthy Floodplains Project is the licensing of floodplain harvesting and the management of these licences through water sharing plans. The framework for implementing this licensing and management regime is provided by the policy. In effect, the policy describes the process for licensing and managing floodplain harvesting within the long-term average annual extraction limits (LTAAEL) already established in water sharing plans, ensuring no future growth in extractions on a valley-wide basis. For clarity, the LTAAEL established in water sharing plans, is analogous with the Baseline Diversion Limit (BDL) referenced in the 2012 Basin Plan (MDBA 2018). The portion of floodplain harvesting diversions within the BDL for the Gwydir Valley is approximately 137.5 GL/y, which includes runoff harvesting and overbank flow harvesting. Based on the modelling these long-term average floodplain harvesting diversions are currently around 174 GL/y which is 36 GL/y over the BDL. Implementation of the policy will bring the estimated long-term average annual floodplain harvesting diversions to 121 GL/y which is below the BDL. This is a 30% reduction in floodplain harvesting diversions.

The process for reducing floodplain harvesting diversions and determining new share components differs for regulated and unregulated water sources. Where volumes need to be reduced to not exceed the LTAAEL, impacts are distributed as equitably as possible across all licenced individuals. The policy ensures that

> ‘share components for individual floodplain harvesting access licences in regulated river water sources will be determined in two steps:
>
> The long-term volume of water that all eligible works are capable of taking will be determined—this process will determine both individual and total floodplain harvesting volumes from eligible development.
>
> Scaling of individual floodplain harvesting volumes based on eligible development will be used in conjunction with account management rules to achieve a volume of entitlement that will not exceed the total LTAAEL and will distribute impacts as equitably as possible across individuals—this will determine a total share component for each individual’ (NSW Office of Water 2013)

The process for determining share components for floodplain harvesting access licences in unregulated water sources is different to the process for regulated water sources. The share component is based on whether an eligible application demonstrates that the area irrigated using water from a flood work is in addition to the area assessed during the volumetric conversion process for unregulated river access licences in the same water source. If the work is in addition to the original unregulated river access licence, then a new access licence may be issued and determined using the volumetric conversion process (NSW Office of Water 2013).

Figure 5 shows the designated Gwydir Valley floodplain, the management zones for the Floodplain Management Plan for the Gwydir Valley Floodplain 2016 and eligible floodplain harvesting properties. Eligibility of floodplain harvesting properties or works which may subsequently qualify to receive a floodplain harvesting access licence is specified in the policy. The criteria relate specifically to works capable of floodplain harvesting that, on or before 3 July 2008, were:

- constructed on a floodplain in accordance with an approval granted under Part 2 or Part 8 of the *Water Act 1912* or Part 3 of Chapter 3 of the *Water Management Act 2000*, or
- subject to a pending application for an approval to construct on a floodplain under Part 2 or Part 8 of the *Water Act 1912* or Part 3 of Chapter 3 of the *Water Management Act 2000*, or
- constructed on a floodplain and it can be proven that the work did not require an approval under Part 2 or Part 8 of the *Water Act 1912*.

Any existing work capable of floodplain harvesting that requires an approval and an application for an approval that was not made on or before 3 July 2008 is not eligible for a floodplain harvesting access licence. However, these flood works may be used for floodplain harvesting if they apply for and are granted an approval and can be linked to a relevant access licence that can account for the take of water from the work. In the Gwydir Valley floodplain, 135 of the 161 applications for floodplain harvesting access were deemed eligible (DPIE Water 2019a).

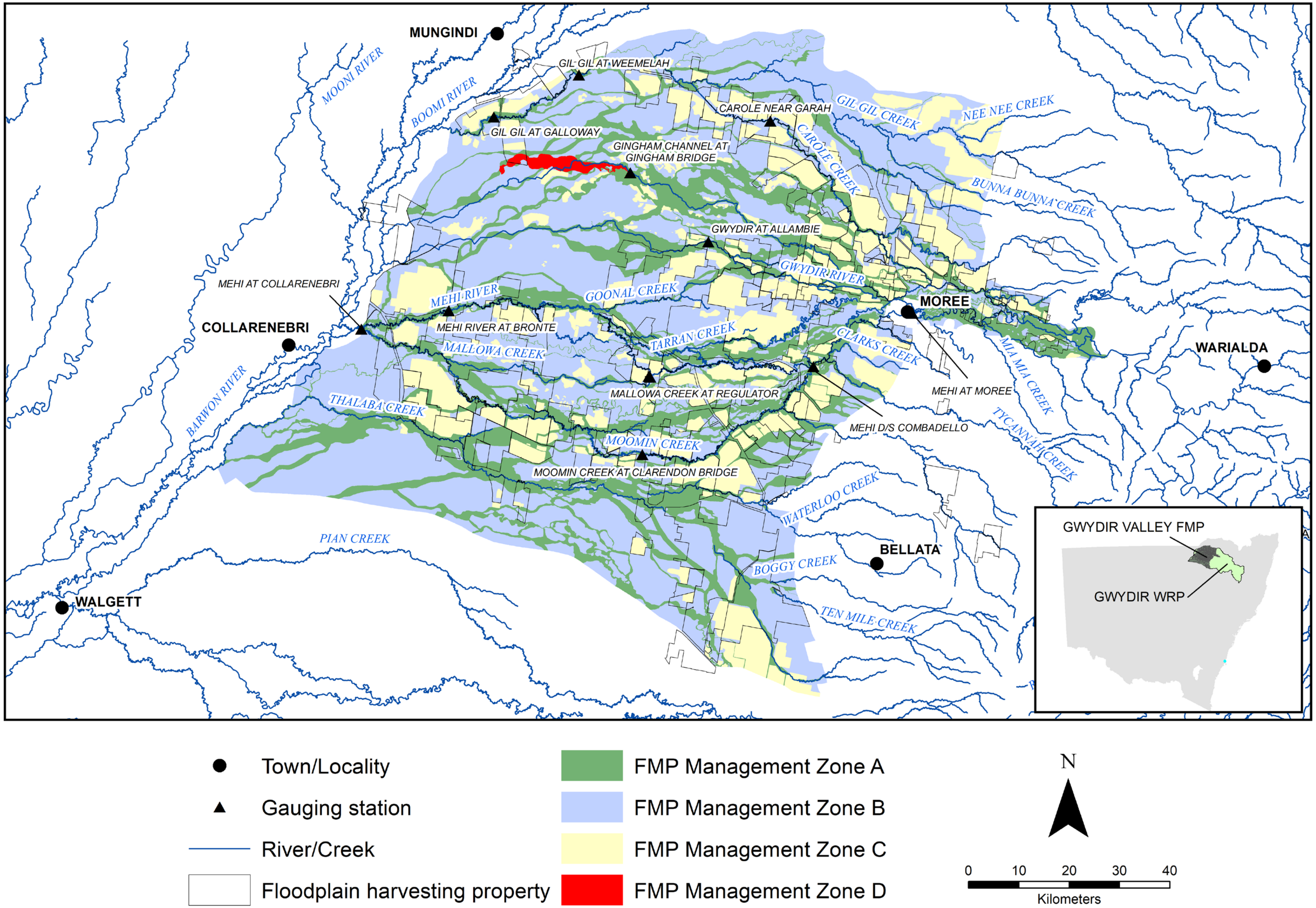

Figure 5 Map of floodplain management zones A, B, C and D as set out in the Gwydir Valley Floodplain Management Plan 2016. Only floodplain harvesting properties eligible for floodplain harvesting access licences are shown. FMP = Floodplain Management Plan

3 Environmental assets and values on the floodplain

3.1 Overview of known assets and values

The Gwydir Valley floodplain is characterised by flowing rivers and creeks, flood channels or flood runners, and wetlands. These wetlands include intermittently connected anabranches, lakes, lagoons, and billabongs which support an array of water-dependent environmental values. These include native fish, native vegetation, waterbirds, frogs, reptiles, macroinvertebrates, important ecosystem functions (e.g. productivity) and location (i.e. breakout zone) specific assets such as Ramsar and nationally important wetlands. A full list of known environmental values in the Gwydir Valley floodplain and key geographical assets is provided in Appendix A and summarised below.

3.1.1 Native fish

At least 15 native fish species are known to occur in the lower tributaries and floodplain of the Gwydir River (DPIE EES 2020a). This includes threatened species listed under federal legislation, like the Silver Perch (*Bidyanus bidyanus*) and Murray Cod (*Maccullochella peelii*) (*Environment Protection and Biodiversity Conservation Act 1989*), as well as the state-listed endangered Southern Purple Spotted Gudgeon (*Mogurnda adspersa*) and endangered populations of Olive Perchlet (*Ambassis agassizii*; Western Population) and Eel-tailed Catfish (*Tandanus*; Murray-Darling Basin) (*Fisheries Management Act 1994*). The floodplain also provides critical food resources, drought refuge sites and important habitat for native fish.

Figure 6 The western population of the Olive Perchlet (*Ambassis agassizii*) is predicted to benefit from improved floodplain flows in the Gwydir Valley. It is listed as an endangered population under the *Fisheries Management Act 1994* and is an example of a short-moderate lived floodplain specialist. [Photo: Gunther Schmida]

3.1.2 Waterbirds

Waterbirds are a group of highly mobile species that can respond to floods over large spatial scales. There are more than 75 species of waterbirds recorded or predicted to occur in the Gingham and Lower Gwydir Wetlands (DPIE EES 2020a) (such as the yellow-billed spoonbill shown in Figure 7). This represents 80% of all waterbird species found in Australia (Brandis et al. 2009). A number of these species are listed under the *NSW Biodiversity Act 2019* as vulnerable; like the magpie goose (*Anseranas semipalmata*), freckled duck (*Stictonetta naevosa*) and the endangered black-necked stork (*Ephippiorhynchus* asiaticus)). In addition to high waterbird species richness, the Gwydir Valley floodplain has a number of waterbird rookeries which are of regional and national significance for colonial-nesting waterbirds (Spencer et al. 2010).

Figure 7 The magnificent yellow-billed spoonbill has been recorded on the Gwydir Valley floodplain and is a common colonial-nesting waterbird in south east Australia [Photo: Patrick Kavanagh]

3.1.3 Native vegetation

Several floodplain vegetation species can be considered functionally important and it is highly likely that by meeting the water requirements of these key species, other vegetation species will benefit (Casanova 2015). The key water-dependent vegetation species include river red gum (*Eucalyptus camaldulensis*), coolabah (*Eucalyptus coolabah*), black box (*Eucalyptus largiflorens*), lignum (*Muehlenbeckia florulenta*), river cooba (*Acacia stenophylla*) and non-woody wetland vegetation such as marsh club-rush (*Bolboschoenus fluviatilis*). The Gwydir Wetlands have one of the largest known stands of marsh club-rush, which is a key species of the marsh club-rush sedgeland, listed as a Critically Endangered Ecological Community under the *NSW Biodiversity Conservation Act 2016* and floodplain harvesting is noted as a threat to this community.

3.1.4 Amphibians and reptiles

The Gwydir Valley floodplain provides habitat for other flood dependent fauna including frogs, turtles, and amphibious reptiles (Appendix A). There are at least 12 species of frogs that are known to occur in the Gwydir Valley floodplain, 6 of these are flood dependent species, including the eastern sign-bearing froglet (*Crinia parinsignifera*), barking marsh frog (*Limnodynastes fletcheri*) and salmon striped frog (*Limnodynastes salmini*) (DPIE EES 2020a). Water-dependent reptiles include the Australian water dragon (*Intellagama lesueurii*) and three species of freshwater turtle.

3.1.5 Important ecosystem functions

A variety of ecosystem functions are linked to floodplain inundation. One of the key functions supported by overbank flood events is increased productivity for the floodplain and the connected riverine environment (McGinness and Arthur 2011). The Gwydir Wetlands on the floodplain of the lower Gwydir River contains extensive anabranches and billabongs. Anabranches and billabongs can provide large amounts of organic carbon and other nutrients during flood events which are essential to supporting aquatic ecosystem functions and stimulating productivity (CSIRO 2007). Four important ecological flow corridors are present, including the Five Mile lagoon, lower Gwydir and Gingham, Yarraman and Mallowa ecological flow corridors. These corridors provide a number of critical ecosystem functions such as dispersal pathways for biological processes (e.g. by supporting increases in their food sources, increased productivity can be linked to increased populations of larger organisms like fish (Wootton and Power 1993)).

3.1.6 Wetlands

The Gwydir Wetlands are listed as wetlands of international importance under the Ramsar convention 1999 and are considered one of the significant semi-permanent inland wetlands in northern NSW (Keyte 1994). The Gwydir Wetlands incorporates the Gwydir Wetlands State Conservation Area (SCA) and the 4 Ramsar listed subsites west of Moree within the Gingham Watercourse and Lower Gwydir areas. The subsites are: Old Dromana, Goddard's Lease, Crinolyn and Windella (Department of Agriculture, Water, and the Environment 2020). The Gwydir Wetlands is the remaining part of a larger wetland system which once covered more than 200,000 hectares but now covers only 823 hectares (DPIE EES 2020a). Diverse vegetation and waterbird communities are just some important features of these wetlands. Other significant lagoons and wetlands have been identified in Schedule 4 of the Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012. These wetlands support a wide range of aquatic species through the provision of aquatic habitats and drought refugia.

3.2 Identifying assets and values in floodplain harvesting areas

Not all environmental values are predicted or known to occur in all areas of the floodplain. Some, such as small-bodied fish, can be restricted to wetlands and refugia. Others, like the river red gum, are widespread. To ensure high confidence in predicted ecological outcomes, only water-dependent environmental values previously recorded, predicted or known to occur near locations where floodplain harvesting occurs were used in the assessment of environmental benefits. This provides greater confidence when predicting the environmental impacts of implementing the policy as changes to floodplain hydrology can be linked to a breakout zone with the predicted ecological responses of assets in that breakout zone. Whilst predicting broad scale benefits for the entire floodplain and downstream water sources has a lower confidence due to the hydrological data available (discussed further in Section 4), broad scale outcomes will be explored where feasible.

The approach adopted to identify these values and assets in the Gwydir Valley floodplain is summarised in Figure 8 and the following sub-sections.

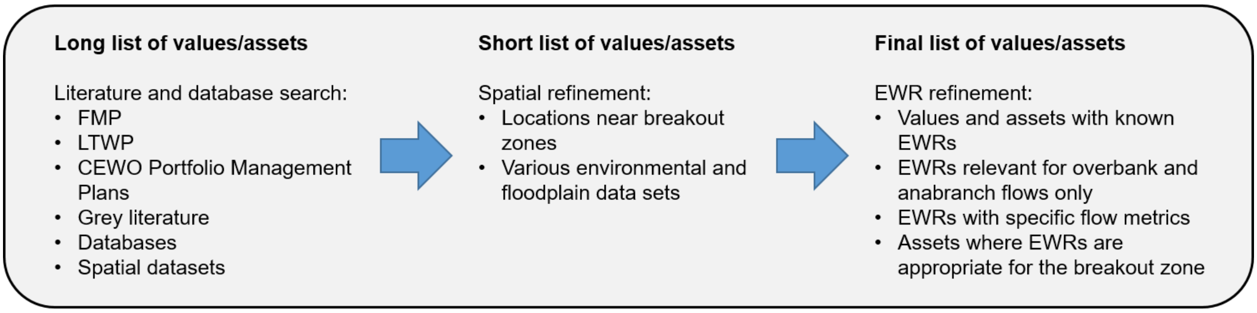

Figure 8 Summary of the approach adopted to identify water-dependent environmental values and assets in floodplain harvesting areas. FMP = Floodplain Management Plan, LTWP = Long-term water plans, CEWO = Commonwealth Environmental Water Office, EWR = environmental water requirement

3.2.1 Literature and database search

A literature and database search was undertaken to identify water-dependent environmental values and assets in the Gwydir Floodplain. These include species, populations, communities, ecosystem functions and specific locations (e.g. wetlands) known to support key environmental values and assets. This generated a 'long list' of values and assets.

Key literature included:

- Background document to the Floodplain Management Plan for the Gwydir Valley floodplain (DPI Water 2015)
- Gwydir Long-Term Water Plan (DPIE EES 2020a, 2020b)
- Commonwealth Environmental Water Portfolio Management Plan (CEWO 2019)
- Risk Assessment for the Gwydir Water Resource Plan Area (DPIE Water 2019b)
- peer-reviewed literature.

Environmental values (which could include species, populations, communities, ecosystem functions) or assets which are breakout zones, such as wetlands, were selected from the literature if they met the following 3 criteria:

- water-dependent environmental assets or values
- listed as dependent on high flows (i.e. floods) or as benefiting from high flows
- recorded or predicted to occur within the Gwydir Floodplain Management Plan boundary.

3.2.2 Spatial refinement

The next step involved identifying which environmental values and assets occurred within a defined spatial area near the IQQM river system model 'breakout zones'[2] developed by the Department of Planning, Industry and Environment Water (the department). The river system models are the key source for predicting hydrological changes on the floodplain before and after implementing the policy. An overview of the river system model is provided in Chapter 4, with more detail in Appendix D and fully described in (DPIE Water 2021a).

Breakout zones are areas of the floodplain where floodwaters break out onto the floodplain and where floodplain harvesting properties access water on the floodplain (Figure 9). They are often a summary of multiple model nodes where floodplain harvesting properties are accessing water from the floodplain. This could be from a variety of flood runners, anabranches, and direct take from the river channel. The end of system (EOS) floodplain breakout represents the location where most of the changes to floodplain hydrology can be detected within the hydrological models developed by the department.

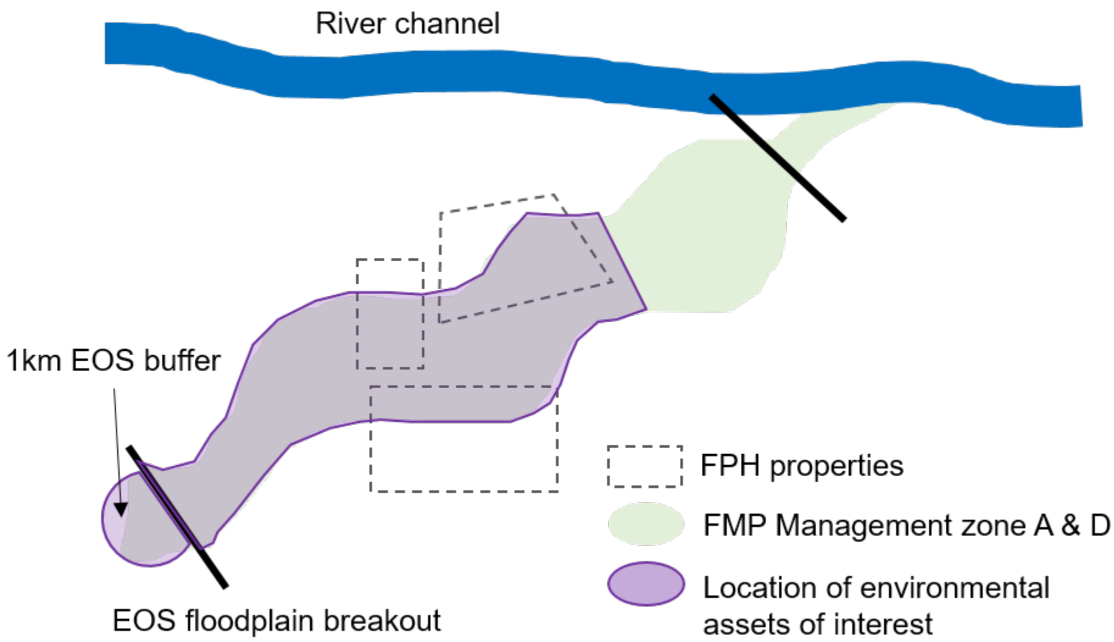

Figure 9 Illustrated depiction of a 'breakout zone'. Breakout zones represent areas where flood waters break out from the river channel onto the floodplain and floodplain harvesting occurs

[2] Refer to Appendix D of *Building the Gwydir Valley river system model* (DPIE Water 2021a) for a description of the derivation of these breakout zones.

The upstream and downstream area was restricted by a defined spatial area between the most upstream eligible floodplain harvesting property and a 1km radius below the end of system floodplain breakout or floodplain harvesting property (which ever was further downstream) in the hydrological model (Figure 9). Breakout zones provide a higher degree of confidence that any modelled changes to overbank flows can be attributed to the asset (i.e. will affect the flow regime at the asset). The Gwydir Valley floodplain was split into 8 breakout zones.

The breakout zone, or area of interest, was then further refined[3] to select environmental assets and values which occurred within ecologically important Gwydir Valley Floodplain Management Plan (FMP) management zones. FMP Zone A signifies a major flood discharge zone and is of significant importance to floodplain assets. FMP Zone D is an environmentally sensitive area providing critical refugia and supporting areas of environmental significance such as swamps, billabongs, rocky bars or warrambools[4]. Both zones also support areas of significant cultural importance (DPI Water 2015). Assets that fell within Zone A or Zone D within each breakout zone were short-listed for assessment, refining the number of environmental assets. Figure 10 summarises the spatial and EWR refinement process.

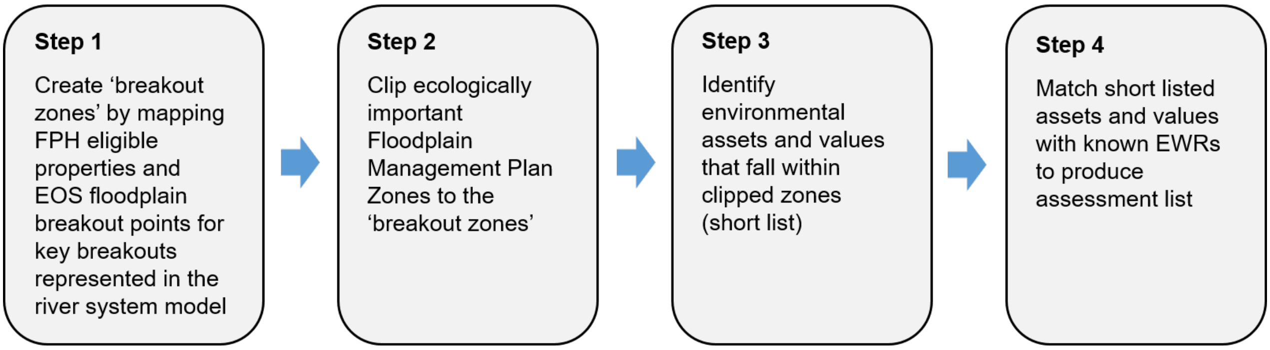

Figure 10 The spatial and EWR refinement process to select environmental assets and values for assessment

Important assets and values most likely also occur in the other Floodplain Management Plan zones and downstream of the breakout zones. However, refinement to the selected areas (i.e. breakout zones) provides a higher level of confidence in the predicted outcomes. This is because there are uncertainties around return flows and inundation extents not included in the river system models. This translates to uncertainties in the longitudinal and lateral distance that the specific modelled outcomes would extend.

3.2.3 Environmental Water Requirement refinement

The last step (Step 4 in Figure 10) was to identify environmental assets and values on the short list with known and measurable EWRs documented in the literature. Understanding the EWRs of specific values is crucial, as the final assessment approach relies on deriving an ecological interpretation by comparing changes in hydrology after implementation of the policy. The EWRs provide the hydrological metrics of interest (e.g. duration, frequency, and timing) for specific assets and allow a comparison of how implementing the policy could influence the frequency of achieving these EWRs.

Refining the list based on environmental assets and values with known EWRs provided a robust approach for predicting the environmental outcomes of implementing the policy (Section 5). As not all water-dependent vegetation species have detailed information on the frequency, duration and timing requirements to maintain, reproduce or regenerate, the 'Umbrella Environmental Value' approach was adopted to select key assets from each environmental asset category (described below). This approach was used by Swirepik et al. (2016) to develop river reach-specific EWRs

[3] ArcGIS (10.3.1) computer-based mapping and analytics software was used for this task

[4] A warrambool is local language, meaning (in this context) a water overflow channel.

across the Murray-Darling Basin. It recognises that providing water for values with detailed EWR information (e.g. river red gum) should reflect the needs of a broader set of assets and values in the area. The detailed environmental water requirements for the Gwydir Valley floodplain are provided in Appendix C .

3.3 Final list of environmental assets and values

In deriving the final list, the goal was to identify key breakout zones on the floodplain:

- that are of high environmental value, and
- that are predicted to be affected by changes in overbank flows, and
- where there is a high confidence that the river system model could be used to predict changed hydrological regimes which impact EWRs.

High level descriptions for assets and values were identified (Table 1) and used to describe the final list of assets and values to be assessed in each of the 8 breakout zones on the floodplain (listed in Table 2). These occur from upstream of Moree to Collarenebri in the south west and near Mungindi in the north west. They support a suite of environmental assets and values including threatened plants, animals, communities, wetlands, and functions. The critical components of each asset's EWRs are detailed in Appendix C .

