HEALTHY FLOODPLAINS

Environmental outcomes of implementing the Floodplain Harvesting Policy in the Border Rivers 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) 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), scheduled to be in place in the five northern 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 2019) changes to the hydrology of the floodplain, this report provides an assessment of potential outcomes for the environment of implementing the policy in the NSW Border Rivers Valley. Key hydrological metrics and environmental water requirements (EWRs) were used to test and identify these outcomes for assets (e.g. location) and values (e.g. species) including native fish, native vegetation, waterbirds, important ecosystem functions and wetlands.

Key findings

Figure 1 provides a mapped high level summary of potential outcomes across the NSW Border Rivers valley for native fish, waterbirds, native vegetation and water volumes. Most environmental water requirements are predicted to be achieved more frequently under the policy In addition, the predicted improvements to floodplain hydrology (volumes, durations and timing of floods) suggest that environmental outcomes for the NSW Border Rivers will be primarily beneficial with some negative outcomes at a few breakout zones[1].

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 ecologically relevant hydrological metrics are predicted to improve once the policy is implemented. This varied with breakout zone on the floodplain but in general, improved mean annual volume, frequency of events, summer volumes, and reduced inter-event periods are all predicted benefits for the environment. During flood years, the policy is predicted to allow 15 gigalitres (GL) in mean annual volumes to return to the floodplain across all breakout zones in the NSW Border Rivers floodplain. In some breakout zones, modelled flood events are not recorded in autumn until the policy is implemented. The largest improvements to hydrological metrics are in the 8 breakout zones above Mungindi (I in Figure 1). Relatively small improvements are predicted for the most downstream breakout zone at Mungindi.

Improved modelling of return flows may identify improved downstream benefits at Mungindi and in the Barwon-Darling. Whilst most hydrological outcomes are predicted to improve under the policy, spring and winter event durations (number of flow days) and spring volumes are not predicted to improve substantially.

[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.

Native fish

Outcomes for 4 native fish guilds - flow dependent specialists (e.g. Golden Perch), generalist species (e.g. Bony Herring), short-moderate lived floodplain specialists (e.g. Southern Purple Spotted Gudgeon), and in-channel specialists (e.g. Murray Cod) are assessed in this report.

Whilst some negative outcomes are predicted at specific breakout zones, outcomes for native fish guilds are predominantly positive. Improved flood duration, frequency and timing increased the number of EWRs achieved for reproduction and adult maintenance for all fish guilds. Some of the largest predicted benefits are average increases of more than 20% in achievement of the flooding frequency and interflow period required to maintain adults within these fish guilds. Of the 34 tests spread across 11 EWR metrics and 4 fish guilds, only 3 are predicted to reduce (by less than 10%). These are for recruitment opportunities for generalists and flow dependent specialists, and the timing of floods for spawning in short-moderate lived floodplain specialists.

All breakout zones but one are predicted to realise positive outcomes for native fish. The Boonal (A) and Whalan (D) breakout zones are predicted to benefit the most, with Yarrowee (H) breakout zone being slightly disadvantaged.

Waterbirds

There are more than 25 waterbird species comprising both colonial and non-colonial nesters either predicted or recorded in the NSW Border Rivers valley breakout zones. A variety of improvements are predicted for waterbirds.

Eight EWRs were tested, and 6 are predicted to improve by more than 23% on average. Assuming breeding events occur, improved flood frequencies should provide better opportunities for a range of non-colonial waterbird species. In addition, more events occurring in summer should provide breeding opportunities in this season. Improved outcomes for key habitat, for example coolabah trees should also contribute to waterbird benefits. In contrast, the frequency of winter floods, number of flow days and flow volume in autumn and winter are not predicted to improve. This indicates that although waterbird requirements during summer should enhance, there is still room for improvement in floodplain flow management in winter and spring.

Although the average across breakout zones suggests benefits for waterbirds, most improvements are predicted for the Boonal (A) and Whalan (D) breakout zones (Figure 1).