Table 1 Categories of values and assets used for final assessment

Category	Description
Value – native fish	Native fish dependent on or gaining significant benefits from floodplains or overbank flows including predicted occurrence of threatened species
Value – native vegetation	Plant Community Types (PCTs) and important plant species
Value– waterbirds	Predicted distributions, recorded, and known observations of a variety of waterbirds including species listed as threatened and in international migratory waterbird agreements
Value – important ecosystem functions	Primary production and nutrient supply are supported by high flow events
Value – flow-dependent frogs	Threatened or important native frogs dependent on or gaining significant benefits from floodplains or overbank flows including predicted occurrence
Asset – wetlands	A range of lagoons, billabongs and waterholes known to provide important habitat and refuge for a variety of water-dependent communities

Table 2 Final list of water-dependent floodplain assets and values and their characterisation for each breakout zone. Key breakout points are the river system model nodes. V = Vulnerable, E = Endangered, C = CAMBA, J = JAMBA, K = ROKAMBA. [1]NSW Biodiversity Conservation Act 2016, [2]listed on the *EPBC Act*, [3]listed in the *Fisheries Management Act (1994)*

Breakout	Key breakout points	Asset/Value	Characterisation
(A) Deadman/Biniguy	<u>EOS to Floodplain:</u> Biniguy, Deadman Ck	Native fish	**Recorded:** Murray River Rainbowfish, Australian Smelt, Spangled Perch, Unspecked Hardyhead, Western Carp Gudgeon, Eel-tailed Catfish – MDB population (E)[3], Firetail Gudgeon, Golden Perch, Midgleys Carp Gudgeon, Murray Cod (V)[2], Carp Gudgeon, Bony Bream **Predicted:** Silver Perch (V)[2], Olive Perchlet – Western population (E)[3]

Breakout	Key breakout points	Asset/Value	Characterisation
		Waterbirds	**Colonial-nesting:** little black cormorant, little pied cormorant, white-faced heron, Australasian darter, Australian pelican, intermediate egret **Non-colonial:** Australian wood duck, dusky moorhen, grey teal, Pacific black duck
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, river cooba, river red gum
		Frogs	**Recorded**: broad-palmed frog
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	No wetlands
(B) Marshall EOS to Floodplain	Redbank, Marshall Ponds Ck, Wallon and Bunna Bunna	Native fish	**Recorded:** Murray River Rainbowfish, Australian Smelt, Spangled Perch, Unspecked Hardyhead, Western Carp Gudgeon, Eel-tailed Catfish – MDB population (E)[3], Firetail Gudgeon, Golden Perch, Midgleys Carp Gudgeon, Murray Cod (V)[2], Carp Gudgeon, Bony Bream **Predicted:** Silver Perch (V)[2], Olive Perchlet – Western population (E)[3]
		Waterbirds	**Colonial-nesting:** Australian white ibis, eastern great egret, great cormorant, little egret, little black cormorant, little pied cormorant, royal spoonbill, straw-necked ibis, white-faced heron, white-necked heron, yellow-billed spoonbill, Australasian darter, Australian pelican, intermediate egret, pied cormorant **Non-colonial:** Australian wood duck, black swan, black-fronted dotterel, black-winged stilt, Eurasian coot, great crested grebe, grey teal, hardhead, hoary-headed grebe, masked lapwing, musk duck, Pacific black duck, pink-eared duck, red-kneed dotterel, whiskered tern **Predicted:** Australian painted snipe (E)[1,2,4]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, river cooba, river red gum, water couch
		Frogs	**Recorded:** broad-palmed frog, **Predicted:** Sloane's froglet
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	No wetlands
(C) Carole/Gil Gil Creek EOS to Floodplain:	Carole, Midkin (Carole), Gil Gil, near Garah (Carole)	Native fish	**Recorded:** Murray River Rainbowfish, Australian Smelt, Spangled Perch, Unspecked Hardyhead, Western Carp Gudgeon, Eel-tailed Catfish – MDB population (E)[3], Firetail Gudgeon, Golden Perch, Midgleys Carp Gudgeon, Carp Gudgeon, Bony Bream **Predicted:** Eel-tailed Catfish – MDB population (E)[3]

Breakout	Key breakout points	Asset/Value	Characterisation
		Waterbirds	**Colonial-nesting:** Australian white ibis, eastern great egret, glossy ibis, great cormorant, little egret, little black cormorant, little pied cormorant, royal spoonbill, straw-necked ibis, white-faced heron, white-necked heron, yellow-billed spoonbill, Australasian darter, Australian pelican, intermediate egret, pied cormorant **Non-colonial:** Australasian grebe, Australasian shoveler, Australian wood duck, black swan, black-fronted dotterel, black-necked stork (E)[1], black-winged stilt, blue-billed duck (V)[1], Eurasian coot, great crested grebe, grey teal, hardhead, hoary-headed grebe, masked lapwing, musk duck, nankeen kestrel, Pacific black duck, pink-eared duck, plumed whistling-duck, red-kneed dotterel, whiskered tern **Predicted:** magpie goose (V)[1], freckled duck (V)[1], brolga (V)[1], Australian painted snipe (E)[1,2,4]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, river cooba, water couch
		Frogs	**Predicted:** Sloane's froglet
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	No wetlands
(D) Gil Gil/Carole Creek EOS to Floodplain:	Gil Gil-Carole junction, Weemalah, Carwal Ck	Native fish	**Recorded:** Spangled Perch, Golden Perch, Carp Gudgeon, Bony Bream **Predicted:** Eel-tailed Catfish – MDB population (E)[3], Australian Smelt, Murray Cod (V)[2], Southern Purple Spotted Gudgeon (E)[3], Silver Perch (V)[2], Murray River Rainbowfish
		Waterbirds	Waterbird rookery site **Colonial-nesting:** eastern great egret, white-faced heron **Non-colonial:** Australian wood duck, Pacific black duck **Predicted**: magpie goose (V)[1]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, black box, river cooba, water couch
		Frogs	Eastern sign-bearing froglet
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	No wetlands
(E) Gwydir/ Gingham	EOS to Floodplain: Millewa and Eureka, Moree (Cooma), Ridgewood, Norwood (D/S Tyreel Weir), Yarraman, Gwydir (Eureka), Tyreel Farm, Gingham, Brageen Crossing, Allambie	Native fish	**Recorded:** Murray River Rainbowfish, Australian Smelt, Spangled Perch, Unspecked Hardyhead, Western Carp Gudgeon, Eel-tailed Catfish – MDB population (E)[3], Firetail Gudgeon, Golden Perch, Midgleys Carp Gudgeon, Murray Cod (V)[2], Carp Gudgeon, Bony Bream **Predicted:** Eel-tailed Catfish – MDB population (E)[3], Silver Perch (V)[2], Olive Perchlet – Western population (E)[3], Southern Purple Spotted Gudgeon (E)[3]

Breakout	Key breakout points	Asset/Value	Characterisation
		Waterbirds	Waterbird rookery site **Colonial-nesting:** Australian white ibis, eastern great egret, little black cormorant, little egret, nankeen night heron, royal spoonbill, straw-necked ibis, white-faced heron, white-necked heron, yellow-billed spoonbill, Australasian darter, Australian pelican, glossy ibis, great cormorant, intermediate egret, little pied cormorant **Non-colonial:** Australasian Bittern (E)[1], Australasian grebe, Australasian shoveler, Australian bustard (E)[1], Australian painted snipe (E)[1,2,4], Australian pratincole, Australian spotted crake, Australian wood duck, banded lapwing, , black swan, black-fronted dotterel, black-necked stork (E)[1], black-tailed native-hen, black-winged stilt, brolga (V)[1], Bush stone-curlew (E)[1], Caspian tern (J)[4], chestnut teal, common greenshank (C,J,K)[4], dusky moorhen, Eurasian coot, freckled duck (V)[1], great crested grebe, grey teal, Australian gull-billed tern, hardhead, hoary-headed grebe, Latham's snipe (J,K), magpie goose (V)[1], marsh sandpiper (C,J,K)[4], masked lapwing, musk duck, Pacific black duck, pink-eared duck, plumed whistling-duck, purple swamphen, red-capped plover, red-kneed dotterel, red-necked avocet, sharp-tailed sandpiper (C,J,K)[4], whiskered tern **Predicted:** blue-billed duck (V)[1]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, river cooba, river red gum, water couch, cumbungi, marsh club-rush
		Frogs	**Recorded:** barking frog, **Predicted:** Sloane's froglet
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	Gwydir Wetlands State Conservation Area (SCA), Old Dromana, Goddard's Lease Ramsar subsites. Crinolyn and Windella Ramsar subsites are located downstream of this breakout and would be impacted by changes reported from the assessment of outcomes from this breakout

Breakout	Key breakout points	Asset/Value	Characterisation
(F) Mehi EOS to Floodplain: Mallowa, Moree, Coombah (Mallowa),	Moree (various), D/S Ballinboora (Meh4), D/S Ballinboora (Meh5), Moomin (Taroo)	Native fish	**Recorded:** Murray River Rainbowfish, Silver Perch (V)[2], Australian Smelt, Spangled Perch, Western Carp Gudgeon, Eel-tailed Catfish – MDB population (E)[3], Firetail Gudgeon, Golden Perch, Murray Cod (V)[2], Carp Gudgeon, Bony Bream **Predicted:** Silver Perch (V)[2], Eel-tailed Catfish – MDB population (E)[3], Olive Perchlet – Western population (E)[3], Southern Purple Spotted Gudgeon (E)[3]
		Waterbirds	**Colonial-nesting:** Australian white ibis, cattle egret, eastern great egret, great cormorant, little black cormorant, little egret, little pied cormorant, nankeen night heron, royal spoonbill, straw-necked ibis, white-faced heron, white-necked heron, yellow-billed spoonbill, Australasian darter, Australian pelican, intermediate egret, pied cormorant **Non-colonial:** Australasian grebe, Australian bustard (E)[1], Australian pratincole, Australian wood duck, banded lapwing, , black swan, black-fronted dotterel, black-necked stork (E)[1], black-tailed native-hen, black-winged stilt, blue-billed duck (V)[1] , brolga (V)[1], buff-banded rail, Bush stone-curlew (E)[1], Caspian tern (J)[4], chestnut teal, common greenshank (C,J,K)[4], dusky moorhen, Eurasian coot, freckled duck (V)[1], great crested grebe, grey falcon (E)[1], grey teal, Australian gull-billed tern, hardhead, hoary-headed grebe, Latham's snipe (J,K), masked lapwing, Pacific black duck, pink-eared duck, plumed whistling-duck, purple swamphen, red-kneed dotterel, red-necked avocet **Predicted:** magpie goose (V)[1], Australian painted snipe (E)[1,2,4]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, black box, river cooba, river red gum
		Frogs	**Recorded:** barking frog, **Predicted:** Sloane's froglet
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	No wetlands
(G) Moomin Creek EOS to Floodplain:	Wologimba Ck, Glendello (Moomin), Clarendon (Moomin), Alma (Moomin), from Gurley Ck	Native fish	**Recorded:** Australian Smelt, Murray River Rainbowfish, Australian Smelt, Spangled Perch, Golden Perch, Murray Cod (V)[2], Carp Gudgeon, Bony Bream **Predicted:** Eel-tailed Catfish – MDB population (E)[3], Silver Perch (V)[2], Olive Perchlet – Western population (E)[3], Southern Purple Spotted Gudgeon (E)[3]
		Waterbirds	**Colonial-nesting:** eastern great egret, little pied cormorant, nankeen night heron, straw-necked ibis, white-faced heron, white-necked heron, yellow-billed spoonbill, Australasian darter, pied cormorant **Non-colonial:** Australasian grebe, Australian wood duck, black-tailed native-hen, hoary-headed grebe, grey teal, Pacific black duck **Predicted:** magpie goose (V)[1], freckled duck (V)[1], brolga (V)[1], blue-billed duck (V)[1], Australian painted snipe (E)[1,2,4]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, river cooba, river red gum, marsh club-rush, water couch

Breakout	Key breakout points	Asset/Value	Characterisation
		Frogs	**Predicted:** Sloane's froglet
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	Mallowa wetlands, Mongyer lagoon, Collytootela lagoon
(H) Thalaba EOS to Floodplain:	Thalaba Ck	Native fish	**Recorded:** Spangled Perch, Golden Perch **Predicted:** Silver Perch (V)[2], Olive Perchlet – Western population (E)[3], Southern Purple Spotted Gudgeon (E)[3]
		Waterbirds	**Colonial-nesting:** little pied cormorant, nankeen night heron, white-faced heron **Non-colonial:** Australian wood duck, plumed whistling-duck **Predicted**: magpie goose (V)[1], freckled duck (V)[1], brolga (V)[1], blue-billed duck (V)[1], Australian painted snipe (E)[1,2,4]
		Native vegetation	Lignum woodland, lignum shrubland, coolabah, river cooba, river red gum, water couch
		Frogs and Reptiles	**Recorded:** barking frog, eastern sign-bearing froglet, **Predicted:** Sloane's froglet
		Important ecological functions	Nutrient, carbon, and primary production
		Wetlands	Mongyer lagoon, Collytootela lagoon

Figure 11 depicts the locations of breakout zones, eligible floodplain harvesting properties and hydrological gauges. Figure 12 to Figure 16 provide fine scale maps of key water-dependent environmental assets and values in each breakout zone. Note, not all data were able to be represented on these maps as many spatial layers overlay each other. Key water-dependent plant community types were the main focus for these maps.

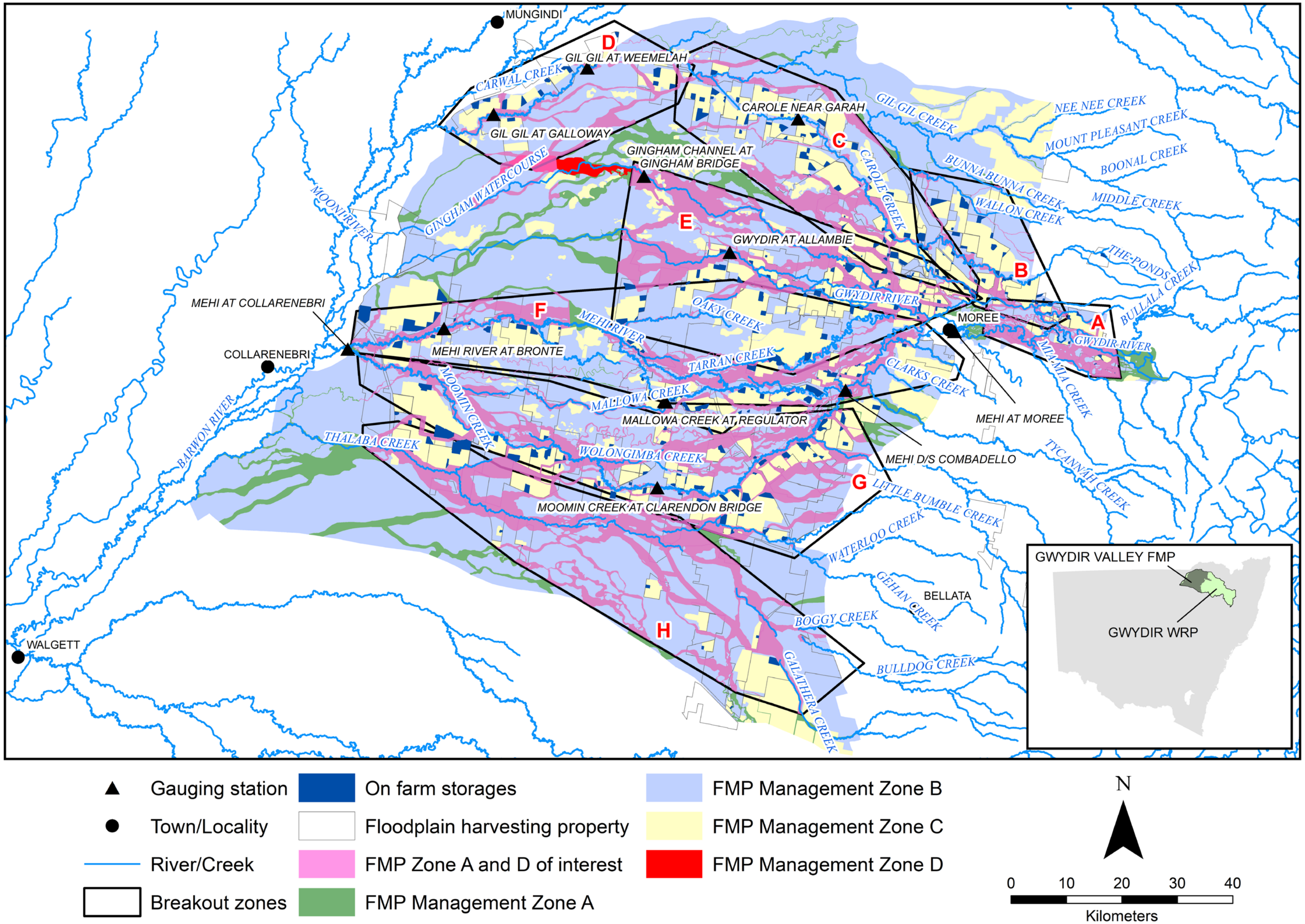

Figure 11 Map of the Gwydir Valley floodplain showing the Floodplain Management Plan (FMP) zones and the FMP zones of interest used to select environmental assets and values for inclusion in this assessment. Breakout zones are: A Deadman/Biniguy, B Marshall, C Carole/Gil Gil, D Gil Gil/Carole, E Gwydir/Gingham, F Mehi, G Moomin Creek, H Thalaba

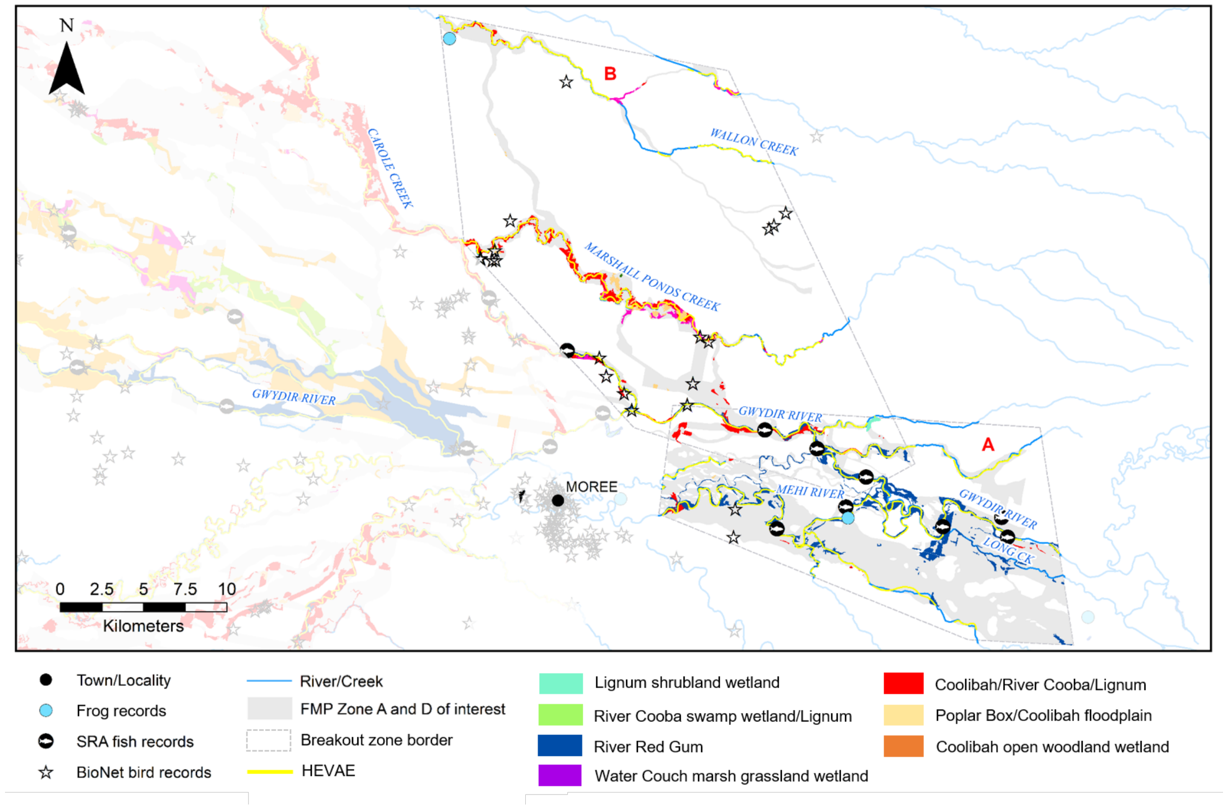

Figure 12 Location of key water-dependent environmental assets and values at breakout zones A Deadman/Biniguy and B Marshall. Appendix B details data sources not able to be presented

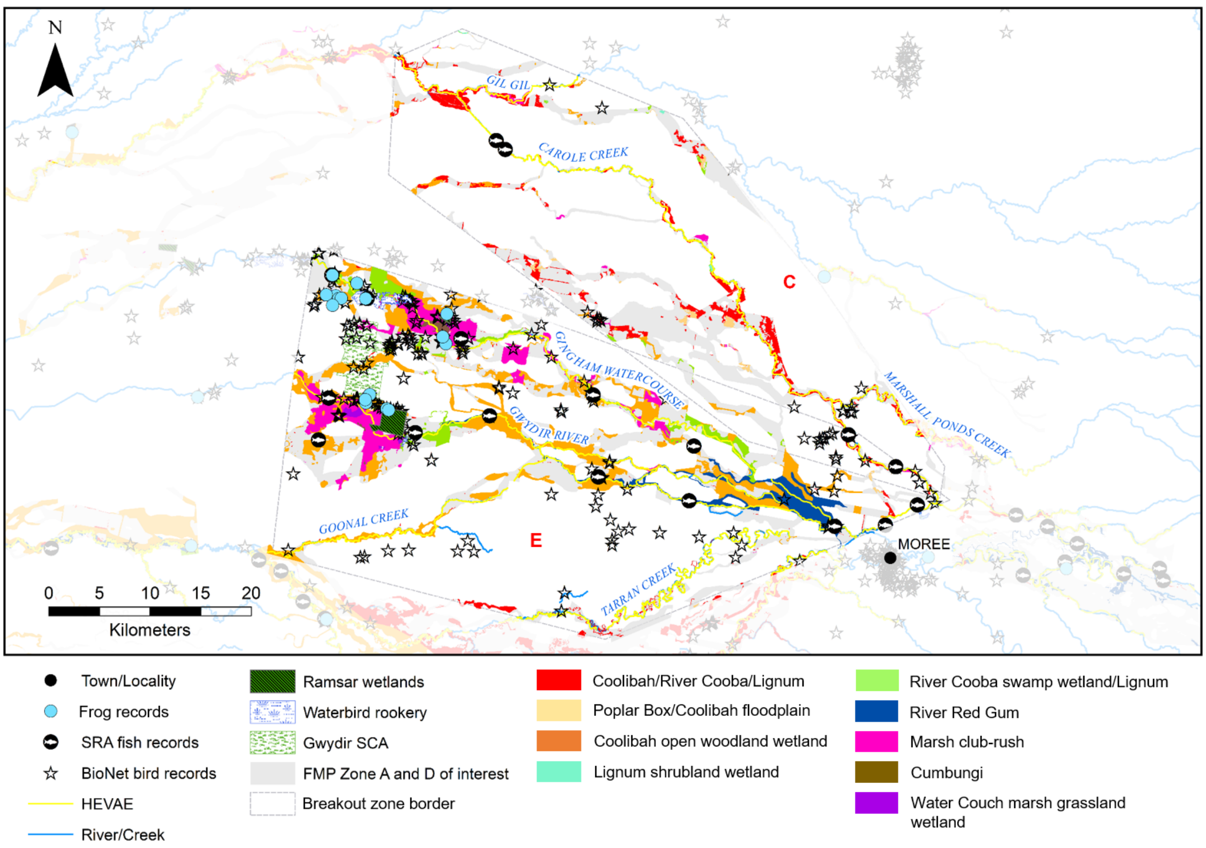

Figure 13 Location of key water-dependent environmental assets and values at breakout zones C Carole/Gil Gil and E Gwydir/Gingham. Appendix B details data sources not able to be presented

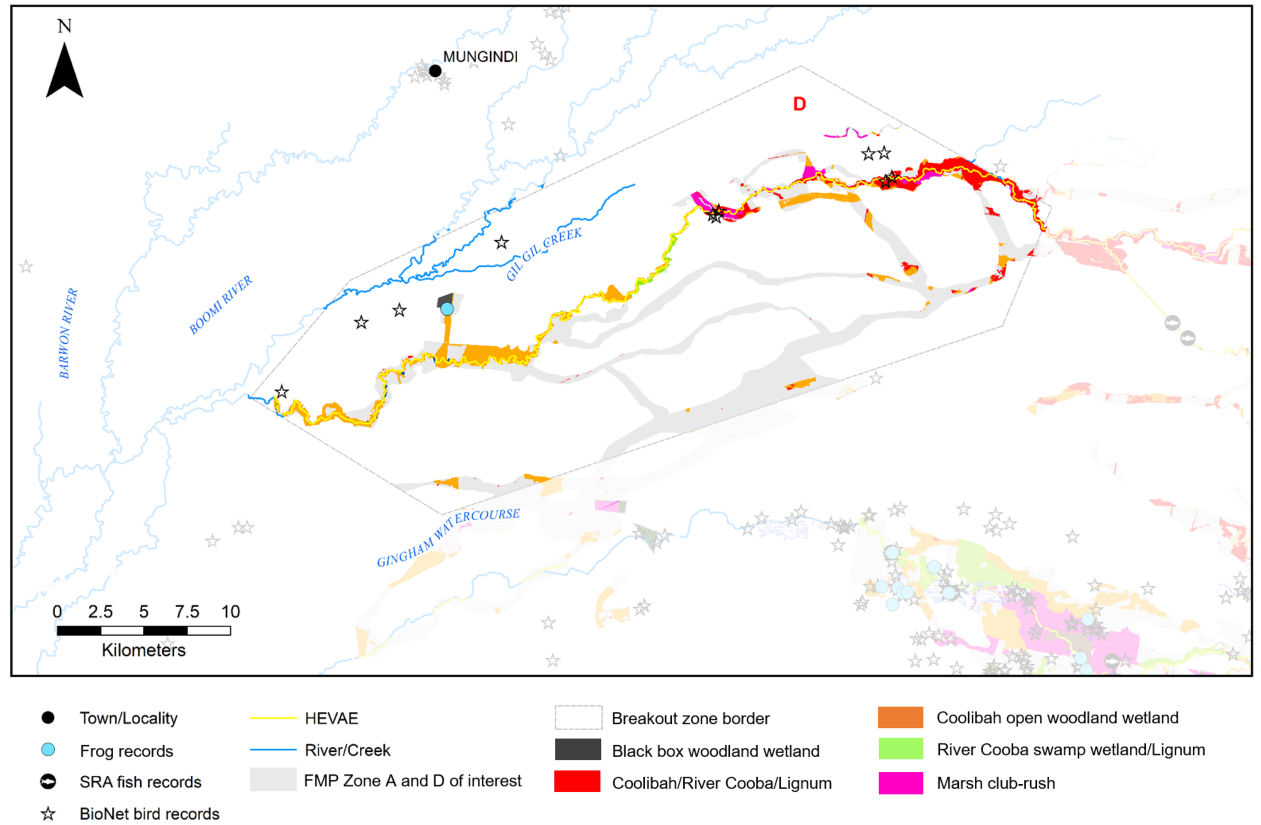

Figure 14 Location of key water-dependent environmental assets and values at breakout zone D Gil Gil/Carole. Appendix B details data sources not able to be presented

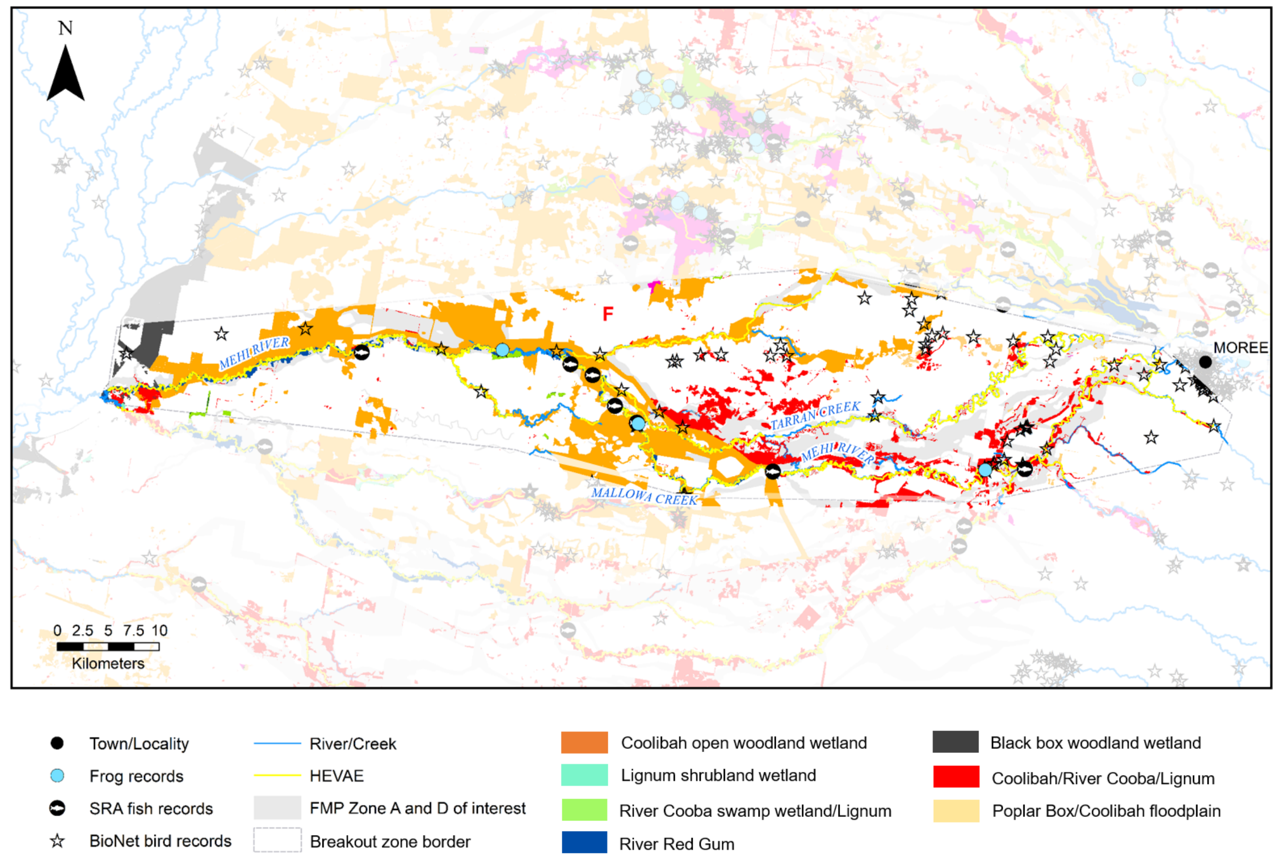

Figure 15 Location of key water-dependent environmental assets and values at breakout zone F Mehi. Appendix B details data sources not able to be presented

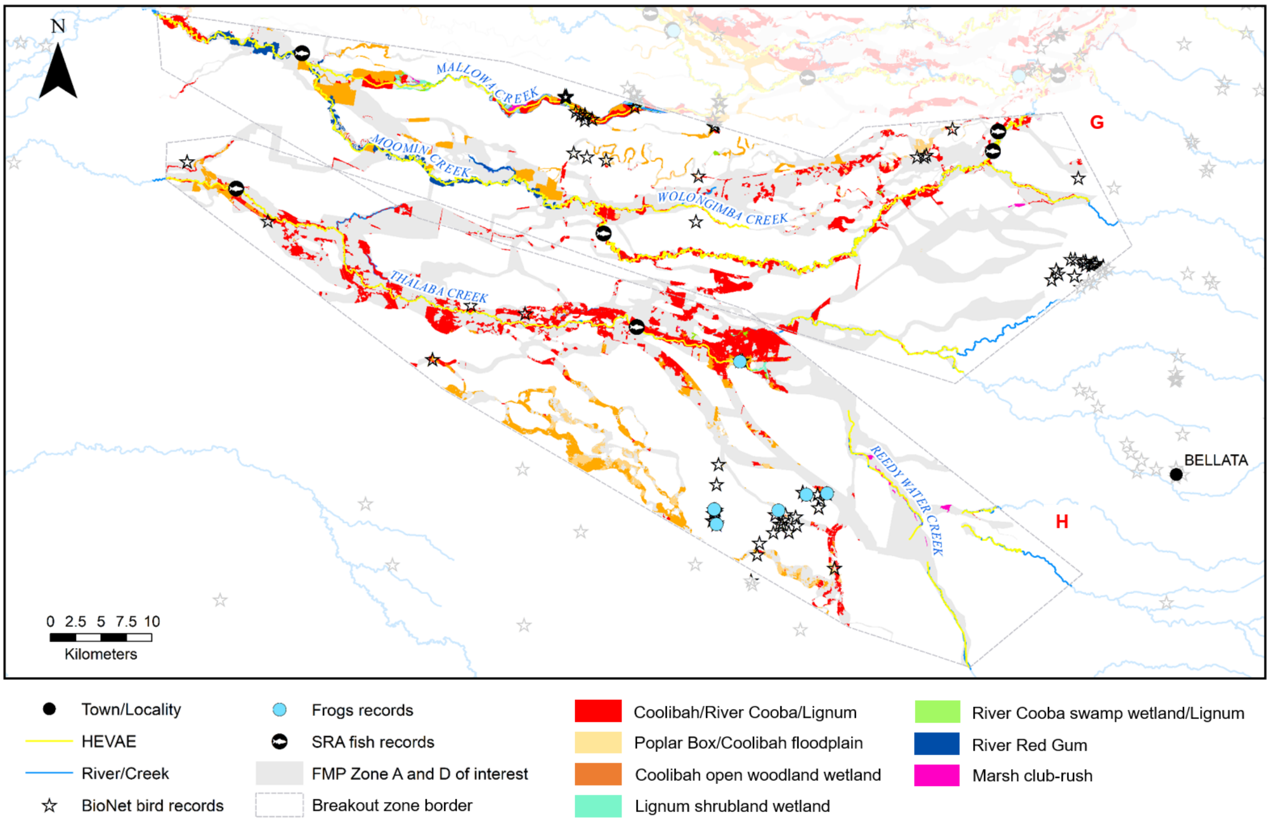

Figure 16 Location of key water-dependent environmental assets and values at breakout zones G Moomin Creek and H Thalaba. Appendix B details data sources not able to be presented

4 Hydrological changes on the floodplain

4.1 River system model overview

Implementation of the policy has increased investment in data and modelling to quantify floodplain harvesting more accurately. This section provides a broad overview of the river system models developed by the department. Further information can be found for each model in the 'Model Build reports' for each Valley (e.g. *Building the Gwydir Valley river system model* (DPIE Water 2021a)).

River system models have been used for many decades to determine water availability, flows and diversions under varying climate conditions. They serve as a critical step in informing the development of water sharing arrangements. The Gwydir Valley river system model is designed to support contemporary water management decisions in the Gwydir Valley regulated river system, whether it is a rule change in the water sharing plan, or estimating long term average water balances for components such as diversions for compliance purposes. These models have two overarching objectives:

- to support traditional water policy, planning and compliance uses, such as implementing the Basin Plan (the plan) and estimating plan limits
- to determine volumetric entitlements for floodplain harvesting consistent with the policy.

4.1.1 Modelling platform

The Gwydir Valley river system model is built using the IQQM software platform. IQQM simulates flows through a system. These flows can be water, sediment, contaminants, water accounts or water trade. It provides sufficient functionality to simulate the process of water moving out onto floodplains. IQQM models simulate a system by defining components and adding links and nodes till the system to be modelled is adequately represented. The added links and nodes define different actions. Nodes are added to represent locations where water can be added, diverted, stored, and recorded (for reporting). Specifically, nodes can include:

- water sources (supply), such as inflows, storages
- water users (demand), such as crops, towns, industries, the environment
- reporting points, such as gauges and environmental assets.

Links connect, store and route water passing between nodes.

4.1.2 Parameterisation

Each component of the model can be configured to reasonably represent the river system, a process known as parameterisation (DPIE Water 2021a). Parameters can be assigned directly from the data source or refined through calibration against recorded data to improve the model performance. Parameter values are estimated using one or a mix of the following methods:

- assigned directly, based on measured data, such as survey or remotely sensed data of on-farm storages
- assigned based on published advice from industry or research
- calibrated by systematically adjusting to match recorded data at the site or of system behaviours – this method iteratively checks how well model outputs match recorded data and parameters are adjusted to improve performance.

4.1.3 Modelling approach

The river system model uses a water balance approach that ensures that all flows (in, out and stored) balance over a given time step (e.g. days, years etc) and at three spatial scales (farm, reach and river system). Figure 17 shows the key components of a reach water balance. The Environmental Outcomes reports primarily rely on the component of breakout flow remaining on the floodplain after it breaks out onto the floodplain and is accessed by floodplain harvesting.

Model calibration is conducted on a river reach scale using available recorded data. Once river reach water balances are developed, they are combined to represent the entire river system. The model is then validated using a suite of tests to evaluate how well the model performs against observed data over the period of calibration. The Gwydir Valley river system model was validated between the period 01/07/2004 to 30/06/2013 (DPIE Water 2021a).

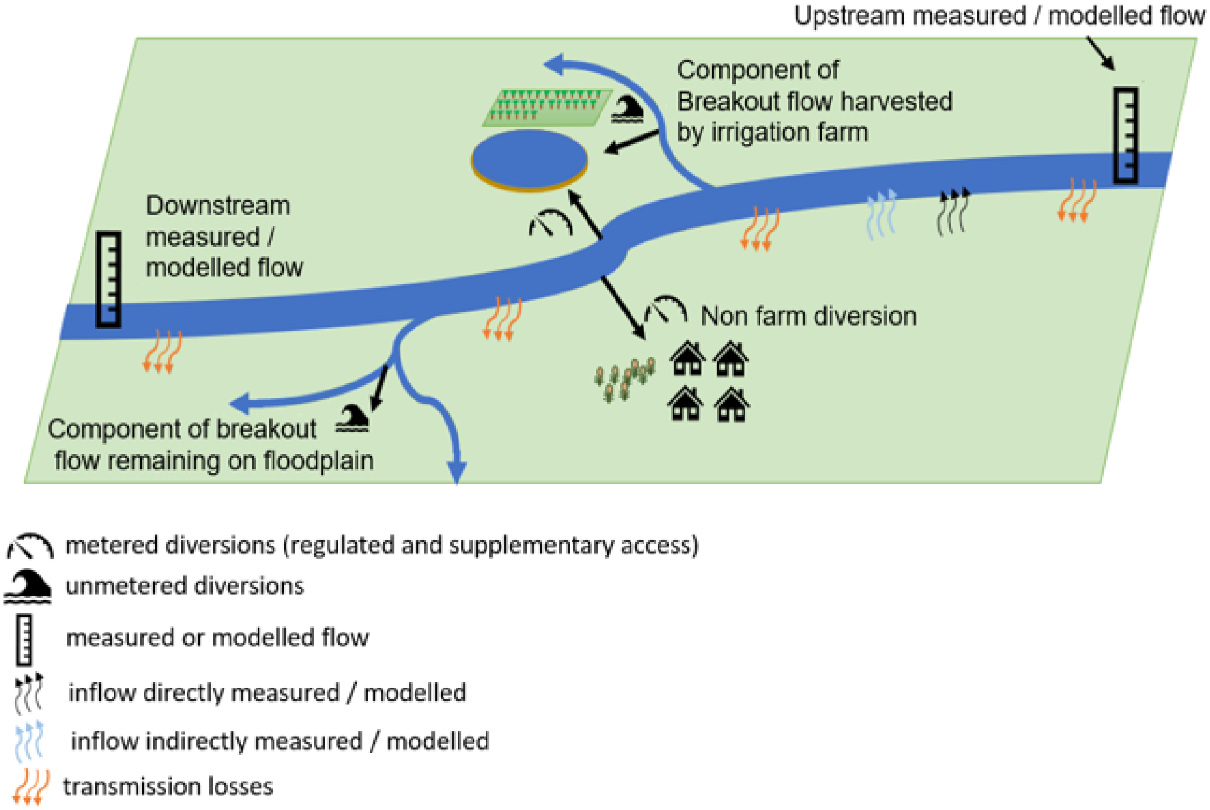

Figure 17 Reach water balance components [Source: Figure 3 (DPIE Water 2021a)]

The final step involves developing and running different simulated scenarios. Managed river system scenarios include the following characteristics:

> 'Fixed development conditions: including catchment and land use, headwater and re-regulating storages, areas developed for irrigation, on-farm storage volumetric capacity, and pump capacity.
>
> Fixed management arrangements, including all rules, resource assessment and allocation processes, and accounting as set out in the water sharing plan, as well as on-farm decision making regarding crop mix, crop area planting as a function of water availability, and irrigation application rates' (DPIE Water 2021a).

These scenarios are detailed in the companion Scenarios report (DPIE Water 2021b).

Within the river system model, each breakout zone is represented by:

- a splitter node [5] (to create the overbank water)
- a few additional nodes (e.g. a virtual storage to stop the allocated water from flowing through the breakout zone)
- all the user supply points (water user nodes) to extract the water (for floodplain harvesting)
- a gauge node at the end, called the breakout EOS node (refer to Figure 9). This is a reporting point in the model, and not an actual gauge.

[5] A node type provided in the IQQM modelling platform

4.1.4 Available hydrological data

The change in floodplain harvesting pre- and post-implementation of the policy can be assessed through the two model scenarios:

1) current conditions without the policy implemented, the Current Conditions Scenario
2) current conditions with floodplain harvesting entitlements and accounting applied, the Plan Limit Scenario.

Hydrological changes due to implementing the policy can then be identified through comparing the two model scenarios: Current Condition Scenario vs Plan Limit Scenario. From here, flow-on environmental floodplain benefits or disadvantages are determined. The following hydrological data is available for each scenario:

- modelled daily time-series flow data (in ML/day) for important gauge nodes in the valley
- modelled daily time-series flow data (in ML/day) (via a IQQM splitter node) to floodplain breakout zones, and an end-of-system (EOS) reporting node (using a Source gauge, called the breakout EOS Node). A schema is provided in Figure 9.

More details on the modelling are provided in Appendix D and the companion Model Build and Scenarios reports (DPIE Water 2021a, 2021b). All modelled flow data cover the period from 1895 to 2016.

4.2 Quantifying changes to floodplain hydrology

4.2.1 Identifying ecologically relevant metrics

Magnitude, frequency, duration, and timing are all ecologically relevant hydrological features of the floodplain flow regime (Richter et al. 1996, Leigh and Sheldon 2008). The strength of an environmental response is often proportional to the magnitude and duration of a flood (Kingsford and Auld 2005, Bunn et al. 2006, Woods et al. 2012). For instance, native fish biomass, health and abundance can increase with the magnitude, duration, and inundation of a flood (Bunn et al. 2006). Vegetation is also responsive to flood inundation extent, duration, and variability (i.e. regularity or frequency). River red gum forests can survive for long periods without inundation but require periodic flooding (every 1-3 years), a flood inundation duration of 2-8 months and an inter-flood dry period between events to be in good condition (Roberts and Marston 2000, Wen et al. 2011). Many waterbirds are also sensitive to the magnitude, frequency, duration, and timing of floods, particularly to achieve successful recruitment (Kingsford and Auld 2005). Reduced rates of rise and increased rates of falls can also reduce environmental benefits, especially during breeding events for waterbirds (Kingsford and Auld 2005, Kingsford et al. 2014).

The timing (e.g. seasonality and frequency) of floods is also critical to achieving a range of ecological outcomes (Robertson et al. 2001, Kingsford et al. 2014, NSW Department of Primary Industries 2015, DPIE EES 2020a). For example, the most common timing for spawning of floodplain specialist fish in the northern Murray-Darling Basin is September to October. Improving the magnitude and duration of floods during this period would therefore achieve the greatest spawning outcomes for these fish (NSW Department of Primary Industries 2015). These hydrological features are also important for a number of other ecological functions (e.g. carbon and nutrient cycling). Therefore, identifying and describing the changes of each hydrological feature is the first step in understanding any environmental benefits of implementing the policy.

Flow metrics that describe the ecologically relevant hydrological features of the floodplain were modified from Richter et al. (1996) and Leigh and Sheldon (2008) and are shown in Table 3. Three types of measures are identified for describing flow metrics: summaries, parametric and non-parametric measures. Non-parametric measures (e.g. medians) are appropriate for many flow regimes due to the less frequent floods and more frequent low flows. However, summaries of totals and parametric measures (e.g. means) are useful where a large number of zero flows occur and the median limits meaningful comparisons (e.g. on regulated floodplains) (Walker et al. 1995, Leigh and Sheldon 2008). As the Gwydir Valley floodplain is a regulated floodplain, some measures will be parametric measures (e.g. means), whilst others will be totals. Using totals (e.g. total duration of summer events) avoids the impact of zeros on the mean and median. Where medians were still calculated, the zero flow periods were removed from the data unless required for meaningful median comparisons. For example, the annual median of days with flow was only calculated in years where the days with flow exceeded 1 ML/day. Zero flows were included in the calculation when one scenario had a flow above this threshold and the other scenario did not. This ensured that more flood events in one scenario did not reduce the annual median of days with flow compared to the other scenario with less flood events.

For annual, seasonal and event time periods, magnitude (volumes and flow rates) will be described by mean, medians and totals. Skewness will also be calculated in terms of median to mean flow ratio (low values represent high skew, and therefore less regularity of flows, and vice versa). The hydrological metrics in Table 3 describe an aspect of a hydrological feature (i.e. magnitude, frequency, duration or timing) or the variability of a metric. Understanding how implementation of the policy impacts the identified hydrological metrics provides the first level of detail required to understand what environmental benefits or disadvantages may occur on the floodplain.

Table 3 Hydrological feature, period of interest and hydrological metrics for magnitude and duration of flood events. Seasonality (timing), frequency and variability are incorporated into each hydrological feature. S = summer, A = autumn, W = winter, Sp = spring

Hydrological feature	Period of interest	Flow metric	Reasoning
Magnitude	Inter-annual	Mean of annual volume (ML)	Provides summary measures of annual volume changes
	Inter-annual	Ratio of median to mean annual volume (ML)	Provides a measure of the changes in regularity of flood volumes
	Seasonal (S/A/W/Sp)[1]	Total of seasonal volumes (ML)	An estimate of changes to seasonal flood volumes over the modelled flow record
	Event	Median of event magnitude (ML/d)	An estimate of the change in the magnitude of flood events
Duration, frequency, and timing	Whole record	Number of years with flow (>1 ML/d)	Identifies if there is an increase in the frequency of flooding over yearly timespans
	Whole record	Total number of days with flow (>1 ML/d)	High level summary of the changes in flood duration
	Seasonal (S/A/W/Sp)[1]	Total of seasonal days with flow (>1 ML/d)	Identifies changes to the number of flood days for spring, summer, autumn, and winter
	Event	Number, total duration and mean inter-event period (days)	Identifies key changes to the number of flood events, the duration of these events and the inter-event period between them
	Event	Total duration of event rise and fall and mean rate of rise and fall	Important metrics for dispersal, fish, and waterbird breeding success

4.2.2 Methods to quantify changes

The two modelled scenarios are the primary source of information used to quantify changes in floodplain flows due to implementing the policy. Therefore, to identify any changes after implementation, the ecologically relevant metrics described in Table 3 were calculated for each modelled flow series using the Time Series Analysis module of the River Analysis Package (RAP) software (Marsh et al. 2003) and using Microsoft Excel (2016).

A comparison of 'current with the policy implemented' against 'current without the policy implemented' modelled scenarios was undertaken for the period 1895 to 2016 for the EOS floodplain breakout areas only (i.e. not the whole floodplain) (Figure 18, Table 4). The current with policy implemented modelled time-series has the floodplain harvesting diversions incorporated into the EOS breakout model node and therefore represents the change due to implementing the policy. This assessment provides a quantified change in ecologically relevant hydrological metrics before and after implementation of the policy based on a modelled long-term record. All predictions are for the period 1895 to 2016 and provide an indication of what changes will be expected in the future when the policy is implemented. Further detail on the limitations and approach used to quantify hydrological changes can be found in Appendix D .

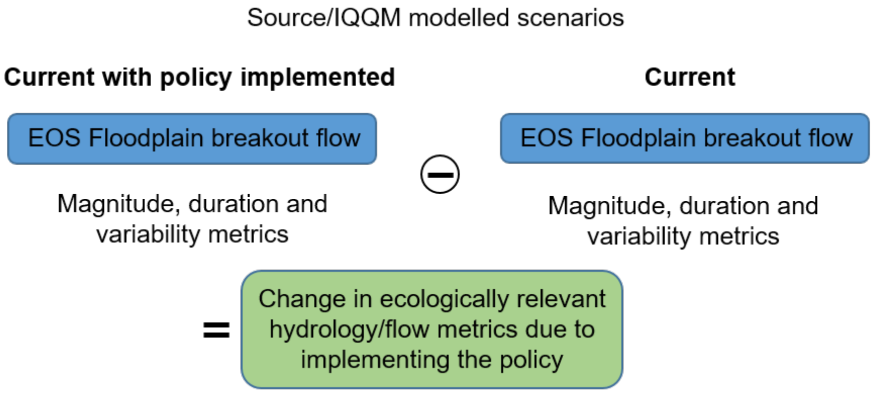

Figure 18 Summary diagram of how modelled breakouts were used to identify changes to floodplain hydrology and assess predicted ecological outcomes

4.3 Hydrological outcomes

4.3.1 Changes to floodplain hydrology

Modelling indicates that the implementation of the policy will result in a range of changes to key hydrological features of the floodplain. This varied with location on the floodplain (i.e. breakout) and the metric of interest. The outcomes are represented as a percentage change from the current scenario to the scenario with the policy implemented for each of the eight breakout zones (Table 4). There were a number of improvements to ecologically relevant floodplain metrics. These are broken down into the key hydrological features below. These interpretations are limited to the modelled outcomes for the end of system breakouts but provide indicative modelled outcomes for a variety of areas on the Gwydir Valley floodplain.

Results presented are modelled long-term (over the period 1895 to 2016) changes to the hydrology of the floodplain that would occur under the policy.

Magnitude

In total, during flood years (i.e. years when there are overbank flows and excluding non-flood years) the policy is predicted to allow an increase of 13% in **mean annual volumes to** return to remain on the floodplain when averaged across all eight breakout zones in the Gwydir Valley floodplain. The current long-term average flood plain harvesting diversions are estimated at 174 GL/year and will reduce to 121 GL/year (30% reduction) after the policy is implemented. The largest percent increase in mean annual volume to remain on the floodplain is 22% (2.22 GL) is at the Deadman/Biniguy breakout zone (Table 4). The highest increase in mean annual volume was in Mehi River breakout zone of 16.5 GL (19%). The Marshall breakout zone however is predicted to have no change in mean annual volume.

With the exception of the Marshall breakout zone, which is predicted have no change or a slight decrease, all breakout zones are predicted to receive some increase in **total seasonal volumes** for all seasons (Table 4). The largest percent increases are predicted at Deadman/Biniguy (64%, 27.4 GL) in autumn and spring (44%, 10.8 GL). The Gwydir/ Gingham breakout zone is predicted have the highest total increase in total volume in all seasons with the highest predicted increase in autumn (32%, 485 GL). This is a significant improvement as it supports the Gwydir Wetlands.

Median event magnitudes provide a measure of change in flow rates (ML/d) during flood events. There is a 20% increase in average median event magnitude across all sites. The highest percentage change is expected in Gwydir/Gingham breakout zone (59%). No change is expected at the Marshall and Gil/Carole breakout zones (Table 4). Whilst noticeable improvements are expected for total seasonal volumes, particularly autumn and summer, this is not consistent across the floodplain. Some breakout zones are predicted to have very little change, particularly Gil Gil/Carole Creeks. However, it is important to recognise that the lack of modelled return flows at each breakout may result in an underestimate of benefits to downstream breakout zones. For example, improved return flows from the Carole/Gil Gil Creeks breakout zone should, in reality, benefit the downstream Gil Gil/Carole Creeks breakout zone.

Duration

Based on the modelled scenarios, the **total number of flow days** across the entire record is predicted to increase in all areas of the floodplain except the Marshall breakout zone (Table 4). The predicted average increase is 12% across the floodplain. Total days with flow improve most at the Gwydir/Gingham breakout zone, increasing by 51% (1506 days). Whilst total days with flow increases by 7% or more at some breakout zones, others remain relatively unchanged (e.g. 2% at the Deadman/Biniguy breakout zone). The breakout zone variability in total flow days suggests that specific breakout zones should receive longer flood durations whilst others will remain relatively unchanged once the policy is implemented. For example, Moomin Creek breakout zone is expected to increase (1%) and Marshall breakout zone is expected to marginally decrease (-1 %) with respect to flood durations. A more detailed assessment of the number of flow days is provided for each month in Section 5.4 – Changes to monthly flow durations.

Seasonal changes to flood durations (days with flow) vary with the season and breakout zone. In general, increases are predicted in the total number of days with flow for all seasons across most breakout zones. Across the floodplain, autumn and summer are expected to have the highest percentage increases (average 18% and 17% increase) and winter and spring the lowest (average 8% and 5% increase). Spring is a critical season for many environmental values, further improvements in flood durations are desirable. There were marginal percentage decreases at the Marshall breakout zone in winter and summer and no change predicted in the autumn and spring.

The most upstream breakout zone Deadman/Biniguy is expected to have only small increases in days with flow and Mehi a slight reduction in spring (-2%). Gwydir/Gingham is predicted to have the highest percentage change in days with flow with 77% increase (476 days with flow) expected in autumn and 78% increase (764 days with flow) in summer. The least change expected is for upstream breakout zones Deadman/Biniguy and Marshall predicted in each season after implementing the policy (Table 4).

Event based metrics

The **number of flood events** is predicted to increase across most sites (Table 4). The largest relative increase in number of events is 109% (215 more events) at Gwydir/Gingham followed by 21% (15 more events) at Moomin Creek. Reductions in **mean inter-event periods** result in shorter periods between subsequent flood events and relate to the frequency of events (i.e. number of events).

The mean duration between events (inter-event period) is predicted to reduce or change very little at five of the breakout zones. The largest change predicted is at Gwydir/Gingham being an average reduction of 110 days (-54%) between events. No change is predicted for Marshall breakout zone after implementation of the policy (Table 4).

Modelled outcomes for the rise and fall statistics of flood events vary by zone and flow metric of interest (Table 4). Across all breakout zones there is expected to be an average percent increase of 9% for the **duration of the rising limb.** The four most upstream breakout zones (A-D) are expected to have a percent reduction (0-4%) of rising limb duration. The four most downstream breakout zones (E-H) are expected to have an increase (3-45%) in rising limb duration of flood events. The largest relative change is a total increase of 129 days (45%) in rising limb duration at Thalaba breakout zone. The mean rate of rise is expected to increase across the floodplain by 12% (average across zones); however, the rate of rise at Gwydir/Gingham and Mehi is expected to reduce by 11% and 6% respectively (Table 4). The **duration of the falling limb** of events is expected to remain unchanged across all zones. The **mean rate of fall** is variable across the breakout zones with rate of fall decreasing at all but two breakout zones (Table 4). The highest increase is expected at Thalaba (255%) and highest decrease at Deadman/Biniguy (-18%) breakout zones.

Table 4 Relative percentage change (increase or decrease) in ecologically relevant flow metrics after implementation of the policy. Values are averaged over the 121-year modelled period. Only flows >1 ML/day were considered flow days. *Negative percentage change (in mean inter-event period) is a positive outcome for the value or asset as it indicates that the mean period between floods (the inter-event period) has reduced

Hydrological feature	Flow metric	Deadman/ Biniguy A	Marshall B	Carole/Gil Gil C	Gil Gil/Carole D	Gwydir/ Gingham E	Mehi F	Moomin Creek G	Thalaba H	Average
Magnitude	Mean of annual volume (flood years only)	22	0	11	11	13	19	14	17	13
	Ratio of median to mean annual volume	35	0	40	8	40	27	55	32	30
	Total autumn volumes	64	1	30	22	32	37	25	17	29
	Total winter volumes	18	-1	7.6	5	12	29	21	25	15
	Total spring volumes	44	0	18	12	19	14	17	15	17
	Total summer volumes	30	0	20	15	28	39	26	28	23
	Median of event magnitude	19	0	43	0	59	15	11	16	20
Duration, frequency, timing	Total flow days	2	-1	8	7	51	13	11	9	12
	Number of events	7	0	6	1	109	14	21	4	20
	Total autumn days with flow	1	0	13	16	77	17	16	3	18
	Total winter days with flow	1	-2	4	6	20	15	10	10	8
	Total spring days with flow	4	0	4	1	19	-2	10	5	5
	Total summer days with flow	2	-1	8	7	78	14	10	11	16
	Mean inter-event period*	-6	0	-4	-2	-54	-12	-18	-4	-12
	Total duration of rises	-3	-4	-1	0	21	3	9	45	9
	Mean rate of rise	36	9	31	0	-11	-6	15	22	12
	Total duration of falls	0	0	0	0	-3	0	-1	0	0
	Mean rate of fall	-18	-1	14	-15	-13	-4	-17	255	25

5 Predicted ecological outcomes

The results presented in this section are based on long-term (1895 to 2016) simulated hydrological changes where the policy is implemented across the entire record. Therefore, past climate and water use variability over the previous 121 yrs is incorporated into the models. In reality, the policy is a proposed future water resource management measure. The predictions reported herein are therefore only indicative of potential outcomes under implementation of the policy.

5.1 Broad scale outcomes

The **volume** of water making its way through floodplain harvesting areas is predicted to increase annually and, in each season. The biggest increases are in autumn and summer (Table 4, Figure 19). The average increase in mean annual volumes across all eight breakout zones is 7.4 GL. The largest increase is in Mehi Creek breakout zone with up to an additional 16.5 GL in volume. With the exception of the Marshall breakout zone, which shows no change, improvements are predicted for **event durations** in all seasons, especially autumn and summer. The **number of events** predicted after implementing the policy is highly variable, with 215 more events (+109%) in the Gwydir/Gingham breakout zone and no increase or marginal change in events at the Marshall breakout zone and marginal increase at Gil/Carole breakout zone (Table 4). The **inter-event period** reduces by up to 109 days (54%) at the Gwydir/Ginghams breakout zone and by an average of 12% for all breakout zones.

In general, the increased volume and duration of events passing through floodplain harvesting areas are expected to contribute to downstream benefits for other regions of the Gwydir Valley and the Barwon-Darling. Further monitoring, data collection and research are required to support an analysis of downstream impacts with particular emphasis on the Barwon-Darling water resource plan area (see Appendix D for more details.).

Returning water use back to the LTAAEL and curtailing future growth in floodplain harvesting through the policy will also provide improvements in reliability of environmental benefits of the Water Sharing Plan for the Gwydir Regulated River Water Source. This is expected to benefit most water-dependent floodplain environmental assets and values in the Gwydir Valley.

5.2 Assessment approach

Understanding the summary statistics for hydrological changes in Chapter 4 is the first step in identifying the benefits of implementing the policy for specific environmental asset and value categories (e.g. native fish).

In addition, known EWRs (Environmental Watering Requirements; provided in Appendix C) increase the capacity to predict whether improved environmental outcomes can be expected under different hydrological scenarios. While duration EWRs were available for most assets or values, this assessment has used **changes to the number of flow days** on the floodplain as a measure of change to flood durations in important seasons (i.e. timing EWRs) for an asset or value. The reasons for substituting a specific EWR duration for this measure are explained in Section 5.3 *Assumptions and limitations*.

For the majority of environmental values, EWRs were grouped into two common themes: (1) maintenance and (2) regeneration/reproduction. As most water-dependent environmental values have different requirements for different life stages, knowing what stages are supported under the policy is important. For example, an EWR for seedling germination in a tree species may be met, but the EWR for maintaining the condition of mature trees of the same species is not met, or vice versa. In many cases the specific EWR had an upper and lower bound (for example, 3 to 5 years in 10 required for reproduction in short-moderate lived floodplain specialists). The shortest duration, usually the lower bound, was used to test the EWR outcomes. Whilst the upper bound is a more conservative estimate, this approach provides a minimum requirement to achieve the documented EWR. The frequency and timing of events needed for maintenance and reproductive outcomes as well as other relevant EWR metrics were sourced from the literature (sources documented in Appendix B).

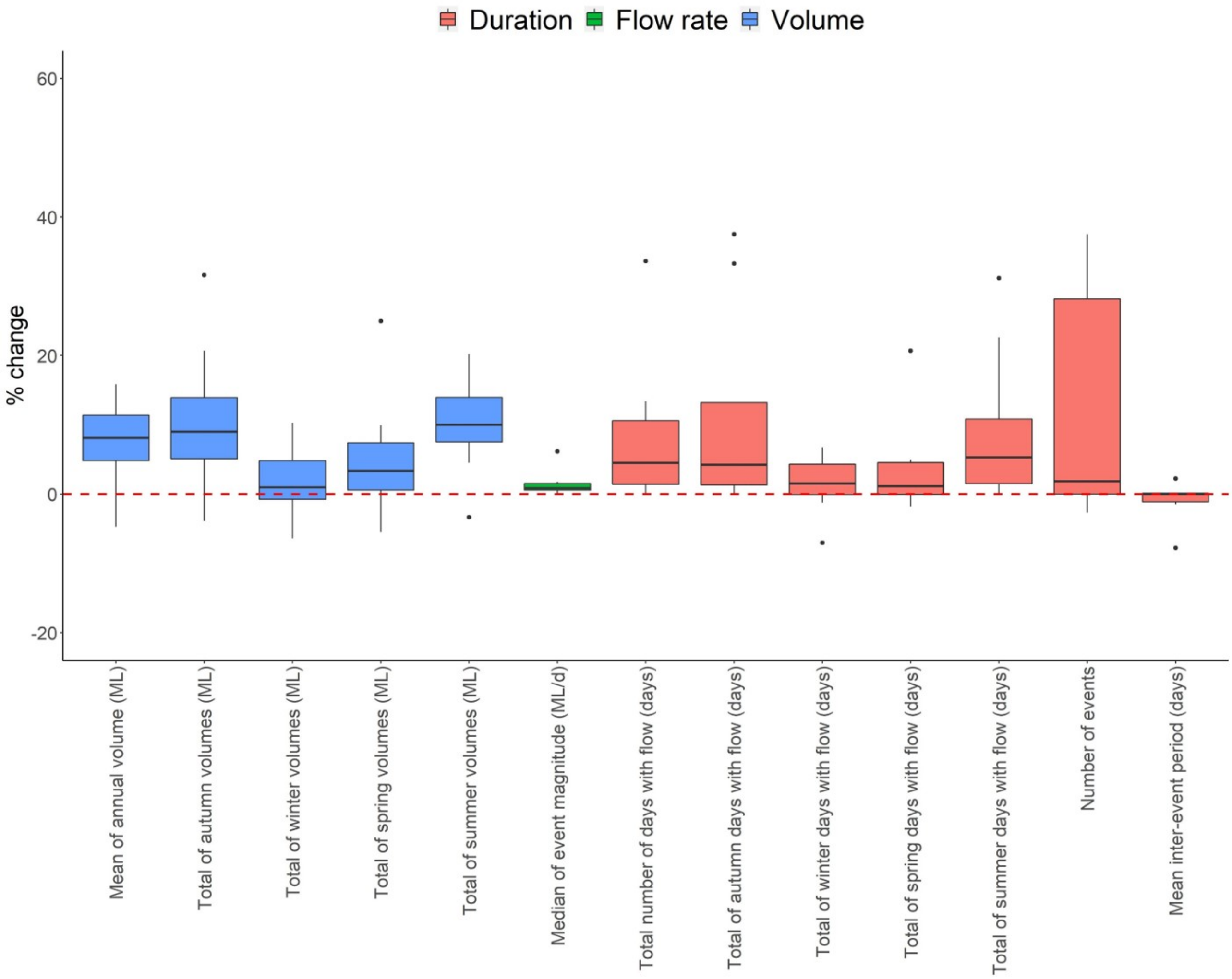

Figure 19 Box plot of percentage change to key hydrological metrics (Duration, Flow rate, Volume) after implementing the policy in the Gwydir Valley. Data represents the medians (bold line inside box), 25th and 75th percentiles (bottom and top of box), minimum and maximum (bottom and top whisker notches) and outliers (points) for the 8 breakout zones

Each EWR was tested under the two model scenarios; with the policy implemented (Plan Limit Scenario) and without (Current Conditions Scenario) (EWR values are listed in Appendix C). This involved first identifying all flood events, including the event duration, in the modelled flow data[6]. As flow onto the floodplain at a breakout was only generated in the models when an overbank flow occurred, any flow above 1 ML/day was considered the start of an event. Events with 5 days or less between flows (i.e. 5 days or less of <1 ML/day flows) were considered one flood event due to the short inter-flow period. From here, the month of, season of, days between, and years between events were then generated[7]. These metrics were then tested against the specific frequency and timing EWRs assigned to environmental assets and values identified on the valley floodplain. This method allowed a simple quantification of how often each EWR was met under the modelled long-term record for both scenarios. The results were also interpreted as a % change in EWRs being

[6] The 'hydrostats' package in RStudio (R Core Team 2015) was used to identify flood (overbank) events and their spell length. Microsoft Excel 2016 was then used to generate temporal statistics from these data.

[7] The Time Series Analysis module of the River Analysis Package (RAP) software (Marsh et al. 2003) and Microsoft Excel 2016 were used for this task.

met after implementing the policy for each asset category to provide a relative measure across breakout zones.

Details of the assets, values and associated EWRs used in this assessment are provided in Appendix A . Considerable time and effort by various authors have been put into developing many of the EWRs used in this assessment. The scientific information which supports each EWR can be sourced from the associated reference in Appendix B . There remains a range of other EWRs within documented literature which could be tested, however we have restricted our assessment to the EWRs listed in Appendix C. Key outcomes are summarised for native fish, waterbirds, native vegetation, important ecosystem functions, wetlands and flow-dependent frogs in this section.

5.3 Assumptions and limitations

As previously stated, the results presented here are modelled, and therefore provide only an indication of possible changes once the policy is implemented. Essentially, all interpretations in this report are high-level predicted changes based on modelled hydrological scenarios and should be treated as a tool for decision making, not as a measure of actual outcomes which will be observed in the future. A range of factors may inhibit modelled and predicted outcomes becoming observed outcomes. Some of these are discussed below.

The predicted ecological outcomes are based on the best available information and are assessed from EWRs sourced from previous studies listed in Appendix C and expert opinion. They relate to the impacts of hydrological changes on water-dependent floodplain environmental assets and values. Predictions are limited to assets and values for which there is some understanding of the surface water requirements of the asset. Understanding, predicting, or quantifying the changes at the spatial and population scale is not possible with the available information. For example, it is not possible to suggest how much the population of Olive Perchlet will improve or deteriorate with the information available. Instead, outcomes are assessed at the asset/value scale and inferred outcomes (positive or negative) are suggested based on improvements to key environmental water requirements and hydrological metrics.

It is assumed that if a documented EWR is met, then an environmental benefit (positive outcome) is achieved. In reality, there may be other factors which could influence whether these outcomes are actually achieved. For example, vegetation community composition and condition may be spatially and temporally variable according to seasonal climatic conditions and the inundation regime which are key drivers of floodplain plant community dynamics. If a vegetation species is under significant stress due to climatic conditions like drought then the expected outcomes of meeting an EWR may not actually be achieved due to the prior condition of the vegetation. Another key limitation is that impacts are spatially and temporally variable, just as the distribution of a plant community can be spatially variable. For example, lignum can occur in dense stands or intergrade into different communities such as coolabah woodlands. Impacts are therefore difficult to measure without monitoring. Also, species respond at different time scales depending on the nature of the impact.

Issues such as land clearing will continue to be a major and ongoing threat to native vegetation, however this is out of the scope of the policy implementation process. The assessment is also limited as it does not assess and spatially map the short or long term impacts of different types of floodplain harvesting structures on ecological outcomes which may vary spatially and temporally depending on the nature of the structure (location, size, function) and/or the level of take (lawful/unlawful). The assumption is that additional volumes of water on the floodplain are able to pass through un-hindered. In reality, ongoing monitoring is required to ensure that flood works do not inhibit floodwaters which are intended to pass through the system for the environment and downstream users.

Unless otherwise identified, predicted outcomes are for the identified breakout zones. Areas outside these breakout zones may see benefits but they would have much lower confidence than those outcomes expected within the breakout zones. These are examples of issues which are not considered in this analysis.

5.3.1 Duration EWRs

Most, if not all, documented floodplain duration EWRs are linked to (a) the duration of a specific flood magnitude/event volume at a flow gauge or to (b) the minimum inundation period required for the EWR. For example, the *Gwydir Long term Watering Plan* Part B (DPIE EES 2020b) suggests a >60,000 ML/day event at the Gwydir @ Yarraman (418004) flow gauge for one day will achieve a small overbank event. This is expected to provide an inundation period of 1 to 6 months in a range of planning units. However, our assessment does not use flow gauges because the river system models consider overbank flows as a 'loss' and do not model return flows from a floodplain into downstream gauging stations. This means that the impacts from implementing the policy are not detected at flow gauges, only on *Floodplain Breakout Nodes.* Therefore, detecting changes to event durations at flow gauges for the two modelled scenarios is not possible. Instead, *Floodplain Breakout Nodes* represent the duration of flowing water on the floodplain, but they do not accurately represent the duration of inundation once flow ceases.

It is most likely that the duration of inundation provided by modelled floods (where flow on the floodplain >1 ML/day) is actually much longer than represented by the river system models due to the fact that many floodplain areas should remain inundated once simulated flow ceases. After flow ceases, the combination of water take, soil infiltration, groundwater recharge, transpiration and evaporation will reduce flood waters in these inundated areas. However, it remains unclear how long each area would remain inundated after flow ceases in the model and therefore how long the actual flood inundation duration may be for a variety of floods. This report does not attempt to predict actual periods of inundation after floodplain flows cease due to the issues raised and other assumptions and limitations in the hydrological models that underpin this ecological assessment (more detail is provided in Appendix D).

Where a duration EWR could not be tested (e.g. native vegetation and waterbirds), an **indication of changes to flood durations was calculated using the change in total flow days for each calendar month.** This allows a high-level assessment of the change to the number of flow days in important seasons or months (e.g. timing EWRs) for different assets and values. For example, floods during spring and summer months are required for maintenance of lignum on the floodplain. Therefore, an assessment of the change to the number of flow days during spring and summer months can provide insight into outcomes for flood durations for this floodplain value. It is important to highlight that this is not an assessment of achieving a duration EWR. Instead, it is a test to identify if there is a change in the number of flow days during the required timing (season/month) of known EWRs.

5.4 Changes to monthly flow durations

As reported above, where a duration EWR could not be tested, the substitute was to calculate the total flow days (>1 ML/day) for each month[8]. The data were interpreted as a percentage change in the number of flow days per month, after implementing the policy. Figure 20 represents the summary statistics (median, 25th and 75th percentiles) across all 8 breakout zones. The percent change results for each breakout zone are presented in Table 5.

The total number of flow days is predicted to increase across most months by a small amount, excluding some months at specific breakout zones (Table 5). A number of breakout zones represented by the outliers (blue dots) in Figure 20 have much larger changes to the number of flow days than the median change across the Gwydir Valley floodplain. For example, the Gwydir/Gingham breakout has the largest predicted increase in total flow days for all months except July, August, and September. Flow days in January (+44%), February (+44%) and April (+40%) increased by more than 100 days with flow in the modelled period. The largest reduction in total flow days is predicted at the Mehi River breakout with the total number of flow days reducing by more than 160 (-13%) days in September. The Marshall breakout is predicted to have the least

[8] The 'hydrostats' package in RStudio (R Core Team 2015) was used to calculate monthly flow days. Microsoft Excel 2016 was then used to generate summary statistics from these data.

change with reductions of 1% in Feb and 5% in August. The number of flow days in all other months are expected to remain unchanged at this breakout zone. (Table 5).

Table 5 Relative percentage change (increase or decrease) in total number of flow days in each month for each breakout zone after implementing the policy. Values are averaged over the simulation period. Only flow > 1 Ml/day were considered flow days

Hydro feature	Breakout zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Duration	A Deadman/ Biniguy	3	2	1	0	0	5	2	0	5	33	0	3
	B Marshall	0	-1	0	0	0	0	0	-5	0	0	0	0
	C Carole/Gil Gil	8	10	13	17	4	10	-2	4	2	0	7	4
	D Gil Gil/Carole	3	11	15	8	17	13	3	4	-1	0	2	4
	E Gwydir/Gingham	44	44	43	40	49	46	-2	-3	3	19	23	43
	F Mehi	16	11	16	10	6	32	19	-1	-13	7	-1	13
	G Moomin Creek	9	9	15	8	12	13	13	3	3	10	13	8
	H Thalaba	14	11	3	0	0	0	14	6	0	10	5	3

Further improvements in the number of flow days in spring is desirable as this is a period of significance for many environmental values (e.g. Oliver Perchlet native fish). The policy provides some benefits to flow days in October and November. However very little change is predicted for September, with even a reduction in flow days in some breakout zones (e.g. Mehi River breakout) (Table 5).

The information presented in this section is used in the following sections to assess whether flood durations in important periods (e.g. EWR timing) for an asset or value are predicted to improve.

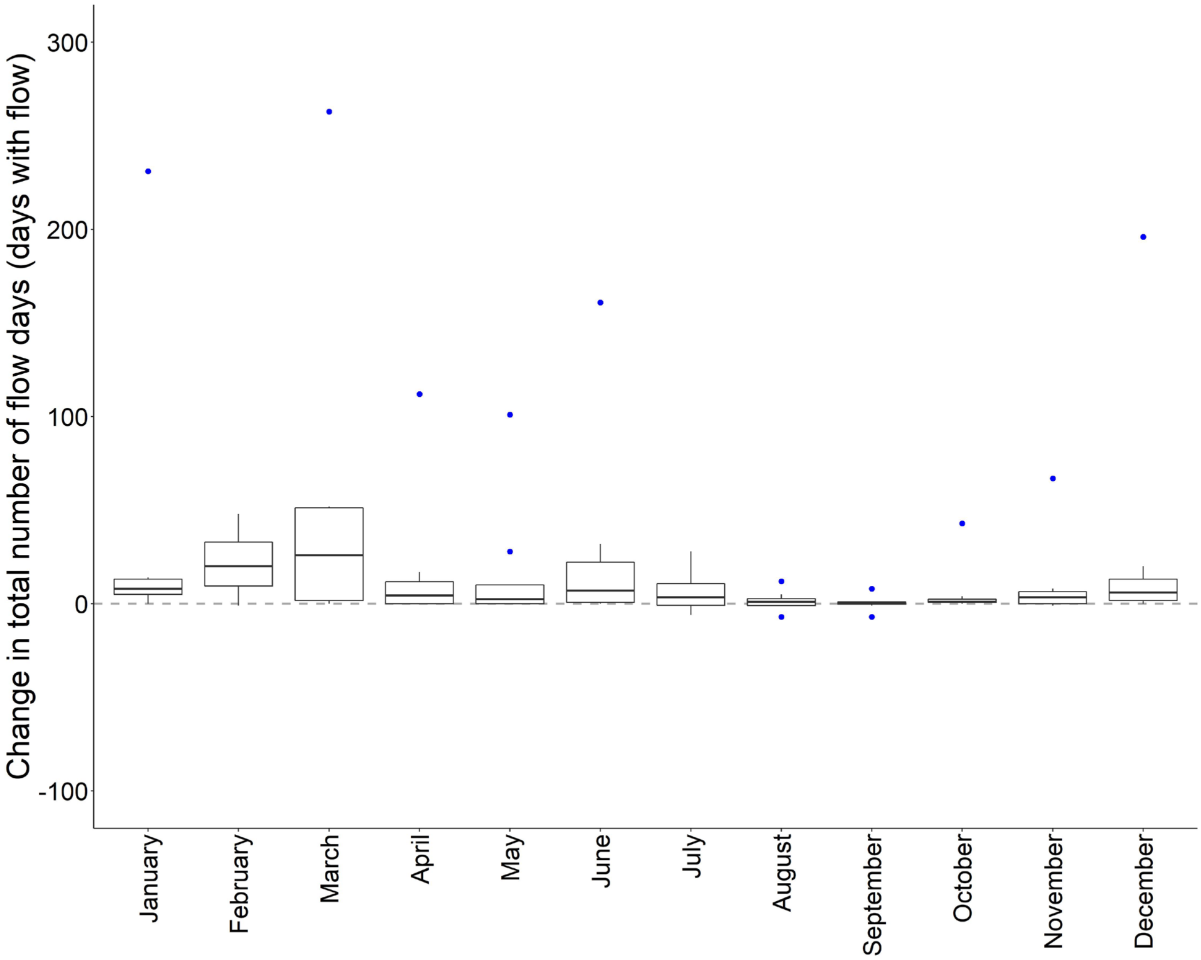

Figure 20 Box plot of change in total number of flow days in each month after implementing the policy in the Gwydir Valley. Values are averaged over the simulation period across all 8 breakout zones. Number of flow days is based on modelled flow >1 ML/day. Boxes show the medians (bold line inside box), 25th and 75th percentiles (bottom and top of box), minimum and maximum (bottom and top whiskers) and outliers (blue points) for the 8 breakout zones

5.5 Native fish

5.5.1 Metrics

The key fish values used in this assessment are the Silver Perch, Golden Perch, Spangled Perch, Australian Smelt, Bony Bream, Carp Gudgeon, Murray-Darling Rainbowfish, Unspecked Hardyhead, Olive Perchlet, Eel-tailed Catfish and Murray Cod. These species can be grouped into four native fish guilds based on NSW DPI Fisheries Northern Basin fish guild groupings (NSW Department of Primary Industries 2015). At least one species from each guild has been recorded or predicted to occur in all of the breakout zones. The fish guilds and species were:

- flow dependent specialists such as Silver Perch, Spangled Perch and Golden Perch
- generalists, which include a number of species that benefit from improved floodplain outcomes including Australian Smelt, Bony Bream, Carp Gudgeon, Murray-Darling Rainbowfish and Unspecked Hardyhead
- short-moderate lived floodplain specialists including Olive Perchlet
- in-channel specialists like the iconic Murray Cod and Eel-tailed Catfish (Figure 21).

Using specific EWRs for native fish allowed a quantified measure for native fish maintenance and reproductive success for each of the fish guilds. The EWR metrics were categorised by:

- egg development – flood durations required to achieve successful egg development. These durations refer to a flow peak of a set number of days (5-14 depending on guild). Modelled flow at the breakout nodes represent peak flow periods allowing this duration EWR to be tested using the hydrological models
- maintenance – the frequency and timing (seasonality) needed to maintain mature native fish
- reproduction – the flood frequency required to provide sufficient reproduction opportunities for native fish
- recruitment – the timing (seasonality) of flood events required for effective native fish recruitment
- spawning, habitat, and food – native fish often require flood events during specific seasons due to seasonality preferences for spawning. This also relates to the timing of flood events for habitat, food resources and refugia for recruits.

Specific EWRs were not available for all fish species. However, the outcomes for a species native fish guild can provide some insight into the implications for this species (e.g. outcomes for Golden Perch give insight to potential benefits for Spangled Perch). The majority of native fish EWRs were sourced from the *Fish and Flows in the Northern Basin* reports (NSW Department of Primary Industries 2015, 2019) and the long-term water plans developed by the department (DPIE EES 2020a).

In total, 10 water requirements of native fish were tested.

Figure 21 The Eel-tailed Catfish, an endangered population within the Murray-Darling Basin which has been recorded in the Gwydir Valley. [Photo: Bruce Thomson]

5.5.2 General hydrological impacts

Impacts of implementing the policy vary across the breakout zones, with some areas seeing large improvements. Overall, the predicted improvements in key hydrological metrics for flood events should provide future benefits for native fish. The **number of flood events** increases, and the **inter-event period** reduces across most areas of the floodplain, both of which are critical for improving fish outcomes. Increased **annual and summer volumes** and **flow durations** (Table 4) should provide benefits and improvements for all in-stream fish guilds. Boosts in volumes and flow durations to the Gwydir Valley floodplain will potentially provide increased longitudinal and lateral movement opportunities for native fish.

Benefits predicted for **event magnitudes** (ML/day) can be important for some native fish. For example, greater magnitudes can provide more opportunities for riverine specialists like Murray Cod which like higher velocities (0.3 to 0.5 m/sec). Despite limited increases in event magnitudes overall, breakout zone Gwydir/Gingham is predicted to have the highest percent change in median magnitude, with modest improvement in Corale/Gil and Deadman/Biniguy (Table 4, Figure 19). Overall, small-modest improvements are predicted for spring event volumes, which is a critical period for most native fish species; the greatest percent change is predicted in Deadman/Biniguy breakout zone (Table 4).

Event durations, measured as total days with flow, shows an improvement in most breakout zones (Table 4,Table 5, Figure 19). Gwydir/Gingham breakout zone is predicted to have the highest increase in total flow days and spring volumes (Table 4). Similarly, the Gwydir/Gingham breakout zone has the highest percent increase in duration of spring flows despite a monthly reduction in October (Table 4, Table 5). Overall, there is expected to be greater hydrological change to the Gwydir/Gingham breakout zone, least change to Marshall breakout zone and small to modest improvements to other zones, the ecological benefits of which are dependent on specific requirements of the fish guild. In general, further increases in volumes and durations during spring are desirable for better native fish outcomes.

5.5.3 Impacts on fish guild-specific EWRs

An average of 29 of the 30 EWRs for native fish are predicted to improve across the eight floodplain breakout zones (Table 6, Figure 22). In total, 28 of the 30 metrics tested improve by 10% or more. However, these changes vary drastically across the floodplain. For example, achievement of the **timing of floods** required for effective **recruitment** in short-moderate lived floodplain specialists like the Olive Perchlet is predicted to increase by 70% on average. However, the spatial variability of this metric includes a reduction by 1% in one zone (Carole/Gil Gil) and increases by 467% in another (Gwydir/Gingham) (Table 6). Only one native fish EWR is achieved less with the policy implemented, the timing of flows important for spawning in short-moderate lived floodplain specialists (-2%). This means less floods occur in September and October when spawning occurs for this fish guild.

Flow pulse specialists like Golden Perch and short-moderate lived floodplain specialists such as the Flathead Galaxias are likely to benefit the most from the implementation of the policy. However, a range of benefits are predicted for all the recorded native fish guilds on the Gwydir Valley floodplain.

An area of significance for native fish is the Gwydir/Gingham breakout zone which includes the Gwydir Wetlands (Spencer et al. 2010, Southwell et al. 2014). This breakout zone includes a range of species from all four native fish guilds. Twelve native fish species have been recorded in this reach including the Murray-Darling Rainbowfish and the Unspecked Hardyhead, both considered generalists. An additional four species are predicted to occur in this breakout zone, including Silver Perch (Table 2). Based on the average across all metrics tested for each guild the following outcomes are expected for the Gwydir/Gingham breakout zone:

- Short-moderate floodplain specialists: Average improvement of 119% in 9 EWR metrics, the largest is a 466% increase in spring floods followed by summer floods which are important for successful recruitment (recruitment timing).
- Generalists: 98% (average) increase in achievement of the 7 EWR metrics tests. Improvements of 76% or more are expected for all EWR metrics.
- Flow pulse specialists: The 7 EWR metrics tested were achieved 105% more often when averaged across metrics. The lowest percent change was an increase of 76% in the duration of floods required for egg development (5 days min), with 89 more floods meeting this requirement with the policy implemented.
- River specialists: Are expected to have the smallest improvements, with an average increase of 58% in EWR achievement (7 EWRs). This is still considered substantial, with the flood frequency required to maintain fish within this guild increasing by 89 extra events (79% increase) in this breakout zone.

The breakout zones (Gil Gil/Carole and Marshall) are expected to receive no improvements or receive slightly less flood events which meet fish EWR requirements. The changes expected for native fish in the Gil Gil/Carole breakout zone are minimal. Based on the average change across fish guild EWRs, this breakout zone is predicted to have reduced outcomes for flow pulse specialists, -2% EWRs (7 EWRs). Only small improvements are predicted for the other fish guilds. These are +3% for river specialists (7 EWRs), +1.6% for short-moderate lived floodplain specialists (9 EWRs), and +0.5% increase in generalists (7 EWRs).

Along with these direct benefits, indirect benefits, or disadvantages from changes to important ecosystem functions (e.g. productivity) and key habitats may also impact native fish. These are discussed in the following sections.

Table 6 Percentage change in frequency of achieving native fish EWRs in the Gwydir Valley floodplain after implementing the policy. Values represent average (minimum and maximum) predicted outcomes, averaged over the simulation period across the 8 breakout zones. Minimum and maximum are shown in parentheses. S-M FP = short-moderate lived floodplain; N/A = no EWR available

Hydro feature	EWR metric	S-M FP Specialists	Generalists	Flow pulse specialists	River specialists
Duration	Egg development	+12% (0, +45)	+15% (-1, +77)	+15% (-1, +77)	+10% (-2, +22)
Frequency	Maintenance	+22% (0, +99)	+17% (0, +79)	+18% (0, +79)	+17% (0, +79)
	Maintenance (interflow)	+18% (-1, +79)	+18% (-1, +79)	+16% (-15, +79)	+17% (0, +79)
	Reproduction	+20% (-2, +78)	N/A	+16% (0, +77)	+17% (-1, +77)
	Reproduction (interflow)	+15% (-1, +79)	+17% (-1, +77)	N/A	N/A
Timing	Maintenance	N/A	+16% (0, +79)	+15% (-1, +79)	+16% (0, +79)
	Recruitment	+70% (-1, +467)	+37% (0, +217)	+54% (0, +248)	+1% (-33, +25)
	Spawning	-2% (-25, 10)	N/A	+17% (-1, +96)	+10% (0, +60)
	Spawning habitat	+19% (-2, +104)	+15% (0, +79)	N/A	N/A
	Food, refugia	+24% (0, +116)	N/A	N/A	N/A

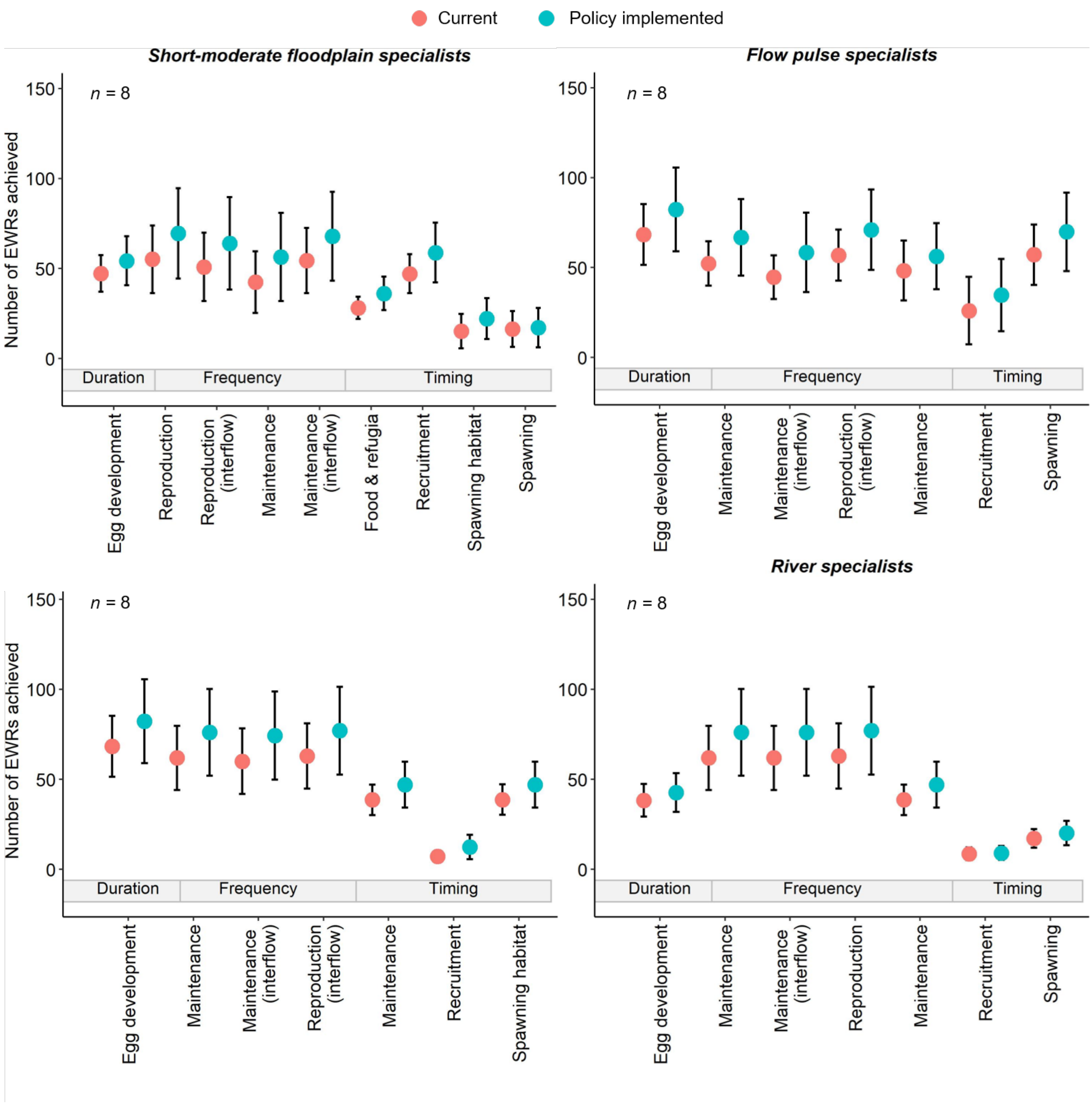

Figure 22 Average number of EWRs achieved for native fish with (policy implemented) and without (Current) the policy implemented over the 121-year simulation period across the 8 breakout zones (*n*). The grey horizontal rectangles identify the hydrological feature (duration, frequency, timing) and the x axis labels are the EWR metric. Error bars represent the standard error, *n* = 8

5.6 Native vegetation

5.6.1 Metrics

The key water-dependent native vegetation values used in this assessment are lignum, blackbox, coolabah (flood-dependent woodland and shrubland), river cooba, river red gum, water couch, marsh club-rush (Figure 23) and cumbungi (non-woody wetland) (Table 2).These species were chosen as key umbrella species for a range of other vegetation values and have detailed EWR information documented. Although other species are predicted, known, or recorded on the floodplain (e.g. poplar box), EWR information was not available and therefore outcomes were not assessed for these species. This assessment tested native vegetation EWRs based on two key hydrological features – **frequency and timing of flood events**; for two key life-stages requirements – **maintenance of established vegetation** and **regeneration or reproduction**. Where there was insufficient information for a specific hydrological feature or life stage the EWR was not assessed. The specific values for each EWR metric varied with each native vegetation species and can be found in Appendix C The majority of EWR values were sourced from Roberts and Marston (2011) and OEH (2018a).

As flood duration is a critical EWR metric for native vegetation, we substituted it with **total flow days in key months/seasons** as an indicator of outcomes for duration EWRs[9]. The full list of key months/seasons is in Appendix C The key months (i.e. timing) where changes in flow days are of interest are primarily spring and summer for most vegetation values, with autumn and winter important for some (e.g. Marsh club-rush).

It is important to recognise that the number of years of watering ‘required’ to achieve specific outcomes is dependent on the vegetation condition, which is spatially variable according to the historical inundation regime across the floodplain (Casanova 2015). This study does not address this issue.

In total, up to 7 (depending on the vegetation type) EWRs were tested for native vegetation.

Figure 23 Flowering head of marsh club-rush [Photo: Kevin Thiele, /flickr.com]

[9] The reason for this substitution is set out in Section 5.3.1. In short, duration of flood water on the floodplain is not modelled.

Figure 24 River red gum, an important eucalyptus tree on the Gwydir Valley floodplain [Photo: John Tann /flickr.com]

5.6.2 General hydrological impacts

Modelling of key hydrological metrics suggests an overall improvement in floodplain outcomes through implementation of the policy (Table 4, Figure 19). Modest increases in the **number, duration, and volume of flow events** across the floodplain are likely to benefit key native vegetation species, providing opportunities for seed dispersal, seedling establishment and maintenance of mature vegetation. Predicted increases in summer volumes (average 23% increase) are likely to be particularly important, as many species require flood events over the warmer months to enable seedling establishment and to avoid desiccation. Benefits to spring floods are smaller, with average increase of 17% across the Gwydir Valley floodplain. Some breakout zones on the floodplain will benefit more than others. For example, the Gwydir/Gingham breakout receives some of the largest flood events in the Gwydir Valley and supports a diverse array of vegetation species. This breakout is also predicted to have the largest volume increase in the valley, a 109% increase in the number of flood events and a 54% reduction in inter-event periods between floods. These changes are all expected to provide benefits to native vegetation in this major floodplain breakout once the policy is implemented.

The **duration of floods** required for most vegetation values varies but is often at least 2 months of inundation. Substantial improvements in the substitute indicator, i.e. change in the **number of flow days** during summer are evident at Gwydir/Gingham (E) breakout zone which supports the Gwydir wetlands (Table 5). Smaller improvements are expected at zones A, C, D, F, G and H, with little to no change expected in the Marshall (B) breakout zone. Summer is a critical period for maintenance, regeneration and reproduction for most vegetation values including river red gum, lignum, coolabah, blackbox, water couch and cumbungi.

Based on the median across all breakout zones, very small changes are predicted for the **number of flow days** in spring (Figure 20), September to November, indicating minimal improvement for spring flood durations. Spring is a critical month for most native vegetation species. Gwydir/Gingham breakout is expected to have more flow days at the start of spring (Sep) after implementation of the policy with smaller improvements predicted in zones D, G and H. Deadman/Biniguy, Marshall, Carole Gil, Gil Carole, Moomin and Thalabe are predicted to have a slight increase to no change and Mehi a slight decrease in total flow days for spring. Winter floods are important for the marsh club-rush and cumbungi. The number of flow days in winter months improved most in Mehi (21%), Moomin (19%) and Thalaba (33%), with smaller increases in Deadman/Biniguy, Marshall, Carole/Gil and Gwydir/Gingham. Gil/Carole is expected to have a reduction in total winter flows. Less flow days during winter months is likely to have negative effects for these vegetation values.

5.6.3 Impacts on native vegetation specific EWRs

Modelling indicates that implementation of the policy in the Gwydir Valley will result in an average increase in the achievement of all the tested native vegetation EWRs (Table 7). Of the 29 metrics tested, all 29 are expected to experience benefits with an average increase in frequency of 26%. The number of EWRs predicted to be achieved, over 121 years under the two policy scenarios, for river red gum, coolabah, lignum and water couch are presented in Figure 25. Under the implemented policy scenario all 8 of the species recorded an average increase in the frequency and timing required for maintenance and seedling establishment related EWRs. However, there is spatial variability amongst the breakout zones, including 3 EWRs that have a slight decrease (see below) and a large benefit seen within the Gwydir/Gingham breakout.

The Gwydir/Gingham breakout supports 7 of the 8 species assessed in this report. The breakout zone is also predicted to receive the biggest benefits for these species compared to other breakout zones on the Gwydir Valley floodplain. For example, flooding frequency required for **water couch** maintenance is predicted to be met 108 times more as a result of policy implementation (96 events without and 204 with the policy implemented: 113% increase). **Cumbungi** is predicted to experience some of the largest increases in the frequency and timing of EWRs, which reflects it only being found in the Gwydir/Gingham breakout zones.

Of the seven EWRs tested for **river redgum**, six are predicted to have no change or improve across all six breakout zones tested. The timing for seedling establishment (Aug-Nov) is the one EWR that decreased (from 10 to 9 events, 10%) in both Mehi and Thalaba breakout zones. However, while Thalaba has fewer flood events from Aug-Nov, it has more total number of flow days (Table 5) resulting in fewer flood events of longer duration during the seedling establishment period.

Gil Carole breakout zone experienced the worst outcome for vegetation. The largest EWR reduction is for **lignum** winter seed dispersal events (3 events, -4%). Gil Carole also had a slight reduction (1 event, -0.64%) in the frequency of flood events that occur every 7 years. This EWR is important for the maintenance of four of the five vegetation types found within the breakout zone (lignum, coolabah, blackbox and river cooba).

The **marsh club-rush** (*Bolboschoenus caldwellii*) is a key species of the marsh club-rush sedgeland in the Darling Riverine Plains Bioregion. This species is listed as a critically endangered ecological community under the NSW Biodiversity Conservation Act 2016. It is predicted to occur in 2 of the assessed breakout zones (Gwydir/Gingham and Moomin Creek). Table 7 shows an increase in all three EWRs being achieved. The number of flood events which achieve the required flood frequency for mature plant maintenance has a large variability between the two breakout zones. Moomin Creek achieves an increase of 14% (3 more events), while Gwydir/Gingham achieves a 124% increase (92 more events). This averages to a 69% increase in the EWR for mature plant maintenance for marsh club-rush, with benefits largely experienced within the Gwydir/Gingham breakout zone. Overall, this critically important vegetation species is expected to benefit from implementation of the policy.

Improvements to native vegetation will likely have flow on benefits for other environmental values on the floodplain, including waterbirds, fish, and key ecological functions. Native vegetation can help to support many animals through the provision of refuge, feeding and breeding habitat. Additionally, vegetation is crucial for sustaining ecological function and can play an important role in increasing productivity, improving water quality, and reducing erosion.

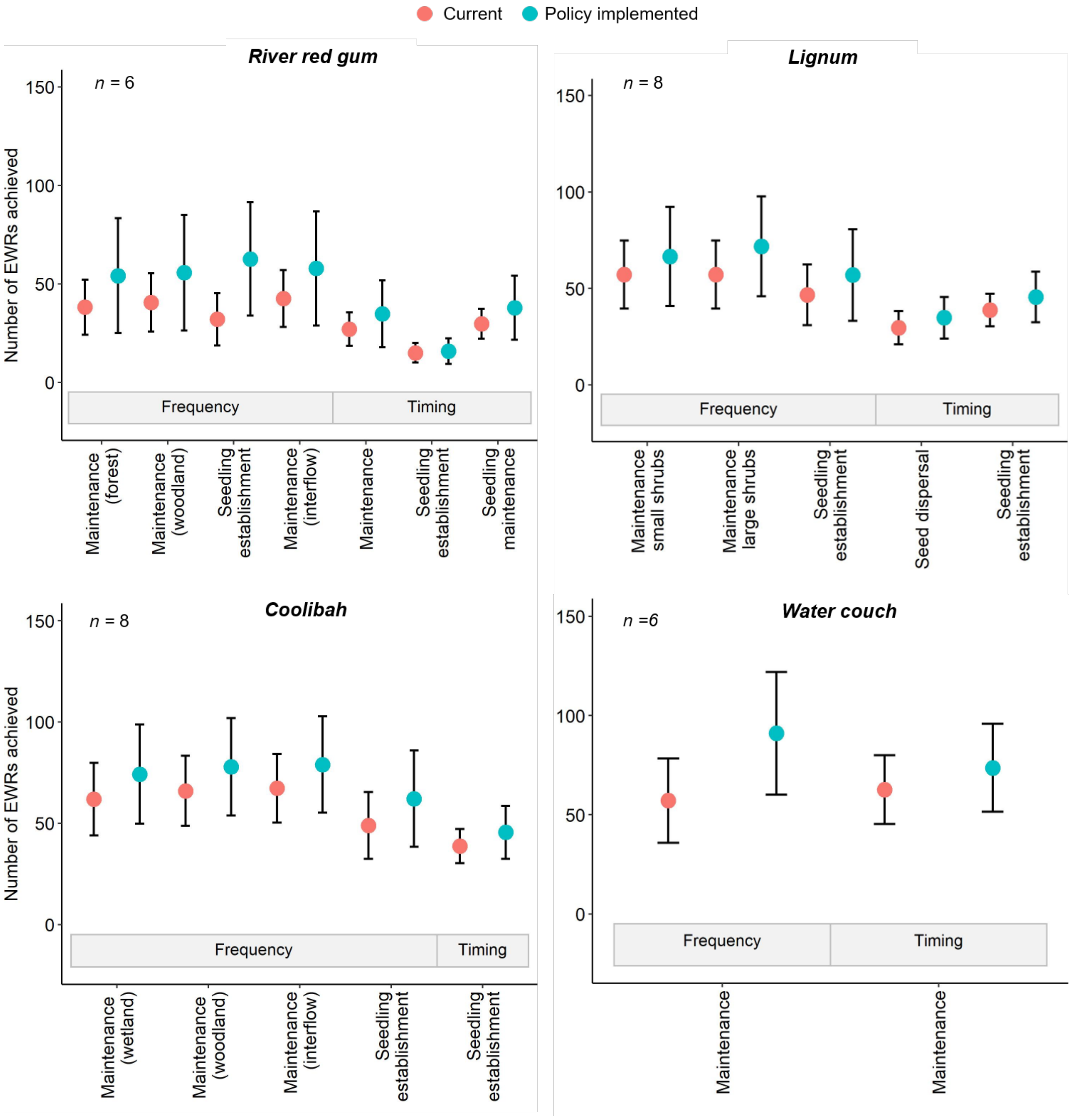

Figure 25 Average number of EWRs achieved for 4 key native vegetation values (river red gum, lignum, coolabah, water couch) with (Policy implemented) and without (Current) the policy implemented in the Gwydir Valley over the 121-year simulation period. The grey horizontal rectangles represent the hydrological feature whilst the x-axis labels are the EWR metric. *n* is the number of breakout zones. Error bars represent the standard error

Table 7 Percentage change in frequency and timing of achieving native vegetation EWRs in the Gwydir Valley floodplain after implementing the *p*olicy. Values represent average, minimum and maximum predicted outcomes, averaged over the simulation period across the 8 breakout zones. Minimum and maximum values are shown in parentheses. *n* represents the sample size, or the number of breakout zones used for each vegetation value; N/A = no EWR available

Hydro feature	EWR metric	Lignum *n* = 8	Blackbox *n* = 2	Coolabah *n* =8	River cooba *n* = 7	River red gum *n* =6	Water couch *n* = 6	Marsh club-rush *n* = 2	Cumbungi *n* = 1
Frequency	Maintenance	Small shrubs +19% (-0.7, +88) Large shrubs 39% (3, +93)	+9% (-0.6, +20)	Wetland +17% (0, +80) Woodland +15% (-0.6, +77)	+15% (-0.7, +77)	Forest +23% (0, +88) Woodland +21% (0, + 80)	+78% (+12, +113)	+69% (+14, +124)	+88%
	Seedling establishment	+23% (-0.7, +108)	+13% (0, +26)	+22% (0, +99)	N/A	+99% (+88, +113)	N/A	+50% (+13, +88)	+99%
	Maintenance (interflow)	N/A	N/A	+15% (-0.6, +77)	N/A	+21% (0, +80)	N/A	N/A	N/A
Timing	Maintenance	N/A	N/A	N/A	N/A	+17% (0, +79)	+13% (0, +60)	+16% (+15, +17)	+74%
	Seedling establishment	+15% (0, +79)	+9% (3, +15)	+15% (0, +79)	N/A	+2% (-10, +26)	N/A	N/A	N/A
	Seedling maintenance	N/A	N/A	N/A	N/A	+18% (0, +79)	N/A	N/A	N/A
	Seedling dispersal	+16% (-4, +74)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5.7 Waterbirds

There are 76 waterbird species predicted or recorded to occur across all breakout zones. The list of species covers colonial-nesting and non-colonial waterbirds from 5 functional feeding groups identified in Brandis and Bino (2016). These are shorebirds, piscivores, large waders, herbivores, and ducks.

5.7.1 Metrics

This assessment focussed on environmental water requirements to **maintain habitat, populations, and breeding for colonial-nesting and non-colonial waterbirds**. Metrics assessed for waterbird outcomes were **frequency** and **timing of floods**. Frequency and timing EWRs were sourced from the Gwydir LTWP (DPIE EES 2020).

Figure 26 The Australasian darter, one of the many fish-eating waterbirds found on the Gwydir Valley floodplain [Photo: Rob Russell/flickr.com]

EWR outcomes for colonial and non-colonial waterbirds were assessed using information derived from the wetland inundation (WL) and overbank flows (OB) listed in the Gwydir LTWP (DPIE EES 2020). Overbank flows are when water breaks the riverbank and wetland inundation events are defined by the Gwydir LTWP as:

> ‘flows that fill wetlands via regulating structures below bankfull over weeks or sometimes months (i.e. longer than a typical fresh/pulse), or
>
> flows that are required to inundate wetlands in areas where there are very shallow channels or no discernible channels exist (e.g. terminal wetlands)’ (DPIE EES 2020).

Achievement of these EWRs is predicted to either improve habitat, resources or provide breeding opportunities for a broad range of waterbirds, both colonial and non-colonial. Smaller and shorter events generally provide breeding opportunities for non-colonial waterbirds whilst larger and longer events provide opportunities for both. However, for simplicity we have generalised outcomes for non-colonial and colonial waterbirds using the frequency and timing of OB and WL flows in the LTWP. We used Table 10 and Table 13 (in the LTWP) to refine which timing related LTWP EWRs to maintenance, survival, and breeding for colonial-nesting and non-colonial nesting waterbirds.

Colonial waterbird breeding sites and waterbird rookeries are a critically important environmental asset for waterbird values in the Gwydir and broader Murray-Darling Basin. Colonial-nesting waterbirds are known to only congregate in specific areas of the Gwydir Valley floodplain. The

Gwydir/Gingham breakout supports the Gwydir Wetlands and surrounding waterholes (including Tillaloo and Boyanga) which are the key colonial-nesting waterbird breeding sites in this valley (Spencer 2010). Therefore, frequency and timing LTWP EWRs which are listed as supporting colonial-nesting breeding events (i.e. WL4, OB4 and OB5) are assessed only in the Gwydir/Gingham breakout zone for colonial-nesting waterbirds. The other EWRs which are listed as supporting maintenance and survival of waterbirds (Table 10 and Table 13 of the Gwydir LTWP Part A (DPIE EES 2020a)) are still relevant to colonial-nesting species as they are often dispersed across the landscape when not nesting. Records of colonial-nesting waterbird species in all breakouts of the Gwydir Valley floodplain can be found in Appendix A .

This report incorporates modelled nodes on the floodplain and not gauging station nodes (see Appendix D for reasoning). Therefore, frequency EWRs were simplified to reflect a change in achieving different flood frequencies on the floodplain, rather than achieving a specific wetland (WL) or overbank (OB) threshold for each frequency (e.g. >60,000 ML/d at Gwydir at Yarraman (418004), 1 year in 10). Seven **flood frequencies** were assessed:

- 9, 7, 5, 6, 4, 3 and 1 years in 10 (years).

As flood duration is a critical EWR metric for waterbirds, we used the change to **total flow days in key months/seasons** as an indicator of any outcomes for duration EWRs. The important months or seasons were derived from the LTWP EWRs and are identified in Appendix C . The main months of interest are between August and February, with some early autumn months important for some LTWP EWRs.

This assessment assumes that meeting an EWR results in a beneficial outcome. In reality, the response of waterbirds to flooding can be influenced by a variety of factors not incorporated into this assessment. Therefore, the predicted waterbird outcomes reported herein are a measure of potential outcomes with and without the policy implemented.

In total, 11 water requirements were tested.

5.7.2 General hydrological impacts

The reduced temporal variability, frequency and volume of river flows due to water resource development has significantly impacted waterbirds (Lemly et al. 2000, Nilsson et al. 2005, Dudgeon et al. 2006). Improvements or reductions in these hydrological features are therefore expected to influence outcomes for waterbirds. Modelling of key hydrological metrics suggests an overall improvement in a number of these features in the Gwydir Valley (Table 4, Figure 19). The **frequency of flood events** is predicted to increase, meaning more floodwater can be expected to make it onto and through the floodplain, improving longitudinal connectivity. In addition, the **inter-event period** reduced by -12% across the valley which suggests that the periods between flood events should shorten through implementation of the policy. **Total annual volumes** are also predicted to improve by up to 22% in some breakout zones (e.g. Deadman/Biniguy).

The **total number of flow days** during winter and spring are expected to see only small increases overall (5%-8%) with a reduction in Carole/Gil (-22%) in September and Gwydir/Gingham in October (-33%) (Table 5, Figure 20). However, Gwydir/Gingham is predicted to increase in October (81%) and November (33%), and Carole Gil increase in November (23%). In general, there is a net increase in the number of flow days across the valley, with greater improvement in autumn and summer seasons (Table 4, Figure 19). Shorter periods of flow during August, September, October, and November are predicted to improve from December until May which is a critical period for a range of overbank and wetland inundation EWRs.

The biggest improvements between December and May are expected for the Gwydir/Gingham, Mehi and Gil/Carole breakout zones (Table 5). The Gwydir/Gingham breakout supports the Gwydir Wetlands, a known waterbird rookery and a diverse range of waterbirds. The number of flow days are predicted to increase by 33% to 112% between November and May at this breakout, with the biggest improvements during April (+112%) and December (+95%). The minimal improvement in flow days during late winter and spring (in some cases reduced number of flow days) may be a constraint to achieving improved waterbird outcomes in the Gwydir Valley.

In general, implementation of the policy should improve temporal variability, flood frequency and volume to provide broad-scale benefits for waterbirds in the Gwydir Valley. While considerable improvements in hydrological features are expected, the greatest seasonal improvements are expected in autumn and summer with minimal improvements in flood volumes and duration predicted for winter and spring. Greater improvements in spring would be desirable as this season is important for waterbird breeding.

5.7.3 Impacts on waterbird specific EWRs

The outcomes for waterbirds vary across the 8 breakout zones, but on average, implementing the policy is predicted to provide benefits for the frequency and timing of floods for colonial-nesting and non-colonial waterbirds (Table 8, Figure 27).

Outcomes for the frequency and timing EWRs for waterbirds are predicted to improve for all tested EWRs once the policy is implemented (Table 8). The average number of EWRs achieved under the policy implemented scenario are predicted to increase by 14–163% across the Gwydir Valley floodplain for all EWRs.

The Gwydir Wetlands is a Ramsar listed wetland group with internationally significant breeding areas for colonial nesting waterbirds (Kingsford 2000). The wetlands consist of the Ramsar subsites; Old Dromana, Goddard’s Lease, Crinolyn and Windella in addition to the Gwydir Wetlands SCA. Other sites nearby include the Gingham waterhole and other important waterholes (DECCW 2011). The Gwydir Wetlands is located in the Gwydir/Gingham breakout, with the Crinolyn and Windella subsites located directly downstream of the breakout (Figure 13). EWRs which would provide breeding opportunities for colonial-nesting waterbirds were only assessed in the Gwydir/Gingham breakout due to the known colonial-nesting sites in this breakout.

This area is predicted to receive the largest improvements once the policy is implemented. **Breeding** EWRs are expected to be achieved 60–163% more often for colonial-nesting waterbirds. Across the modelled 121-year period, the frequency of appropriately timed events (such as seasonality) are predicted to increase by 35–67 events (93-141%). These improvements should improve survival of waterbirds through maintenance of refugia, improved habitat and more frequent breeding opportunities. The beneficial outcomes due to more frequent and appropriately timed overbank and wetland inundation events would be enhanced with improved flood durations (i.e. number of flow days) during late winter and spring.

Table 8 Percentage change in frequency of achieving waterbird EWRs in the Gwydir Valley floodplain after implementing the policy. Values represent average, minimum and maximum habitat maintenance, and survival outcomes, averaged over the 121-year simulation period. EWRs for habitat maintenance and survival are averaged across 8 breakout zones for colonial-nesting species. Breeding EWRs for colonial-nesting species are only relevant to the Gwydir/Gingham breakout. Minimum and maximum are shown in parentheses. *n* represents the sample size or the number of breakouts in which a value was present

Hydro feature	EWR metric	EWR detail	Colonial-nesting n **= 8 for non-breeding EWRs and** n **= 1 for breeding EWRs**	Non-colonial nesting n **= 8**
Frequency	Maintenance and survival	9 years in 10	+31% (-1, +221)	+31% (-1, +221)
		7 years in 10	+61% (-2, +200)	+61% (-2, +200)
	Maintenance, survival, and breeding opportunities	5 years in 10	+46% (0, +170)	+46% (0, +170)
		4 years in 10	+71% (-2, +350)	+71% (-2, +350)
		3 years in 10	+163%	+37% (-3, +163)
	Breeding	2 years in 10	+163%	+36% (0, +163)
		1 year in 10	+124%	+23% (-1, +124)
Timing	Maintenance only	September – March	+17% (-3, +87)	+17% (-3, +87)
	Maintenance and breeding opportunities	October - April	+20% (-4, +100)	+20% (-4, +100)
		August - February	+60%	+14% (0, +60)
	Breeding	September - May	+91%	+18% (-1, +91)

Along with these direct measures, changes to important ecosystem functions (e.g. productivity) and key habitats (e.g. native vegetation) indirectly influence waterbird outcomes, either positively or negatively. For example, improved outcomes for native vegetation should have a range of flow on effects for waterbirds. More frequent flooding at appropriate times should improve lignum vegetation which is a preferred nesting site for colonial-nesting waterbirds (Spencer 2010). Another example is coolabah trees which are important roosting and nesting habitat for a range of waterbirds (Spencer 2010). The positive outcomes for coolabah are likely to contribute to better outcomes for a variety of waterbirds. A range of other vegetation values (e.g. cumbungi) are crucial for waterbirds, the predicted outcomes for these values may benefit waterbirds on the Gwydir Valley floodplain.

In general, more frequent, and appropriately timed events should provide improved outcomes for all colonial-nesting and non-colonial waterbirds in the Gwydir Valley.

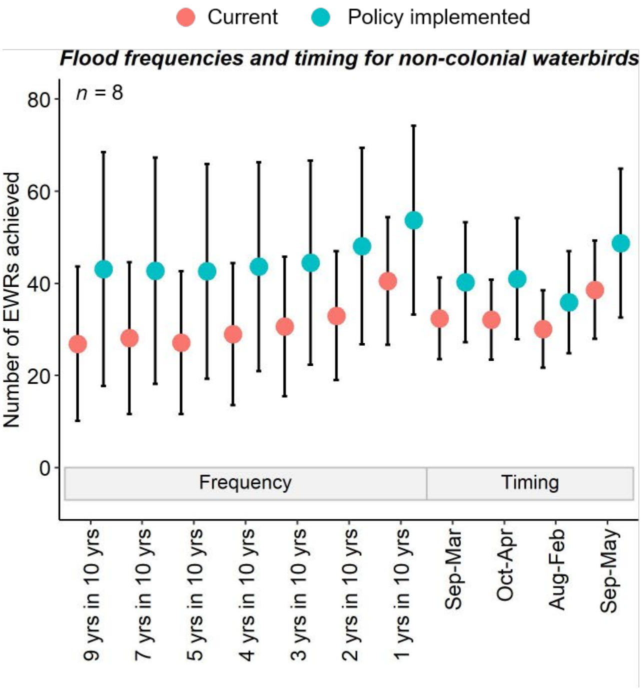

Figure 27 Left: average number of frequency and timing related EWRs achieved for non-colonial nesting waterbirds with (Policy implemented) and without (Current) the policy implemented in the Gwydir Valley. Data is based on the 121-year model period across 8 breakout zones (*n*). The grey horizontal rectangles represent the hydrological feature whilst the x axis labels are the EWR metric. Error bars represent the standard error; *n =8*. Right: the endangered Australian painted snipe, a non-colonial waterbird [Photo: Laurie Boyle]

5.8 Important ecosystem functions

5.8.1 Metrics

Floodplains support a myriad of important ecosystems functions. Seven EWR metrics for a range of important ecosystem functions were used in this assessment, mainly related to nutrient supply and ecosystem productivity:

- the **duration of events needed to achieve productivity outcomes**. Longer event durations are expected to provide better productivity outcomes including increased invertebrate abundances (Boulton and Lloyd 1992, Ballinger et al. 2005). Based on expert opinion, the durations and outcomes were classified as:
  - reduced (days with flow <1 week)
  - better (1-2 weeks of days with flow)
  - best (>2 weeks of days with flow).
- the **event duration required to enhance dissolved organic carbon** (DOC) supply from anabranches (McGinness and Arthur 2011)
- the **inter-event frequency** (periods between floods) needed for anabranch productivity. Regular drying and wetting of anabranches can maintain base levels of productivity between overbank flows. Reduced inter-event periods can provide greater levels of productivity (McGinness and Arthur 2011)
- the **frequenc**y required to prevent DOC build up and potential blackwater events (DPIE EES 2020a)
- seasonal timing: **summer floods** provide the best outcomes for resources such as zooplankton (SKM 2009).

These represent some, but not all, of the EWRs considered important for ecosystem functions on the floodplain. This report uses these EWRs as a simplistic approach to indicate potential ecosystem function outcomes which may be provided by implementing the policy. Details of the EWR values used are provided in Appendix C .

5.8.2 General hydrological impacts

Changes to a number of hydrological features can influence key ecosystem functions. The predicted increases in the **number of events, mean annual volume and total summer volumes** (Table 4, Figure 19) should all provide beneficial outcomes for primary and secondary productivity as well as nutrient supply. Reduced **inter-event periods** should also increase the regularity of DOC supply from anabranches on the floodplain.

Whilst there are a number of improvements in relevant hydrological metrics for ecosystem functions, greater outcomes could be achieved if the timing or seasonality of these improvements were changed. For example, the largest increase in flood volumes is predicted for autumn months, with only modest improvements in spring and summer. Spring and summer are periods when greater productivity outcomes would be achieved. Of the breakout zones the Gwydir/Gingham, Mehi and Gil/Carole breakout zones (Table 5) have the greatest percent change in days with flow over summer-autumn with Deadman/Biniguy expected to have a small change and Marshall to have no change. Greater outcomes could be achieved if there were increases in seasonal flood volumes, frequency and duration at the Deadman/Biniguy and Marshall breakout zone, which is likely to improve ecosystem functions within the catchment and potentially downstream environments.

5.8.3 Impacts on specific EWRs for ecosystem functions

Modelling indicates that implementation of the policy in the Gwydir Valley will have beneficial outcomes for the tested ecosystem function EWRs (Table 9, Figure 28). The predicted improvements include:

- an increase in the number of floods with longer durations (i.e. more days of flow) which should support improved productivity outcomes and dissolved organic carbon supply,
- improved flood frequency (+16%) which may reduce blackwater events in the future,
- mean inter-event period is expected to reduce by 10% on average across the floodplain. This should result in better productivity outcomes provided by anabranches
- more floods during summer months (23% more on average) when biological activity is higher and temperature stress is greatest.

The frequency of the **'best' events** (i.e. event lasts for more than 2 weeks) for productivity outcomes is predicted to increase by 11% on average with the policy implemented. More events are expected to occur in **summer** months by up to 116% in the Gwydir/Gingham breakout zone alone (Table 9). Combined increases in events during summer and more frequent events of longer duration should provide beneficial outcomes during this warmer and highly productive period for aquatic organisms like zooplankton (SKM 2009).

The event frequency required to **reduce DOC build up** on floodplains and prevent the associated blackwater events is predicted to be met more often (up 16% on average). This outcome is highly variable with some breakout zones expected to have increased achievement of this EWR by up to 77% (Gwydir/Gingham) and others remaining unchanged (Gil Gil/Carole Creek and Marshall). Any improvements in preventing organic build up on the floodplain and reducing the frequency and severity of blackwater events is a positive outcome for native fish and other organisms at risk due to hypoxic (oxygen deficient) flood waters (Whitworth et al. 2012).

Whilst the average outcomes for the tested ecosystem function EWRs improved across the floodplain, some breakout zones are expected to improve more than others. For example, the Gwydir/Gingham breakout zone which supports a range of important assets and values is expected to have substantial improvements for all tested EWRs. This includes a reduction of 43% in the average period between floods and an increase of 116% for floods occurring during summer months. This equates to 44 additional flood events occurring during summer months over the 121-year simulation period. In contrast, the Gil Gil/Carole Creek breakout zone is expected to have little to no change based on the tested EWRs, with a reduction of 29% for floods with durations of 1-2 weeks long.

Table 9 Percentage change in frequency of achieving EWRs for ecosystem functions on the Gwydir Valley floodplain after implementing the policy. Values represent average (minimum and maximum) predicted outcomes, over the 121-year simulation period across the 8 breakout zones.

Hydro feature	EWR metric	% change
Duration	Less productivity outcomes (<1 week)	+53% (0, +145)
	Better productivity outcomes (1-2 weeks)	+33% (-29, +261)
	Best productivity outcomes (>2 weeks)	+11% (-14, +29)
	High dissolved organic carbon concentrations	+13% (-1, +66)
Frequency	Prevent blackwater and carbon build-up	+16% (-1, +77)
	Anabranch wetting and drying cycles (mean inter-event frequency/period)	-10% (-43, +1)
Timing	Better outcomes (summer)	+23% (0, +116)

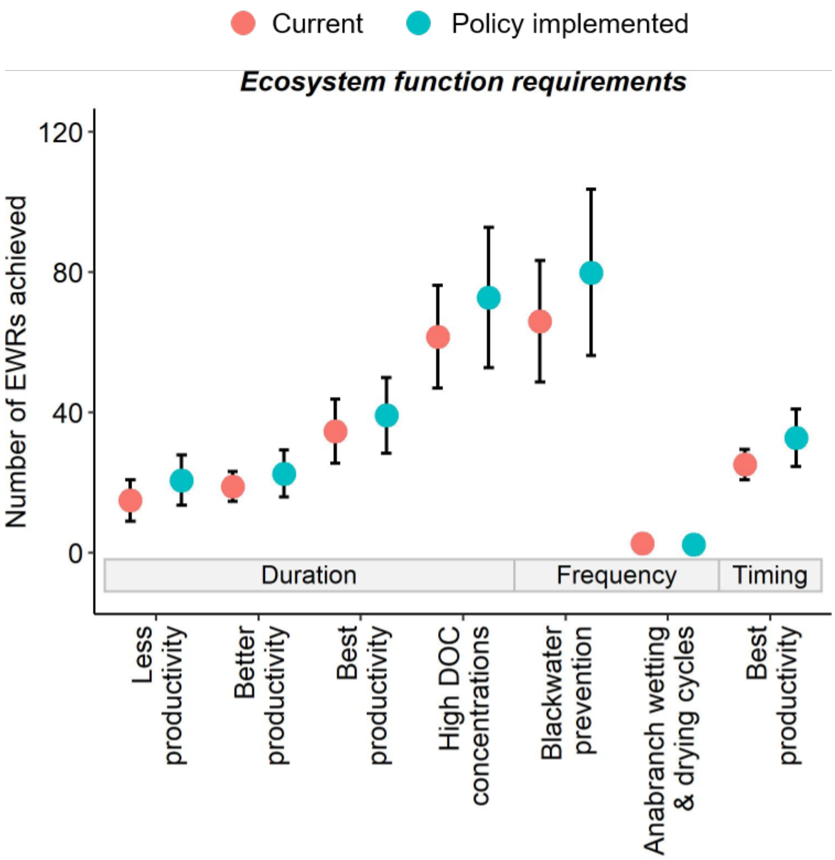

Figure 28 Average number of EWRs achieved for identified ecosystem functions with (policy implemented) and without (current) the policy implemented over the 121-year model period and across the 8 breakout zones (n). The grey horizontal rectangles represent the hydrological feature whilst the x axis labels are the EWR metric. Error bars represent the standard error

5.9 Wetlands

A variety of wetlands occur on the Gwydir Valley floodplain, including numerous significant anabranches, lagoons, wetlands, watercourses, and billabongs. Of particular importance is the Gwydir Wetlands Systems, which include Ramsar listed areas of wetland of international significance (Department of Agriculture, Water, and the Environment 2020). The Gwydir Wetlands Ramsar site is composed of four key wetland subsites listed within the Gingham Watercourse and Lower Gwydir areas: Old Dromana, Goddard's Lease, Crinolyn and Windella.

Other significant lagoons and wetlands have been identified in Schedule 4 of the Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012. Those included in this assessment are Mongyer lagoon, Collytootela lagoon and Mallowa wetlands. These wetlands all support a wide range of aquatic species through the provision of aquatic habitats and drought refugia.

5.9.1 Metrics

EWRs for the Gwydir Wetlands and other significant lagoons and wetlands were sourced from Part B of the Gwydir LTWP (DPIE EES 2020b). Only EWRs from appropriate planning units in the Gwydir LTWP Part B that included the wetlands of interest assessed in this report were used in this assessment. These outcomes were not directly targeted for the wetlands themselves but aimed to provide environmental outcomes for the values that each wetland or group of wetlands supports. These values included native fish, native vegetation, waterbirds, ecosystem functions and flow-dependent frogs. For example, overbank (OB1-5) and wetland inundation (WL2-4) events are listed as supporting a broad range of foraging habitats for waterbirds in the Gwydir Wetlands (DPIE EES 2020a). Therefore, **overbank** (OB1-5) and **wetland inundation** (WL2-4) were included as EWRs of interest for the Gwydir Wetlands, along with any other important EWRs listed for this wetland system. As mentioned in the waterbirds section, this report incorporates modelled nodes on the floodplain and not gauging station nodes. Therefore, frequency EWRs were simplified to reflect a change in achieving different flood frequencies for wetlands on the floodplain.

The selected **frequency and timing** EWR metrics from the Gwydir LTWP were only assessed for the breakout zone containing that specific wetland or group of wetlands. The wetland and associated breakout zones are:

- Gwydir Wetlands (all four Ramsar subsites inclusive of those just downstream of the breakout) – Gwydir/Gingham breakout zone
- Mallowa wetlands – Moomin Creek breakout zone
- Mongyer lagoon, Collytootela lagoon – Moomin Creek and Thalaba breakout zones.

There are no available OB or WL EWRs in the Gwydir LTWP Part B for the Thalaba Creek water source planning unit. This planning unit represented the Thalaba breakout zone. Instead, the nearby EWRs for the Moomin Creek planning unit were used for the Thalaba breakout. Details of the EWRs are provided in Appendix C .

5.9.2 General hydrological impacts

Modelling suggests that implementation of the policy should increase the number of **mean annual volumes, flow days, and total seasonal volumes** for the Gwydir/Gingham, Moomin Creek and Thalaba breakout zones (Table 4 and Table 5).

Mean annual volume will increase by 14% (10.4GL) in Moomin Creek and 17% (2.4GL) in Thalaba breakout zones. **Total volumes** should increase by 17%-15% in spring and 26%-28% in summer for Moomin Creek and Thalaba breakouts respectively over the modelled 121-year period. Only relatively small increases in the duration metrics (**number of flow days**) are predicted for the Moomin Creek and Thalaba breakouts which support Mallowa wetlands, Mongyer lagoon and Collytootela lagoon. In some cases, there are no/minimal changes in flow days for these breakouts (e.g. (March -May) (Table 5).

Overall, predicted improvements in volume, frequency and duration should benefit these three important wetland systems, however wetland ecology supported by Moomin Creek and Thalaba could further benefit from improved flow metrics in autumn and spring.

The Gwydir/Gingham breakout supports the most significant wetland site in the Gwydir Valley: the Gwydir Wetlands. This breakout is expected to receive a 13% increase in mean annual volumes during flood years (13GL), with a 28% increase in total summer volumes and 30% in autumn volumes (Table 4). Smaller increases are also expected in winter and spring (12%-19%) respectively. The number of flow days in summer are predicted to increase by 78% along with 109% more flood events which is 215 additional flood events across the modelled 121-year period. The winter period is likely to receive shorter flood durations, with smaller increases in the number of flow days (120%) which is an additional 148 flow days. The Gwydir/Gingham breakout is predicted to receive the largest hydrological benefits due to implementing the policy (Table 4). This should have positive flow on benefits for the Ramsar listed Gwydir Wetlands and the ecological values that the wetlands support.

Table 10 Percentage change in the total number of flow days in each month after implementing the policy for the Gwydir/Gingham, Moomin Creek and Thalaba breakout zones. Values are averaged over the 121-year simulation period. Only flows > 1 ML/day were considered flow days

Hydro feature	Breakout zone/wetlands	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Duration	E Gwydir/ Gingham Gwydir Wetlands	+53	+71	+71	+49	+112	+3	-6	+5	+83	-33	+33	+95
	G Moomin Creek/ Mallowa wetlands	+14	+12	0	0	0	0	+16	+3	0	0	+8	0
	G Moomin Creek and H Thalaba/ Mongyer lagoon and Collytootela lagoon	+12	+13	0	0	0	0	+16	+10	0	+6	+6	+4

5.9.3 Impacts on specific EWRs for wetlands

The Gwydir Wetlands is predicted to have positive outcomes for all EWRs tested (Table 11). The frequency and timing EWRs increased by 60-221% across all metrics tested. The smallest improvement (+60%) for floods occurring between August and February equates to 35 more events meeting this requirement in the 121-year simulation period. In contrast, a predicted increase of 100 or more flood events (improved frequency +124-221%) should pass through floodplain harvesting areas onto the floodplain. More appropriately timed events in warmer months combined with higher flood frequencies should provide beneficial outcomes for the Gwydir Wetlands and the values this system supports.

The Mallowa wetlands, Mongyer lagoon and Collytootela lagoon are predicted to receive smaller improvements (12-67% increase) for frequency EWRs. Timing EWRs which suggest flood events are required between August and February (+6%) are only expected to improve in the Moomin breakout zone. This should provide some benefits to these three wetlands. (Table 11).

Table 11 Percentage change in frequency of achieving EWRs for key wetlands of the Gwydir Valley floodplain after implementing the policy. The outcomes represent the percentage change for the breakout zones which support these wetlands, averaged over the 121-year simulation period. N/A identifies where EWR metrics are not documented in the LTWP planning unit relevant to the breakout

Hydro feature	EWR metric	Gwydir Wetlands	Mallowa wetlands	Mongyer and Collytootela lagoon	Mongyer and Collytootela lagoon
Breakout zone		**Gwydir/ Gingham**	**Moomin Creek**	**Moomin Creek**	**Thalaba**
Frequency	9 years in 10	+221%	N/A	N/A	N/A
	7 years in 10	+184%	N/A	N/A	N/A
	5 years in 10	+198%	N/A	N/A	N/A
	4 years in 10	+170%	N/A	N/A	N/A
	3 years in 10	+163%	+67%	+67%	0%
	2 years in 10	+162%	N/A	N/A	N/A
	1 year in 10	+124%	+14%	+14%	+12%
Timing	September–March	+87%	N/A	N/A	N/A
	October–April	+100%	N/A	N/A	N/A
	August–February	+60%	+6%	+6%	0%
	September–May	+91%	N/A	N/A	N/A

5.10 Flow-dependent frogs

The Gwydir floodplain contains important refugia and habitat for flow-dependent frog species including anabranches, lagoons, wetlands, watercourses, and billabongs. Increased frequency of flooding events and duration of inundation to these habitats is likely to have a range of benefits to maintenance and breeding outcomes for flow-dependent frogs. Three flow-dependent frog species have been recorded or are predicted to occur in the 8 breakout zones. These are the barking frog, Sloane's froglet and the broad-palmed frog (Figure 29). Numerous other species have been recorded including up to 6 flow-dependent frog species in recent surveys of the Gwydir wetland system (Ocock JF and Spencer J 2018, DPIE EES 2020c). This report generalises the predicted outcomes for all flow-dependent frog species in the valley.

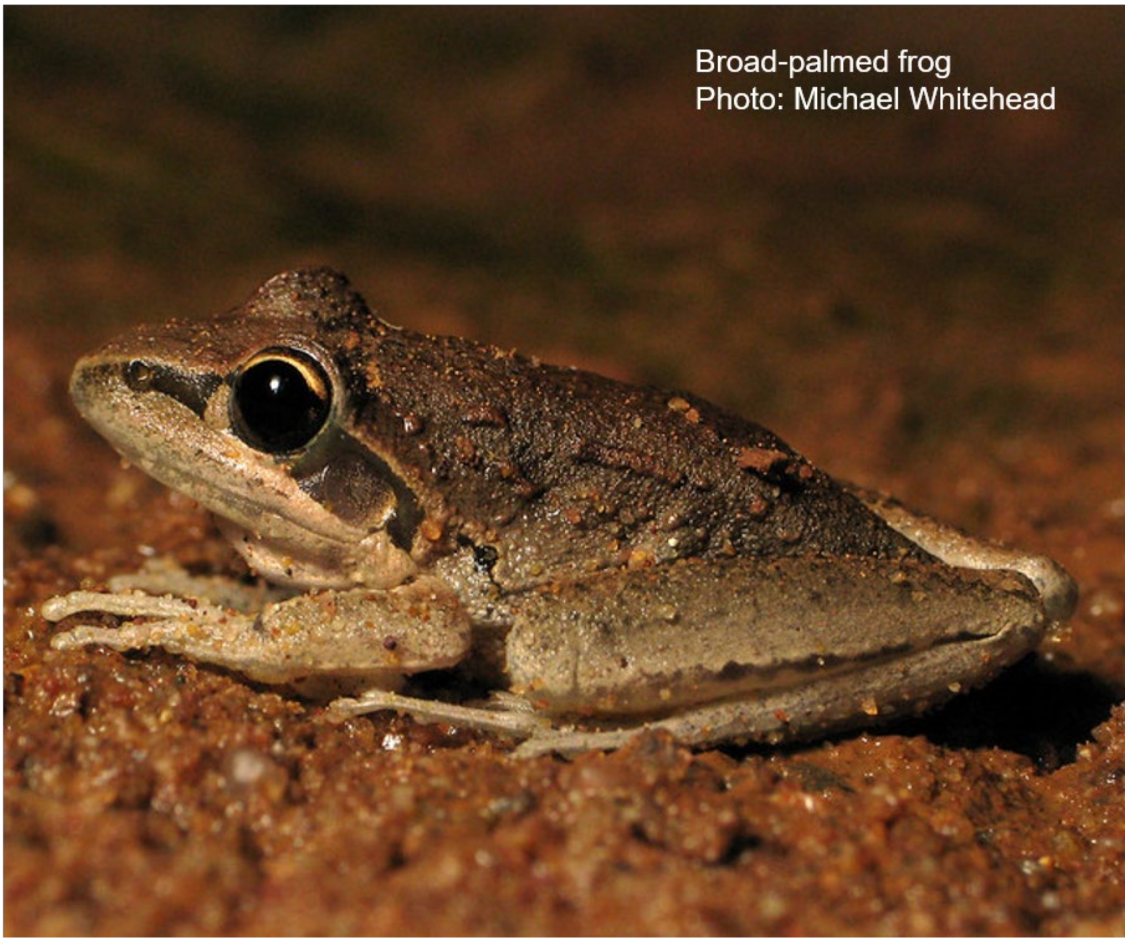

Figure 29 The broad-palmed frog, a ground-dwelling tree frog [Photo: Michael Whitehead]

5.10.1 Metrics

To identify the impact of changes in hydrological features such as frequency, duration and timing of events, specific **frequency and timing** EWRs listed against expected frog outcomes in the Gwydir LTWP (DPIE EES 2020a), likely to maintain or provide reproduction opportunities for frogs, were tested. Small wetland inundation (WL) and overbank (OB) events are important for a number of wetland values including maintaining frog populations. The breeding requirements are generalised for all frogs but vary from the frequency and timing of WL and OB events.

Details of the EWRs are provided in Appendix C . In total, 6 water requirements for flow-dependent frogs were tested.

5.10.2 Impacts on specific EWRs for flow-dependent frogs

Implementation of the policy is predicted to provide improvements for all six frog EWRs assessed (Figure 30, Table 12). An increase of 15% or more is predicted for the timing and frequency of flood events important for flow-dependent frogs on the floodplain. As with the benefits for other assets and values, the Gwydir/Gingham breakout is expected to receive some of the greatest benefits with a 64-221% improvement across all frequency and timing EWRs. The number of floods occurring during the summer for summer breeding species is expected to increase by 87%, which equates to 53 more events in the 121-year simulation period.

Predicted improvements in the **number of flow days** (Figure 20) between December and March should benefit flow-dependent frogs on the floodplain. However, longer durations during spring, specifically September and October would provide even better outcomes for frogs.

Table 12 Percentage change in the frequency of achieving flow dependant frog EWRs in the Gwydir Valley floodplain after implementing the policy. Values represent average, minimum and maximum predicted outcomes, averaged over the simulation period across the 8 breakout zones. Minimum and maximum are shown in parentheses

Hydro feature	EWR metric	% change
Frequency	Maintenance: 9 years in 10	+31% (-1, +221)
	Maintenance: 7 years in 10	+62% (-2, +200)
	Breeding	+23% (-1, +124)
Timing	Maintenance: Sep-Mar	+17% (-3, +87)
	Breeding: spring to summer breeders	+20% (-3, +100)
	Breeding: flexible breeders: Jul-Apr	+15% (-3, +64)

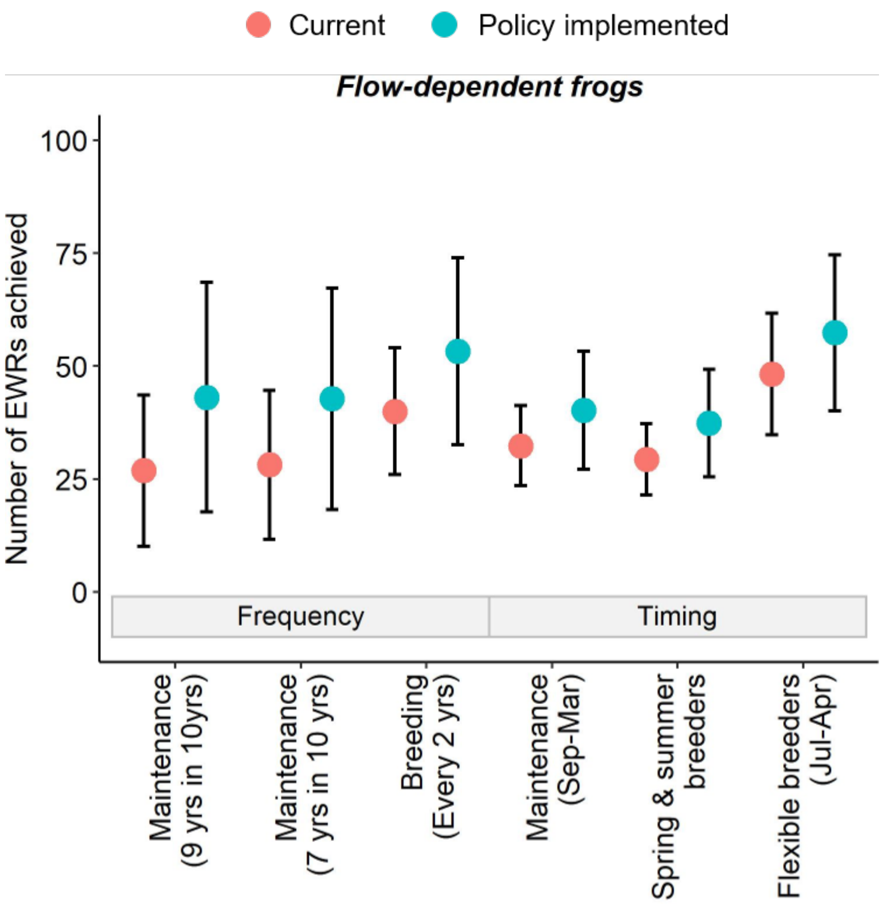

Figure 30 Average number of EWRs achieved for flow-dependent frogs with (policy implemented) and without (current) the policy implemented in the Gwydir Valley floodplain over the 121-year simulation across the 8 breakout zones (*n*). The grey horizontal rectangles represent the hydrological feature whilst the x axis labels are the EWR metric. Error bars represent the standard error

6 Breakout zone specific changes to EWRs

The average percentage change in the achievement of all tested EWRs for a given asset (or group of values) was calculated for native fish, waterbirds and native vegetation for each of the 8 breakout zones (Table 13). Summarised outcomes for these 3 key environmental value categories at each breakout zone provide an assessment of zone-specific outcomes on the Gwydir Valley floodplain. The average percentage change represents a high-level summary of the predicted increase or decrease in the number of EWRs met after implementation of the policy. For the majority of environmental values, implementing the policy resulted in modelled improvements at most breakout zones, with some breakout zones predicted to see greater improvements than others.

Between 7 and 9 **native fish** EWRs were tested for each fish guild, depending on the available EWR information (Table 6). Breakout zone specific changes were summarised by averaging the percent change for these EWRs at each breakout zone. At least a 7% increase in predicted EWR achievement is expected for all four native fish guilds at six of the eight breakout zones. In contrast, at the Gil Gil/Carole Creek and Marshall breakouts, the number of EWRs met is not expected to change with the policy implemented. The Gwydir/Gingham breakout is expected to receive the best native fish outcomes (+97%) averaged across the four guilds, followed by the Mehi River (+22%) and Moomin Creek (+12%) breakouts.

Up to seven different EWRs were tested for **native vegetation** (Table 7) and averaged for each vegetation value (i.e. species) (Table 13). On average, native vegetation values are expected to see a positive change in EWR achievement at all eight breakout zones. The greatest improvements are predicted for Gwydir/Gingham breakout (+82%). This breakout supports the Gwydir Wetlands and a diverse array of native vegetation species. The modelling suggests that there will be little improvement (+1%) for vegetation in the Gil Gil/Carole Creek breakout zone.

For **waterbirds**, 11 EWRs were tested (Table 8) and averaged for each breakout zone (Table 13). The average achievement of these 11 EWRs increased for all but two of the breakouts. Little to no change is predicted for the Marshal (0% change) and Thalaba (+1%) breakouts. A small reduction in the achievement of both colonial and non-colonial waterbird EWRs is predicted for the Gil Gil/Carole breakout zone. In contrast, the Gwydir/Gingham (+142%), Mehi River (+33%) and Moomin Creek (+33%) breakout zones are predicted to improve substantially. The improvements in the Gwydir/Gingham breakout zone are critical, as this zone supports the Gwydir Wetlands and is critical to waterbird populations in the Northern Murray-Darling Basin.

Overall, implementation of the policy is likely to benefit 6 of the 8 breakouts with the greatest benefits in the Gwydir/Gingham, Mehi River and Moomin Creek breakout zones. The Gil Gil/Carole Creek and Marshall breakouts are not expected to receive much benefit from implementing the policy. It is possible that improved return flow modelling could identify benefits to the environmental values in the Gil Gil/Carole breakout as the upstream Carole/Gil Gil breakout is expected to benefit from implementation of the policy (Table 13). These outcomes suggest that a greater focus on these areas may be required in the future or that modelled return flows need to be incorporated into the hydrological models to detect impacts in these breakout zones.

Table 13 Percentage change in the number of EWRs met for a given environmental value after implementation of the policy for the 8 breakout zones of the Gwydir Valley floodplain. Values represent average (minimum and maximum) predicted outcomes, averaged across EWR metrics for each group unless a value was not recorded within that breakout zone. Not present = where an environmental value was not recorded in the breakout zone and the EWR was not assessed for that value

Asset/value category	Environmental value	Deadman/ Biniguy A	Marshall B	Carole/ Gil Gil C	Gil Gil/ Carole D	Gwydir/ Gingham E	Mehi F	Moomin Creek G	Thalaba H
Native fish	Short-moderate lived floodplain specialists	+7% (0, +15)	+1% (0, +9)	+7% (-13, +13)	+2% (-2, +7)	+119% (0, +467)	+20% (-25, +50)	+11% (0, +25)	+9% (0, +25)
	Generalists	7% (0, +11)	0% (0, 0)	+9% (+8, +13)	0% (-1, +3)	+98% (+77, +217)	+21% (+15, +33)	+13% (+8, +33)	+5% (0, +7)
	Flow pulse specialists	+7% (0, +11)	0% (0, 0)	+10% (+8, +15)	-2% (-15, +3)	+105% (+77, +248)	+36% (+15, +133)	+13% (+6, +33)	+5% (0, +7)
	River specialist	+7% (0, +13)	+0% (0, 0)	+4% (-2, +8)	+3% (-1, 17)	+58% (+13, +79)	+10% (-33, +24)	+12% (0, +25)	+7% (0, +22)
	Average of all native fish guilds	**+7%**	**0%**	**+8%**	**0%**	**+97%**	**+22%**	**+12%**	**+7%**
Waterbirds	Colonial-nesting*	+3% (0, +10)	0% (0, 0)	+16% (+7, +27)	-2% (0, -4)	+142% (+60, +221)	+115% (0, +350)	+35% (0, +100)	0% (0, 0)
	Non-colonial nesting	+6% (+0, +14)	0% (0, 0)	+13% (+6, +27)	-1% (-4, +1)	+142% (+60, +221)	+80% (0, +350)	+30% (0, +100)	+3% (0, +25)
	Average of both colonial and non-colonial	**+5%**	**+0%**	**+14%**	**-1%**	**+142%**	**+92%**	**+33%**	**+1%**
Native vegetation	Lignum	+16% (+4, +50)	+5% (0, +25)	+12% (+8, +21)	0% (-4, +3)	+88% (+74, +108)	-10% (-26, +6)	+17% (+8, +39)	+12% (0, +36)
	Coolabah	+5% (+3, +10)	+0% (+0, +0)	+9% (+8, +12)	0% (-1, +3)	+82% (+77, +99)	-16% (-11, -26)	+11% (+8, +16)	+4 (0, +11)
	River cooba (only 1 EWR tested)	+5%	+0%	+8%	-1%	+77%	Not present	+10%	+3%
	River red gum	+18% (0, +95)	+14% (0, +100)	Not present	Not present	+77% (+26, +113)	-13% (-40, +41)	+20% (0, +88)	+15% (-10, +100)

Asset/value category	Environmental value	Deadman/ Biniguy A	Marshall B	Carole/ Gil Gil C	Gil Gil/ Carole D	Gwydir/ Gingham E	Mehi F	Moomin Creek G	Thalaba H
	Blackbox	Not present	Not present	Not present	+1% (-1, +3)	Not present	-19% (-15, +-26)	Not present	Not present
	Marsh clubrush	Not present	Not present	Not present	Not present	+76% (+15, +124)	Not present	+14% (+13, +17)	Not present
	Cumbungi	Not present	Not present	Not present	Not present	+87% (+74, +99)	Not present	Not present	Not present
	Water couch	Not present	+50% (0, +100)	+30% (+6, +55)	7% (+1, +12)	+86% (+60, +113)	Not present	+49% (+11, +88)	+52% (+3, +100)
	Average of All native vegetation	**+13%**	**+11%**	**+13%**	**+1%**	**+82%**	**+24%**	**+19%**	**+14%**

*Excludes colonial-nesting waterbird breeding EWRs in all breakout zones except the Gwydir/Gingham breakout. This is because colonial-nesting waterbirds are known to only breed in sites within this breakout.

7 References

Legislation

Basin Plan 2021 No. 6. https://www.legislation.gov.au/Details/F2018C00451

(NSW) *Water Act 1912* No 44. https://legislation.nsw.gov.au/~/view/act/1912/44

(NSW) *Fisheries Management Act 1994* No 39. https://www.legislation.nsw.gov.au/~/view/act/1994/38

Environment Protection and Biodiversity Conservation Act 1999. Administered by the Department of Agriculture, Water, and the Environment. https://www.legislation.gov.au/Series/C2004A00485

NSW *Biodiversity Conservation Act* 2016. https://www.legislation.nsw.gov.au/~/view/act/2016/63

NSW *Biodiversity Act* 2019. https://www.legislation.nsw.gov.au/view/html/inforce/current/act-2016-063

NSW Floodplain Harvesting policy. First published May 2013, updated September 2018. http://www.water.nsw.gov.au/__data/assets/pdf_file/0012/548499/floodplain_harvesting_policy.pdf. Referred to in this report as the policy

(NSW) Water Management Act 2000 No 92. Last updated 2020. https://legislation.nsw.gov.au/~/view/act/2000/92/

Gwydir specific

Floodplain Management Plan for the Gwydir Valley Floodplain 2016. https://www.legislation.nsw.gov.au/view/html/inforce/current/sl-2016-0509

Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012 https://www.legislation.nsw.gov.au/view/html/inforce/current/sl-2012-0355

Water Sharing Plan for the Gwydir Regulated River Water Source 2016 https://www.legislation.nsw.gov.au/view/html/inforce/current/sl-2015-0629

Reports and journal articles

Alluvium. 2019. Independent review of NSW Floodplain Harvesting policy implementation. A report for the NSW Department of Planning, Industry and Environment Water, Sydney.

Ballinger, A., R. M. Nally, and P. S. Lake. 2005. Immediate and longer-term effects of managed flooding on floodplain invertebrate assemblages in south-eastern Australia: Generation and maintenance of a mosaic landscape. Freshwater Biology 50:1190–1205.

Boulton, A. J., and L. N. Lloyd. 1992. Flooding frequency and invertebrate emergence from dry floodplain sediments of the river Murray, Australia. Australia. Regul. Rivers: Res. Mgmt. 7:137–151.

Brandis, K., L. Nairn, J. Porter, and R. Kingsford. 2009. Preliminary assessment for the environmental water requirements of waterbird species in the Murray Darling Basin. School of Biological, Environmental and Earth Sciences, University of New South Wales.

Bunn, S. E., M. C. Thoms, S. K. Hamilton, and S. J. Capon. 2006. Flow variability in dryland rivers: Boom, bust and the bits in between. River Research and Applications 22:179–186.

Casanova, M. 2015. Review of water requirements for key floodplain vegetation for the Northern Basin: Literature review and expert knowledge assessment. Canberra, A.C.T. Murray–Darling Basin Authority.

CEWO. 2019. Commonwealth Environmental Water Portfolio Management Plan: Gwydir River Valley 2019–20. Page 33. Commonwealth of Australia.

CSIRO. 2007. Water availability in the Border Rivers: A summary of a report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. Page 12. (Available from: https://publications.csiro.au/publications/#publication/PIlegacy:700)

DECCW. 2011. Gwydir Wetlands adaptive environmental management plan: Synthesis of information projects and actions. Department of Environment, Climate Change and Water NSW, Sydney, N.S.W.

Department of Agriculture, Water, and the Environment. 2020. Australian Ramsar Wetlands. Australian Wetlands Database. (Available from: https://www.environment.gov.au/water/wetlands/australian-wetlands-database)

DPI Water. 2015. Rural floodplain management plans: Background document to the floodplain management plan for the Gwydir Valley Floodplain 2015. NSW Department of Industry – Water.

DPIE EES. 2020a. Gwydir Long Term Water Plan Part A: Gwydir catchment. Page 99. ISBN 978-1-92575-421-6, Department of Planning, Industry and Environment - Environment, Energy and Science, Sydney NSW 2000.

DPIE EES. 2020b. Gwydir Long Term Water Plan Part B: Gwydir planning units. Page 131. Department of Planning, Industry and Environment - Environment, Energy and Science, Sydney NSW 2000.

DPIE EES. 2020c, January 28. Safe haven for frogs in Gwydir wetlands. (Available from: https://www.environment.nsw.gov.au/news/safe-haven-for-frogs-in-gwydir-wetlands)

DPIE Water. 2019a. Guideline for the implementation of the NSW Floodplain Harvesting Policy. Page 23. INT19/95946, Department of Planning, Industry and Environment - Water, Parramatta, NSW.

DPIE Water. 2019b. Risk assessment for the Gwydir Surface Water Resource Plan Area (SW15): Part 1. Department of Planning, Industry and Environment - Water, Sydney NSW, Australia.

DPIE Water. 2021a. Building the river system model for the Gwydir Valley regulated river system. Department of Planning, Industry and Environment - Water, Sydney NSW, Australia.

DPIE Water. 2021b. Floodplain Harvesting Entitlements for the Gwydir Regulated River System: Model scenarios. Department of Planning, Industry and Environment - Water, Sydney NSW, Australia.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z.-I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A.-H. Prieur-Richard, D. Soto, M. L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: Importance, threats, status, and conservation challenges. Biological Reviews 81:163–182.

Healey, M., A. Raine, A. Lewis, B. Hossain, F. Hancock, and J. Sayers. 2018. Applying the High Ecological Value Aquatic Ecosystem (HEVAE) Framework to Water Management Needs in NSW. DPI Water, Sydney.

Keyte, P. A. 1994. Lower Gwydir wetland plan of management 1994 to 1997. NSW Department of Water Resources, Sydney.

Kingsford, E. R., J. Lau, and J. O'Connor. 2014. Birds of the Murray–Darling Basin. Birdlife Australia.

Kingsford, R. T. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecology 25:109–127.

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

Leigh, C., and F. Sheldon. 2008. Hydrological changes and ecological impacts associated with water resource development in large floodplain rivers in the Australian tropics. River Research and Applications 24:1251–1270.

Lemly, A. D., R. T. Kingsford, and J. R. Thompson. 2000. Irrigated Agriculture and Wildlife Conservation: Conflict on a Global Scale. Environmental Management 25:485–512.

Marsh, N. A., M. J. Stewardson, and Kennard, M.J. 2003. River Analysis Package. CRC for Catchment Hydrology, Monash University, Melbourne.

McGinness, H. M., and A. D. Arthur. 2011. Carbon dynamics during flood events in a lowland river: The importance of anabranches. Freshwater Biology 56:1593–1605.

MDBA. 2012. Assessment of environmental water requirements for the proposed Basin Plan: Gwydir Wetlands. Canberra, ACT. (Available from: http://www.mdba.gov.au/sites/default/files/archived/proposed/EWR-Lower-Murrumbidgee-River.docx)

MDBA. 2018, February 22. Murray Darling Basin Plan 2012. Australian Government. Nilsson, C., C. A. Reidy, M. Dynesius, and C. Revenga. 2005. Fragmentation and flow regulation of the world's large river systems. Science 308:405–408.

NRC. 2019. Review of the Water Sharing Plan for the Barwon-Darling Unregulated and Alluvial Water Sources 2012. Natural Resources Commission.

NSW Department of Primary Industries. 2015. Fish and Flows in the Northern Basin: Responses of fish to changes in flow in the Northern Murray-Darling Basin—Valley scale report. Prepared for the Murray-Darling Basin Authority. NSW Department of Primary Industries. (Available from: http://www.mdba.gov.au/kid/files/2552%20-%20Fish%20and%20Flows%20in%20the%20Northern%20Basin%20Stage%202%20Valley%20Scale%20Report_final%20for%20web.pdf)

NSW Department of Primary Industries. 2019. Fish and flows in the Northern Basin stage II: Background report. NSW Department of Primary Industries, Tamworth. (Available from: www.dpi.nsw.gov.au)

NSW Office of Water. 2013. NSW Floodplain Harvesting Policy. Page 17. NSW Department of Primary Industries, Office of Water.

Ocock JF and Spencer J. 2018. Frog and tadpole surveys in the Gwydir Wetlands, spring 2017. Unpublished summary report April 2018, NSW Office of Environment and Heritage, Sydney.

OEH. 2018. Border Rivers Long Term Water Plan Parts A and B - Draft for exhibition. Page 131. ISBN 978-1-925755-03-9, Office of Environment and Heritage, Sydney NSW 2000.

R Core Team. 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Reid, M. A., M. C. Reid, and M. C. Thoms. 2016. Ecological significance of hydrological connectivity for wetland plant communities on a dryland floodplain river, MacIntyre River, Australia. Aquatic Sciences 78:139–158.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A Method for Assessing Hydrologic Alteration within Ecosystems. Conservation Biology 10:1163–1174.

Roberts, J., and F. Marston. 2000. Water Regime of Wetland and Floodplain Plants in the Murray-Darling Basin: A Source Book of Ecological Knowledge. 30/00, CSIRO Canberra.

Roberts, J., and F. Marston. 2011. Water regime for wetland and floodplain plants: A source book for the Murray-Darling Basin. National Water Commission, Canberra.

Robertson, A. I., P. Bacon, and G. Heagney. 2001. The responses of floodplain primary production to flood frequency and timing: *Responses of floodplain primary production*. Journal of Applied Ecology 38:126–136.

Scott, A. 1997. Relationships between waterbird ecology and river flows in the Murray-Darling Basin. Page 46. CSIRO Land and Water.

SKM. 2009. Environmental Values and Watering Priorities for the Northern Murray Darling Basin. Report to the Australian Government. Sinclair Knight Merz, Malvern, Victoria.

Southwell, M., G. Wilson, D. Ryder, and P. Sparks. 2014. Monitoring the ecological response of Commonwealth Environmental Water delivered in 2013-14 in the Gwydir River system. Page 122. Commonwealth of Australia.

Spencer, J. A. 2010. Historical records of waterbirds and fish populations in the Gwydir Wetlands. Department of Environment, Climate Change and Water NSW, Sydney. (Available from: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Water/Wetlands/wetlands-gwydir-waterbirds-fish-records-100325.pdf)

Spencer, J. A., E. C. Heagney, and J. L. Porter. 2010. Final report on the Gwydir waterbird and fish habitat study. NSW Wetland Recovery Program. Rivers and Wetlands Unit, Department of Environment, Climate Change and Water NSW and University of New South Wales, Sydney NSW, Australia.

Steinfeld, C. M. M., and R. T. Kingsford. 2013. Disconnecting the floodplain: Earthworks and their ecological effect on a dryland floodplain in the Murray-Darling Basin, Australia. River Research and Applications 29:206–218.

Swirepik, J. L., I. C. Burns, F. J. Dyer, I. A. Neave, M. G. O'Brien, G. M. Pryde, and R. M. Thompson. 2016. Establishing Environmental Water Requirements for the Murray-Darling Basin, Australia's Largest Developed River System: Establishing Environmental Water Requirements. River Research and Applications 32:1153–1165.

Vertessy, R., D. Barma, L. Baumgartner, S. Mitrovic, F. Sheldon, and N. Bond. 2019. Independent assessment of the 2018-19 fish deaths in the Lower Darling—Interime Report.

Walker, K. F., F. Sheldon, and J. T. Puckridge. 1995. A perspective on dryland river ecosystems. River Research and Applications 11.

Wen, L., K. Rogers, J. Ling, and N. Saintilan. 2011. The impacts of river regulation and water diversion on the hydrological drought characteristics in the Lower Murrumbidgee River, Australia. Journal of Hydrology 405:382–391.

Whitworth, K. L., D. S. Baldwin, and J. L. Kerr. 2012. Drought, floods, and water quality: Drivers of a severe hypoxic blackwater event in a major river system (the southern Murray–Darling Basin, Australia). Journal of Hydrology 450–451:190–198.

Woods, R., J. Lobegeiger, J. Fawcett, and J. Marshall. 2012. Riverine and floodplain ecosystem responses to flooding in the lower Balonne and Border Rivers. Report number: ISBN 978-1-925075-00-7, Queensland Government-Department of Environment and Resource Management. (Available from: https://www.researchgate.net/publication/295443241_Riverine_and_floodplain_ecosystem_responses_to_flooding_in_the_lower_Balonne_and_Border_Rivers)

Wootton, J. T., and M. E. Power. 1993. Productivity, consumers, and the structure of a river food chain. Proceedings of the National Academy of Sciences of the United States of America 90:1384–1387.

Appendix A Summary of all recorded water-dependent floodplain environmental assets and values in the Gwydir Valley

These data are based on available literature and spatial datasets.

Table 14 Legend for Table 15

Used in	Legend / acronyms
Specific asset descriptions	V = Vulnerable, E = Endangered, C = CAMBA, J = JAMBA, K = ROKAMBA. [1]NSW listed threatened species, [2]listed on the EPBC Act, [3]listed in the Fisheries Management Act (1994), [4]Declaration under section 248 of the EPBC Act 1999 - List of Marine Species
Source	FMP - Floodplain Management Plans, LTWP - long-term water plans, HEVAE - high ecological value aquatic ecosystems, SKM - Sinclair Knight Merz, SRA - sustainable rivers audit (SRA), WSP water sharing plan
Acronyms	Commonwealth Environmental Water Office Long Term Intervention Monitoring Project (CEWO), Floodplain Management Plans (FMP), Floodplain Management Plans - Appendices (FMPa), long-term water plans (LTWP), Murray Darling Basin Authority assessment of environmental water requirements (MDBA), high ecological value aquatic ecosystems (HEVAE), Sinclair Knight Merz (SKM), sustainable rivers audit (SRA), water sharing plan (WSP)

Table 15 Recorded water-dependent floodplain environmental assets and values and sources of information

Asset type	Source	Specific asset
Ecological asset type – wetlands	FMP	Floodplain watercourses – drainage lines, lagoons, billabongs, waterholes, and lakes Semi-permanent wetland – shallow freshwater wetland sedgeland (PCT53), sedgeland – forbland wetland (PCT 447), Common Reed - Bushy Groundsel (PCT 181), Cumbungi rushland wetland (PCT 182), Water Couch marsh grassland wetland (PCT 204), Marsh Club-rush wetland very tall sedgeland (PCT 205), Permanent and semi-permanent freshwater lakes (PCT 238) Floodplain wetlands – river cooba swamp wetland (PCT241), lignum shrubland wetland (PCT 247)
Ecological asset type – other floodplain ecosystems	FMP	Flood-dependent forest/woodland (wetlands) – River Red Gum open forest/woodland wetland (PCT36), River Red Gum riparian tall woodland/open forest wetland (PCT 78) Flood-dependent woodland – Blackbox woodland wetland (PCT37), Coolabah-River Cooba-Lignum woodland wetland (PCT39), Coolabah open woodland wetland (PCT40), Poplar Box-Coolabah floodplain woodland (PCT87), Carbeen +/- Coolabah grassy woodland (PCT628)
Endangered Ecological Communities	HEVAE, FMP	Lowland Darling River EEC, Marsh Club-rush Sedgeland EEC, Carbeen Open Forest EEC, Coolabah-Black Box Woodland EEC, Myall rosewood EEC
Important lagoons and wetlands (FMP, WSP listed)	WSP, FMP	Ramsar listed wetlands – Gwydir Wetlands, Gwydir Wetlands SCA, Old Dromana, Goddard's Lease, Crinolyn, Windella, Gingham Watercourse, Mallowa Wetlands, Barbers Lagoon, Collytootela Lagoon, Moboullboona Waterhole, Mongyer Lagoon, Yarraman Lagoon.

Asset type	Source	Specific asset
Vegetation	LTWP, HEVAE	River Red Gum, Black Box, Coolabah, River Cooba, Belah, Lignum, non-woody wetland, Braid Fern (E)[2], Shrub Sida (E)[2], C*yperus conicus* (E)[2], Baradine Red Gum, Marsh Club-rush, Ribbed Spike Rush, Water Couch, Tussock Rushes, Cumbungi, Sedges, Nardoo, Common Reed, Juncus species.
Fish	LTWP, SRA Fish dataset, HEVAE, FMPa	Floodplain specialists -Southern Purple Spotted Gudgeon (E)[3], Olive Perchlet – Western population (E)[3], Rendahl's Tandan, Flathead Galaxias Flow pulse specialists – Golden Perch, Silver Perch (V)[2], Spangled Perch Generalists – Australian Smelt, Carp Gudgeon, Midgeleys carp gudgeon, Mountain Galaxias, Firetail gudgeon, Flathead Gudgeon, Murray-Darling Rainbowfish, Bony Herring, Unspecked Hardyhead River specialists – Southern Purple Spotted Gudgeon (E)[3], Murray Cod (V)[2], River Blackfish, Eel-tailed Catfish – MDB population (E)[3], Darling River Hardyhead
Frogs and reptiles	FMP, LTWP	Flow-dependent frog species - Eastern sign-bearing froglet, barking marsh frog, salmon striped frog, broad-palmed frog, spotted marsh frog, Peron's tree frog, Sloane's froglet Turtles – Broad-shelled turtle, eastern long-necked turtle, Macquarie turtle. Others - Water dragon, Water Rat
Groundwater recharge	FMP	Key areas of groundwater recharge on the floodplain
Functions	LTWP, SKM	Protect refugia, create habitat, provide for movement of water dependant biota, support mobilisation and transport of nutrient, carbon and primary production, ecological flow corridors, and increase contribution of flows from tributaries into Murray and Barwon-Darling.

Appendix B List of all datasets used to refine environmental assets and values in the Gwydir Valley

Table 16 Datasets used to refine assets and values and their source

<table>
<tr><th>Data set</th><th>Year</th><th colspan="2">Source / Reference</th><th>Details</th></tr>
<tr><td>Gwydir Valley Flood Management Plan Management Zones</td><td>2015</td><td>DPIE EES</td><td>NSW Office of Environment and Heritage Floodplain Management Plans

NSW Office of Environment and Heritage Healthy Floodplains Team</td><td>FMP Management Zones. Based on hydraulic, ecological, cultural, and socio-economic criteria. Four zones are included in the FMP These are Zones: A -major flood discharge zone; B - major flood paths and flood storage; C- areas outside the large design flood (2012) extent or existing flood protected areas; D - environmentally sensitive areas.</td></tr>
<tr><td>Gwydir Flood Management Plan Ecological Assets Vegetation</td><td>2016</td><td>DPIE EES</td><td rowspan="2">NSW Office of Environment and Heritage (2013) Gwydir Valley-Wide Floodplain Management Plan: Flood Behaviour Investigation. Report prepared for the Healthy Floodplains Project. Unpublished report.

Bowen, S and Simpson, S. L. (2010). Changes in the Extent and Condition of the Vegetation Communities of the Gwydir Wetlands and Floodplain 1996-2008. Final Report for the NSW Wetland Recovery Program. NSW Department of Environment Climate Change and Water, Sydney. (Gwydir Wetlands 2008. VIS Dataset ID: 3922).

Eco Logical Australia (2008). Vegetation Mapping for the Namoi and Border Rivers-Gwydir CMAs: Compilation of API Datasets and Preparation of a Hierarchical Vegetation Classification. Final Report for Border Rivers-Gwydir and Namoi CMAs. Project Nos. 125-002 & 129-002. March 2008. (brg_comp09. VIS Dataset ID: 3801).

NSW Office of Environment and Heritage (2015). BRG-Namoi Regional Native Vegetation Mapping. Technical Notes, NSW Office of Environment and Heritage, Sydney, Australia. (BRG Namoi v2. VIS Dataset ID: 4204).</td><td>Priority vegetation assets to inform development of the Gwydir FMP floodplain management plan 2015. Composite vegetation map derived from Gwydir Wetlands and Floodplain Vegetation Mapping, 2008 - VIS_ID 3922 and Composite vegetation map for the Border Rivers-Gwydir Catchment (2009) VIS_ID 3801. Refer to Gwydir Flood Behaviour Investigation Report for further information.</td></tr>
<tr><td>Gwydir Flood Management Plan Ecological Assets Flood Dependent Vegetation</td><td>2019</td><td>DPIE EES</td><td>Mapped distribution of flood dependent plant community types (PCT) and important lagoons, billabongs, watercourses, and wetlands in the Gwydir Valley.</td></tr>
</table>

Data set	Year	Source / Reference		Details
Ecological Water Flow Corridor	2019	DPIE EES	NSW Office of Environment and Heritage Healthy Floodplains Team and Daryl Albertson (DPIE EES)	Ecological water flow corridors are tracts of floodplain land that have been identified as important for conveying significant floodwater discharge during smaller flood events (less than 1 in 8 AEP) through the floodplain and for watering connected flood-dependent communities
Gwydir WSP Schedule 4 lagoons and wetlands	2016	DPIE Water	Office of Environment and Heritage - derived significant lagoons and wetlands from the Gwydir Unreg WSP to develop a spatial layer that represents ecological assets that may form management zone D with subsequent plan revisions.	Significant identified lagoons and wetlands within the boundary of the Gwydir FMP that are listed on Schedule 4 of Water Sharing Plan for the Gwydir Unregulated and Alluvial Water Sources 2012
Ramsar wetlands	2016	DPIE EES	NSW Office of Environment and Heritage Healthy Floodplains Team	Ramsar wetlands within the Gwydir FMP floodplain boundary
Flood-dependent fauna (Fish)	2015	DPI Fisheries	DPI NSW (2015) Aquatic Biodiversity Value Mapping Project. Fisheries, N. S. W. (2012) Freshwater Fish Database Wilson, G.G. 2009. Responses of fish assemblages to flow variability in the Gwydir Wetlands ecosystem, 2008-2009. Final Report to the New South Wales Department of Environment, Climate Change and Water. Spencer, J.A., Heagney, E.C. and Porter, J.L. 2010. Final report on the Gwydir waterbird and fish habitat study. NSW Wetland Recovery Program. Rivers and Wetlands Unit, Department of Environment, Climate Change and Water NSW and University of New South Wales, Sydney. University of New England, Armidale. 19 pp	Fish species occurrence records in Gwydir FMP Floodplain used in OEH Science Marxan analysis
Flood-dependent fauna (frogs)	2015	DPIE EES	NSW Wildlife Atlas BIONET	Barking frog (*Limnodynastes fletcheri*), eastern Sign-bearing froglet (*Crinia parinsignifera*) and broad palmed frog (*Litoria latopalmata*) occurrence records in Gwydir FMP Floodplain used in OEH Science Marxan analysis
Flood-dependent fauna (reptiles)	2015	DPIE EES	NSW Wildlife Atlas BIONET	Eastern water dragon (*Physignathus lesueurii*) occurrence records in Gwydir FMP Floodplain used in OEH Science Marxan analysis

Data set	Year	Source / Reference		Details
Flood-dependent fauna (turtles)	2015	DPIE EES	NSW Wildlife Atlas BIONET Spencer, J.A., Heagney, E.C. and Porter, J.L. 2010. Final report on the Gwydir waterbird and fish habitat study. NSW Wetland Recovery Program. Rivers and Wetlands Unit, Department of Environment, Climate Change and Water NSW and University of New South Wales, Sydney.	Eastern snake-necked Turtle (*Chelodina longicollis*), Macquarie turtle (*Emydura macquarii*) and broad-shelled river turtle (*Macrochelodina expansa*) occurrence records in Gwydir FMP Floodplain used in OEH Science Marxan analysis
Waterbird breeding	Unknown	DPIE EES	Jennifer Spencer (DPIE EES), Healthy Floodplains Team	Old boyanga egret, Old boyanga ibis, Gingham East, Gwydir egret, Boyanga, Baroona and Tillaloo breeding locations (rookeries)
High Ecological Value Aquatic Ecosystems	2018	DPIE Water	Healey et al. (2018): Applying the high ecological value aquatic ecosystem (HEVAE) Framework to Water Management Needs in NSW.	HEVAE (high ecological value aquatic ecosystem) - Identifying environmental assets, values, and ecosystems functions. This dataset includes: Endangered Ecological Communities MaxEnt Threatened Fish distributions Recorded and known threatened species sightings (waterbirds, fish, invertebrates, plants etc). Rankings for Diversity, Distinctiveness, Vital Habitat and Naturalness
High priority Groundwater Dependent Ecosystems	N/A	Enterprise Database	Enterprise Database extracted on 24/10/2019	Mapped high priority groundwater dependent ecosystems
Important wetlands	N/A	Enterprise Database	Enterprise Database extracted on 22/10/2019	Mapped important wetlands across Australia
Waterbirds of the Gwydir Valley	N/A	DPIE EES	NSW Wildlife Atlas BIONET	Valid Records for waterbirds. List refined to water dependent assets and values based on literature
Sustainable Rivers Audit fish data	1994-2013	DPI Fisheries	Provided to DPIE Water in 2014 by DPI Fisheries	Site based fish records from the Sustainable Rivers Audit program up until 2013
LTWP planning unit records	2019	DPIE EES	2018 Gwydir Long Term Water Plan Part B: Gwydir catchment—Draft for exhibition. Page 130. ISBN 978 1 92575 430 8, Office of Environment and Heritage, Sydney NSW 2000.	Part B of the LTWP lists the relevant assets and values in each planning unit.

Appendix C Detailed environmental water requirements of key water-dependent environmental assets and values in the Gwydir Valley

Table 17 Footnotes for Table 18

Footnotes
[1](Roberts and Marston 2011), [2](DPIE EES 2020a), [3](Scott 1997), [4](NSW Department of Primary Industries 2015), [5](Kingsford et al. 2014), [6](OEH 2018), [7](SKM 2009), [8](McGinness and Arthur 2011), [9](Reid et al. 2016), [10](NSW Department of Primary Industries 2019), [11](Ballinger et al. 2005), [12](Boulton and Lloyd 1992), [13](Casanova 2015), [14](MDBA 2012, Assessment of environmental water requirements for the proposed Basin Plan: Gwydir Wetlands) N/A = No detail or unable to assess accurately, y = years, m = months, d = days.

Table 18 Details of environmental water requirements of key water-dependent assets and values

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Native fish					
Short-moderate lived floodplain specialists	Frequency	Every 2 years[10] Max inter-event period of 4 years[2,10]	≤2[y] ≤4[y]	3-5 years in 10[4,2] Max inter-event period of 4 years[2,10]	≥3 in 10[y] ≤4[y]
	Duration	Improved number of flow days during Summer	Total number of flow days in Summer	>10 days to allow egg development[2,4,11]	≥10[d]
	Timing	October to April for spawning habitat[2,10] Summer for increased food resources and to maintain refugia[4]	Oct-Apr Summer	September to October is common across species[4]	Sep-Oct
	Other	Dispersal dependent on floods and flood size[2]	N/A	Secondary event after spawning (i.e. summer) enhances recruitment[4] Gradual recession of events important for dispersal of larvae and juveniles[4]	Spring event followed by Summer
Generalists	Frequency	1 in 3-5 years[10] Maximum interflow period of 5 years[10]	≥1 in 5[y] ≤5[y]	2 in 10 years[10]	≥2 in 10[y]

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
	Duration	Improved number of flow days during Spring-Summer	Total number of flow days in Spr-Sum	5 days[11]	≥5[d]
	Timing	Spring to summer[10]	Spr-Sum	September to February flows enhance spawning and provide habitat and resources for recruitment[4]	Spr-Sum
	Other	Improved floodplain metrics will also promote growth and recruitment for these fish via increased floodplain productivity and habitat availability	N/A	Subsequent events enhance recruitment and dispersal outcomes[4]	Sep-Feb with an event no more than 2 months prior
Flow pulse specialists	Frequency	1 in 3-5 years[10] Maximum interflow period of 4 years[2]	≥1 in 5[y] ≤4[y]	2-3 in 10 years[4]	≥2 in 10[y]
	Duration	Improved number of flow days during Spring-Summer	Total number of flow days in Spr-Sum	5 days[4]	≥5[d]
	Timing	Spring to summer[10]	Spr-Sum	Spring to autumn[4]	Spr-Aut
	Other	Velocities of 0.3 $m.s^{-1}$ required for ideal habitat[10]	N/A	Rapid recession assists with egg dispersal[4] Subsequent events enhance recruitment and dispersal outcomes[4]	N/A
In channel specialist: Murray Cod	Frequency	1 in 3-5 years[10] Maximum interflow period of 5 years[10]	≥1 in 5[y] ≤5[y]	2 in 10 years[10] Maximum interflow period of 2 years[10]	≥2 in 10[y] ≤2[y]
	Duration	Improved number of flow days during Spring-Summer	Total number of flow days in Spr-Sum	>14 days to allow egg development and hatching[2,4]	≥14[d]
	Timing	Spring to summer[10]	Spr-Sum	September to December for Murray cod[2]	Sep-Dec
	Other	Velocities of 0.3 $m.s^{-1}$ required for ideal habitat[10]	N/A	Subsequent events enhance recruitment and dispersal outcomes[4]	Win-Spr with an event no more than 2 months prior

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Waterbirds					
Non-colonial waterbirds	Duration	Improved number of flow days during important periods listed in 'Timing' EWRs below. Assessed for: Small wetland inundation (LTWP WL2)[2]: Sep-Mar Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB1)[2]: Sep-Mar Small overbank (LTWP OB2)[2]: Oct-Apr	Total number of flow days in: Sep-Mar Oct-Apr Aug-Feb	Improved number of flow days during important periods listed in 'Timing' EWRs below. Assessed for: Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB2)[2]: Oct-Apr Large overbank (LTWP OB4)[2]: Sep-May	Total number of flow days in: Aug-Dec Aug-Feb Oct-Apr Sep-May
	Frequency	9-10 years in 10[2] 7-9 years in 10[2] 5-7 years in 10[2] 3-5 years in 10[2] 7-8 years in 10[2] 4-7 years in 10[2]	≥9 in 10[y] ≥7 in 10[y] ≥5 in 10[y] ≥3 in 10[y] ≥7 in 10[y] ≥4 in 10[y]	5-7 years in 10[2] 3-5 years in 10[2] 4-7 years in 10[2] 2-3 years in 10[2] 1 year in 10[2]	≥5 in 10[y] ≥3 in 10[y] ≥4 in 10[y] ≥2 in 10[y] ≥1 in 10[y]
	Timing	Small wetland inundation (LTWP WL1)[2]: Anytime Small wetland inundation (LTWP WL2)[2]: Sep-Mar Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB1)[2]: Sep-Mar Small overbank (LTWP OB2)[2]: Oct-Apr	N/A Sep-Mar Oct-Apr Aug-Feb Sep-Mar Oct-Apr	Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB2)[2]: Oct-Apr Large overbank (LTWP OB4)[2]: Sep-May Large overbank (LTWP OB5)[2]: Anytime	Aug-Dec Aug-Feb Oct-Apr Sep-May N/A
	Other	Rate of fall: No faster than 5th percentile of natural[2]	Reduced rate of fall	Rate of fall: No faster than 5th percentile of natural[2]	Reduced rate of fall
Colonial-nesting waterbirds	Duration	Improved number of flow days during important periods listed in 'Timing' EWRs below. Assessed for: Small wetland inundation (LTWP WL2)[2]: Sep-Mar Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB1)[2]: Sep-Mar Small overbank (LTWP OB2)[2]: Oct-Apr	Total number of flow days in: Sep-Mar Oct-Apr Aug-Feb	Improved number of flow days during important periods listed in 'Timing' EWRs below. Assessed for: Large wetland inundation (LTWP WL4)[2]: Aug-Feb Large overbank (LTWP OB4)[2]: Sep-May Large overbank (LTWP OB5)[2]: Anytime	Total number of flow days in: Aug-Feb Sep-May

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
	Frequency	9-10 years in 10[2] 7-9 years in 10[2] 5-7 years in 10[2] 3-5 years in 10[2] 7-8 years in 10[2] 4-7 years in 10[2]	≥9 in 10^{y} ≥7 in 10^{y} ≥5 in 10^{y} ≥3 in 10^{y} ≥7 in 10^{y} ≥4 in 10^{y}	3-5 years in 10[2] 2-3 years in 10[2] 1 year in 10[2]	≥3 in 10^{y} ≥2 in 10^{y} ≥1 in 10^{y}
	Timing	Small wetland inundation (LTWP WL1)[2]: Anytime Small wetland inundation (LTWP WL2)[2]: Sep-Mar Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB1)[2]: Sep-Mar Small overbank (LTWP OB2)[2]: Oct-Apr	N/A Sep-Mar Oct-Apr Aug-Feb Sep-Mar Oct-Apr	Large wetland inundation (LTWP WL4)[2]: Aug-Feb Large overbank (LTWP OB4)[2]: Sep-May Large overbank (LTWP OB5)[2]: Anytime	Aug-Feb Sep-May Anytime
	Other	Rate of fall: No faster than 5th percentile of natural[2]	Reduced rate of fall	Rate of fall: No faster than 5th percentile of natural[2]	Reduced rate of fall
Native vegetation					
Shrublands					
Lignum (shrubland wetlands) *Muehlenbeckia florulenta*	Frequency	Once in 1-3 years for large shrubs[14] Once in 7-10 years for smaller shrubs[14]	≥1 in 3^{y} ≥1 in 7^{y}	Seedlings watered once per 12 to 18 months over first three years: desirable[1]	≥1 in 1.5^{y}
	Duration	Improved number of flow days during Spring-Summer	Total number of flow days in Spr-Sum	Improved number of flow days during Spring-Summer	Total number of flow days in Aut-Win and Spr-Sum
	Timing	Timing not critical[1]	N/A	Autumn to winter. Flooding for dispersal and post-flood recession germination needs to be within a few months of seed release, which is in autumn[1,14] Seedling establishment before or during summer[1,14]	Aut-Win Spr-Sum

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
	Other	Depth Not critical, generally less than 1 m.[1]	N/A	Germination temperature dependent (15-30°C), depth shallow (5 to 15 cm), flowering triggered by flooding which can occur within four weeks of flooding[1]	N/A
Forest and woodlands					
Coolabah Eucalyptus Coolabah	Frequency	Wetland: Every 5-10 years in 10[2] Woodland: 1 year in 10[1,2] The maximum inter-event period is 10–15 years[2]	≥2 in 10[y] ≥1 in 10[y] ≤10[y]	Small inundations in the first and second year improve seedling establishment[1]	≥1 in 2[y]
	Duration	Improved number of flow days	Total number of flow days	Improved number of flow days during Spring-Summer	Total number of flow days in Spr-Sum
	Timing	Not expected to be important for trees. May be important for understorey and associated plant communities, and for dependent fauna[1]	N/A	Spring-summer recession best Seedlings vulnerable to desiccation in summer[1]	Spr-Sum
Blackbox *Eucalyptus largiflorens*	Frequency	Once every 3-7 years[1]	≥1 in 7[y]	Small inundations in the first and second year improve seedling establishment[1]	≥1 in 2[y]
	Duration	Improved number of flow days	Total number of flow days	Improved number of flow days during Spring-Summer	Total number of flow days in Spr-Sum
	Timing	Not critical[1]	N/A	Spring-summer recession best[1]	Spr-Sum
River cooba *Acacia stenophylla*	Frequency	Once every 3-7 years[1]	≥1 in 7[y]	Not known	N/A
	Duration	Flooding is important but the specific requirements are not known[1]	N/A	Flooding is important but the specific requirements are not known[1]	N/A
	Timing	Not critical[1]	N/A	Not known	N/A
River red gum *Eucalyptus camaldulensis*	Frequency	Forests: every 1-3 years Woodlands: every 2-4 years[1] Floodplain: 3-5 years in 10 Max inter-event period 4-5 years[2]	≥1 in 3[y] ≥1 in 4[y] ≥2 in 10[y] ≤5[y]	Follow up flood in 1st or 2nd year is desirable[1]	≥1 in 2[y]

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
	Duration	Improved number of flow days during spring-summer	Total number of flow days in Spr-Sum	Improved number of flow days during Spring-Summer	Total number of flow days in Aug-Nov and Spr-Sum
	Timing	Not critical but the best outcomes during spring-summer[1] September – February[2]	Spr-Sum	Flood in August-November[2] Flood recession in spring-summer to provide warm moist conditions for germination and seeding growth[1] Seedlings vulnerable to desiccation and heat stress in summer[13]	Aug-Nov Spr-Sum
	Other	N/A	N/A	Shallow depths are desirable but where this is unknown, duration is critical[1]	N/A
Grasslands					
Water couch (non-woody wetland) *Paspalum distichum*[1]	Frequency	Every 1-2 years[1]	≥1 in 2^{y}	Not known	N/A
	Duration	5-8 months[1]	≥5^{m}	Not known	N/A
	Timing	Start in late winter or spring with flooding over summer critical	Win-Sum	Not known	N/A
	Other	Depth is critical, shallow is best	N/A	Seeds short lived so if regeneration via seeds is desired annual flooding is recommended	≥1^{y}
Cumbungi	Frequency	Once every 1 to 3 years[1]	≥1 in 3^{y}	Reflood after 2 years desirable[1]	≤1 in 2^{y}
	Duration	Improved number of flow days during Spring-Summer	Total number of flow days in Aut-Win	Improved number of flow days during Spring-Summer	Total number of flow days
	Timing	Starting Autumn - Winter[1]	Aut-Win	Not known	N/A
Marsh club-rush *Bolboschoenus fluviatilis*	Frequency	Annual[1]	≥1 in 1^{y}	Reflood every 3 years[1]	≤1 in 3^{y}
	Duration	3-5 months[1]	≥3^{m}	Not known [1]	N/A

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
	Timing	Critical. Late winter flooding[1]	Win	Not known [1]	N/A
Other assets					
Flow-dependent frog species	Frequency	9-10 years in 10[2] 7-8 years in 10[2]	≥9 in 10^y ≥7 in 10^y	1 to 2 years to support successful breeding[2]	≥1 in 2^y
	Duration	Improved number of flow days during Spring-Summer	Total number of flow days in Sep-Mar	Improved number of flow days during Spring-Summer	Total number of flow days in Oct-Mar and Jul-Apr
	Timing	Small wetland inundation (LTWP WL1)[2]: Anytime Small overbank (LTWP OB1)[2]: Sep-Mar	N/A Sep-Mar	Spring to summer breeders[2]: Oct-Mar Flexible breeders[2]: Jul-Apr	Oct-Mar Jul-Apr
Important ecosystem functions					
Productivity	Frequency	Every 8-10 years to avoid building of carbon and potential blackwater events[6] Reduced duration and increased inter-event duration (i.e. zero flow days) are detrimental to the wetting and drying cycles of anabranches[9]			≥1 in 10^y < Mean and median duration between events^y
	Duration	Longer durations and greater volumes will provide the best outcomes[6,8,11,12]: The following categories were based on expert opinion: Reduced outcomes if durations <1 week, Better outcomes for 1-2 week flood durations, Best outcomes with longer flood durations (>2 weeks) Durations of 6 days provide high dissolved organic carbon concentrations from anabranches[9]			 ≤7^d, ≥7^d-<14^d ≥14^d ≥6^d
	Timing	Wetting and drying of the floodplain surfaces in mid-late summer will promote growth of zooplankton that will provide a suitable food resource for larval and juvenile fish and hence increase recruitment success[7]			Sum
	Other	Flows must return to the river at some point to increase in-channel benefits for fish and other organisms			N/A

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Wetlands (Maintenance and Regeneration/Reproduction of key wetland values inclusive)					
Gwydir Wetlands (Old Dromana, Goddard's Lease, Crinolyn and Windella) Mallowa wetlands Mongyer lagoon Collytootela lagoon	Frequency	9-10 years in 10[2] 8-9 years in 10[2] 5-8 years in 10[2] 3-5 years in 10[2] 7-8 years in 10[2] 4-7 years in 10[2] 3-5 years in 10[2] 2-3 years in 10[2] 1 year in 10[2]			≥9 in 10[y] ≥8 in 10[y] ≥5 in 10[y] ≥3 in 10[y] ≥7 in 10[y] ≥4 in 10[y] ≥3 in 10[y] ≥2 in 10[y] ≥1 in 10[y]
	Timing	Small wetland inundation (LTWP WL1)[2]: Anytime Small wetland inundation (LTWP WL2)[2]: Sep-Mar Large wetland inundation (LTWP WL3)[2]: Oct-Apr Large wetland inundation (LTWP WL4)[2]: Aug-Feb Small overbank (LTWP OB1)[2]: Sep-Mar Small overbank (LTWP OB2)[2]: Oct-Apr Small overbank (LTWP OB3)[2]: Aug-Feb Large overbank (LTWP OB4)[2]: Sep-May Large overbank (LTWP OB5)[2]: Anytime			N/A Sep-Mar Oct-Apr Aug-Feb Sep-Mar Oct-Apr Aug-Feb Sep-May N/A

Appendix D Further detail on the approach to quantify changes in floodplain hydrology

D.1 River system model outputs

D.1.1 Identifying changes to floodplain flow regimes: what is possible with the available information?

The modelling scenarios (Current Conditions and Plan Limit) (i.e. current conditions without the policy implemented and current conditions with the policy implemented respectively) are critical to predicting any environmental benefits for floodplain environmental assets and values through implementing the policy. These scenarios are introduced in the Model Build report (DPIE Water 2021a) and described in detail in the Scenarios report (DPIE Water 2021b). Discussing the intricacy of each model will not be done within this report. However, it is critical to understand what outputs are produced by each model and the limitations associated with predicting environmental benefits or undesirable outcomes. The outputs, approach and limitations are discussed below.

D.1.2 Available model outputs

The planned implementation of the policy has increased investment in data and modelling to quantify floodplain harvesting more accurately. These models are being used to define floodplain harvesting entitlements. The intent of the policy is to control future growth and to remove existing growth where total diversions exceed plan limits under the Basin Plan 2012. The change in floodplain harvesting pre- and post-implementation of the policy can be assessed through the following model scenarios:

- Current Conditions Scenario
- Plan Limit Scenario, i.e. current conditions with the policy implemented (i.e. floodplain harvesting entitlements and accounting applied).

Both scenarios are required to identify any hydrological changes due to implementation of the policy and any flow-on consequences for floodplain environmental assets and values. For each scenario, modelled daily time-series flow data (ML/day) is available for the end of system (EOS) floodplain breakouts below each floodplain harvesting breakout zone. Modelled data covers the period from 1895 to 2016.

D.1.3 Relating floodplain harvesting take to quantified changes

In addition to providing the two modelled daily flow time series, the department has provided estimates of diversion or 'water take' under both scenarios. This provides descriptive statistics, used to help interpret the changes to the floodplain hydrology. Floodplain harvesting take results are reported at valley scale in the companion Scenarios report (DPIE Water 2021b).

D.2 Assumptions and limitations

D.2.1 Modelling flood inundation extent for the policy

The healthy floodplains team at DPIE EES has developed a flood inundation model for a small- and large-scale flood on the Border Rivers, Gwydir, Macquarie, Namoi, and Barwon-Darling floodplains. These models are a mixture of 1D and 2D models using a range of model types. These include TUFLOW, MIKE FLOOD, MIKE 21, MIKE 11 and a variety of others. Each model has the ability to setup and run different magnitude events to identify inundation patterns. This makes them an extremely useful tool when looking at the inundation extent of different flow magnitudes. However, each model run requires significant resources. This assessment would require model runs for a large number of flood magnitudes in each valley. Whilst we acknowledge that this information would be useful, the DPIE Water Source/IQQM river system models provide valuable information which can be used to identify hydrological changes and provide some indication of whether inundation would have increased or decreased through changes to flood volumes and durations. We also acknowledge that the complexity of future climate change may further confound the analysis of floods and associated environmental outcomes.

D.2.2 Modelling return flows and downstream impacts

The river system models currently available represent any residual overbank flow as a 'loss' and residual return flows are not simulated (except in a few rare circumstances). These models therefore cannot assist in determining downstream impacts on flows, gauging stations and gauge station based EWRs like those in the long-term water plans developed for each valley by the department. The assumption is that implementing the policy (and thereby reducing floodplain harvesting take compared to the current situation) will lead to improvements for downstream users and environmental assets and values. Further data collection and research is required to support an analysis of downstream impacts. Compared to the other valley models, the Gwydir IQQM has better accounted for return flows, based on OEH data. However, there will still be significant uncertainty with this representation.

The Independent Peer Review of the policy implementation (Alluvium 2019), Vertessy et al. (2019) report and NRC review (NRC 2019) have all highlighted the importance of improving our understanding of return flows from the floodplain to the river to allow adaptive management over time. This would enhance water management and ensure a balance for environment, social, cultural, and economic outcomes. The department recognises the importance of understanding return flows and downstream impacts and is considering what information will be required to increase this understanding in the future. This is discussed further in the future improvements section.

The models can be used to provide daily time-series flow data of breakout flow which can be used to assess what volumes may be available to the floodplain environment in a general sense. The models simplify complex floodplain flow paths into a few breakout relationships. The models also have simplified methods to account for conveyance and natural losses on the floodplain. This means that the breakout flow may not always be relevant to all floodplain environmental assets and values. It is possible that only a portion of the breakout flow reaches the particular floodplain asset. Similarly, it is possible that in small events no water would have reached the asset. For this reason, assets and values within a defined breakout zone were selected for inclusion to restrict predictions in areas where the model data might not apply or where there is a lower confidence in applicability for that part of the floodplain.

D.2.3 Estimating cumulative downstream hydrological changes

Quantifying cumulative downstream changes in hydrology due to implementing the policy is not possible at this point. This is primarily because return flows from floodplain breakout zones are rarely incorporated into the river system model (as discussed above). While quantifying changes to cumulative downstream flows is not possible at this point in time, the volumes remaining on the floodplain within each valley can be quantified. This will provide an estimate of how much water will pass through floodplain harvesting areas after implementation of the policy. Caution is required when translating this into perceived downstream benefits. Future improvements in our understanding of return flows and critical pathways may improve our ability to quantify downstream changes through improved river system models and through any monitoring, evaluation, and reporting (MER) conducted after implementation.

D.2.4 Identifying impacts on gauging station-based EWRs

Most EWRs established in each long-term water plan or Commonwealth Environmental Water Office Portfolio Management Plan are primarily based on a flow at a nearby gauging station. As return flows are not included in the modelled scenarios, there is no detectable impact on a modelled flow series at a gauging station downstream of a floodplain breakout. Therefore, without this information, it is not possible to identify whether gauging station-based EWRs are achieved more or less with upstream floodplain harvesting licensing (policy implementation) or not. Improvements in modelling of return flows would enable an assessment of upstream impacts on downstream EWR triggers in the future.

D.2.5 Future improvements

The investment in data, method, consultation, review, time, and effort has improved our understanding and estimation of floodplain harvesting. Nevertheless, there is still significant uncertainty in that estimate.

Additional data collection, in particular monitoring of harvesting through the floodplain harvesting monitoring strategy, is required to help to address this uncertainty. Information required includes but is not limited to:

- monitoring program to measure floodplain harvesting
- measurement of major floodplain flows and returns
- estimation of floodplain losses
- groundwater recharge estimates
- assessment of measured floodplain harvesting diversions against modelled floodplain harvesting diversions for adaptive management
- monitoring by NRAR of water harvested through the floodplain harvesting monitoring and auditing strategy to ensure licensed diversions are adhered to.

Lawful structures that allow licensed water take but remain in the flow path of important flood runners will inhibit the modelled benefits predicted within this report. These structures must be monitored to ensure only licenced entitlements are being diverted and flood paths remain connected wherever possible.

Appendix E Glossary

In addition to the information provided in this appendix, the reader is directed to excellent online resources, such as that provided by Water NSW[10].

Table 19 Abbreviations/acronyms used in this report

Abbreviation/ acronym	Description
BDL	Baseline diversion limit
CAMBA	China-Australia Migratory Bird Agreement
CEWO	Commonwealth Environmental Water Office
DOC	Dissolved organic carbon
EOS	End of system
EWR	Environmental water requirement
FMP	Floodplain Management Plan
HEVAE	High ecological value aquatic ecosystems
IQQM	Integrated Quantity Quality Model (NSW in-house river system model)
JAMBA	Japan-Australia Migratory Bird Agreement
LTAAEL	Long term average annual extraction limit
LTWP	Long-term water plan
OFS	On-farm storage
PCT	Plant community type
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreement
SRA	Sustainable Rivers Audit
WSP	Water Sharing Plan

[10] https://www.waternsw.com.au/customer-service/service-and-help/tips/glossary#:~:text=Glossary%20of%20water%20terms%201%20Basic%20landholder%20rights.,7%20Carryover%20Spill%20Reduction.%20...%20More%20items...%20

Table 20 Key terms used in this report

Term	Description
Current Conditions Scenario	Model scenario that uses the best available information on most recent known levels of irrigation infrastructure and entitlements (described in companion Scenarios report (DPIE Water 2021b))
Long-term average annual extraction limit (LTAAEL)	The upper limit on the average of annual extractions from the water source over the period for which an assessment is carried out. (Source: https://www.waternsw.com.au/customer-service/service-and-help/tips/glossary#l)
node	A 'node' in the river system model. A location at which information is attached and information is retrieved. Examples of nodes are Irrigator User nodes, splitter nodes, gauge nodes
Plan limit	The authorised long-term average annual extraction limit as defined in the Water Sharing Plan
Plan limit compliance	Compliance with the Plan limit, which is assessed using long-term modelling
Plan Limit Scenario	Model scenario that results in the lower long-term average diversions from either the conditions set out in the Water Sharing Plan or agreements made under the Murray Darling Basin Ministerial Council on diversions (described in companion Scenarios report (DPIE Water 2021b))
the plan	Shortened term for the (Murray-Darling) Basin Plan
the policy	Shortened term for the NSW Floodplain Harvesting policy 2013