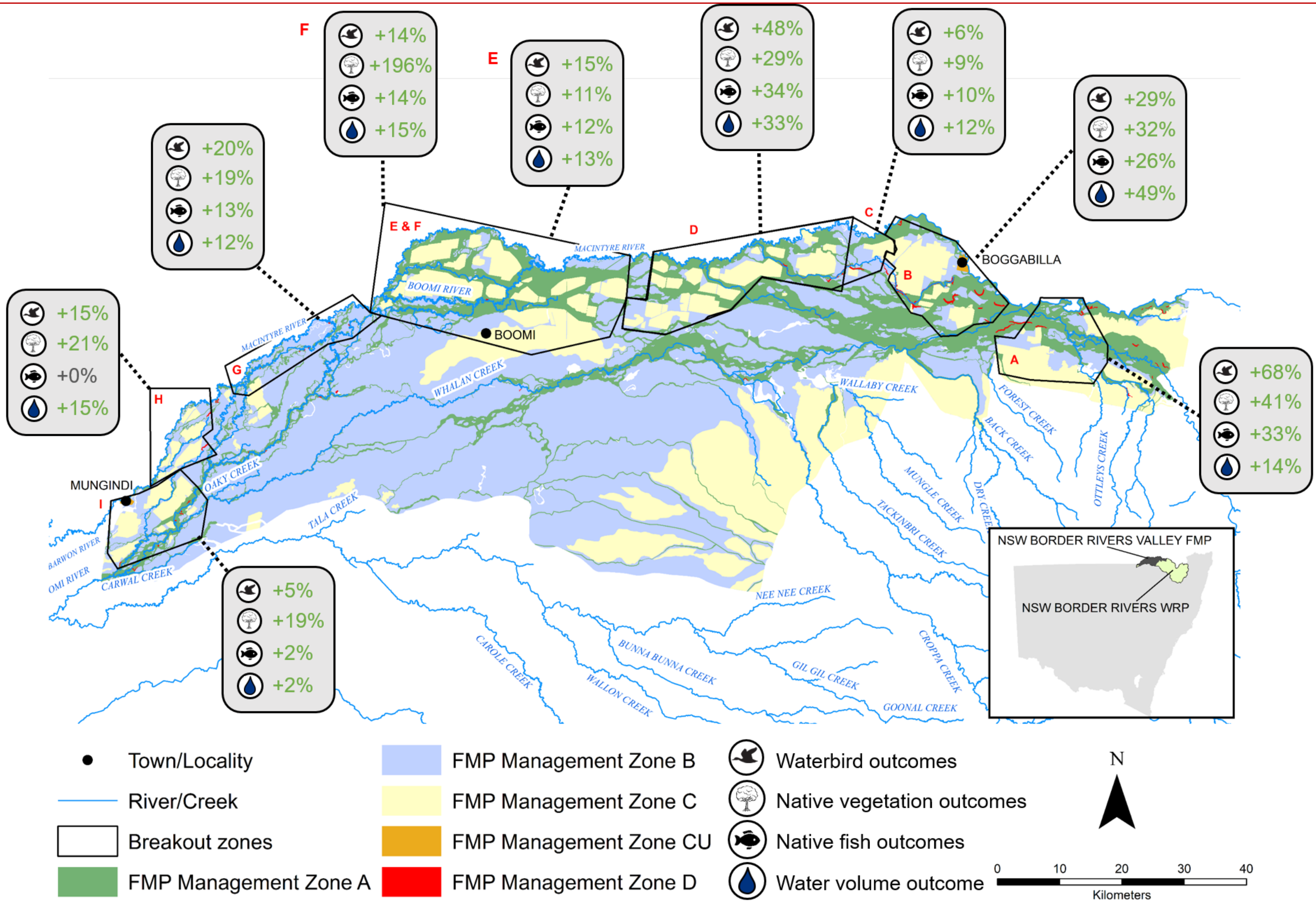

Figure 1 Mapped summary of predicted outcomes for waterbirds, native vegetation, native fish and water volumes for the 9 breakout zones on the NSW Border Rivers valley floodplain. Percent change values show the predicted change from current (no policy) to current with policy implemented based on a 124 year simulation period. Values for waterbird, native vegetation and native fish outcomes are the average change in achieving key EWRs at each breakout zone. Water volume outcomes are the percentage change in mean annual volumes during flood years. FMP = Floodplain Management Plan. Breakout zones from most upstream to most downstream: A Boonal, B Boggabilla, C Goondiwindi, D Whalan, E Tarpaulin (Croppa/Whalan), F Terrewah, G Boomangera, H Yarrowee, I Boomi/Whalan

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 some of the floodplain's dominant vegetation species. These include lignum, coolabah, river cooba, river red gum and water couch.

The largest predicted improvement is in the achievement of flood frequency required to maintain and to provide minimum conditions needed for seedling establishment for all vegetation species. Other predicted benefits include improved timing (seasonality) for mature plant maintenance, seed dispersal, seedling establishment and maintenance. Implementation of the policy is predicted to increase the number of flow days during December and February by up to 518% in some breakout zones on the floodplain (e.g. Boggabilla (B)). This warm period is critical for most vegetation species including river red gum, lignum, coolabah and water couch.

Very small improvements are predicted for spring flood durations and volumes. In addition, the change to the number of flow days during autumn and winter months varies across the floodplain. The policy should aim to improve and provide consistent outcomes (spatially) for events during winter and spring which are critical for lignum and other vegetation species. As with the other environmental values assessed in this report, changes and the size of those changes vary across the floodplain.

Ecosystem functions and wetlands

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

The NSW Border Rivers floodplain supports a number of wetlands, some of national importance such as the Morella Watercourse (in Zone C, Figure 1 and image shown at Figure 2). Mixed outcomes are predicted for these ecosystem functions and important wetlands. Longer flood durations and shorter inter-event periods are likely to provide better outcomes for productivity (e.g. through increases in aquatic invertebrate numbers) and other key resources, such as dissolved organic carbon. The predicted increase in flood events occurring in warmer summer months will also enhance benefits 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 projected to improve the frequency of small flood durations (<1 week duration) and longer flood durations (>2 weeks). This should benefit nationally significant wetlands like the Morella Watercourse. Improved seasonality and flood frequency will also be advantageous for the wetlands identified in this report.

Figure 2 Satellite image of Morella Watercourse during a severe drought in January 2020. This is a nationally significant wetland which provides critical refugia for water-dependent ecosystems. [Image sourced from Sentinel Playground (https://www.sentinel-hub.com/explore/eobrowser), Sinergise Ltd]

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 not yet 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 assessments of EWRs (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

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 also aligns with the objectives of the National Water Initiative, an intergovernmental commitment made by the Council of Australian Governments (COAG) 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).

1.1 Report purpose

This report considers the predicted environmental outcomes (i.e. ecological responses) to changed floodplain harvesting volumes in the Border Rivers valley after implementing the policy. It includes identification of floodplain water-dependent environmental assets and values, 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.

1.2 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 3. Identification of values (such as native fish species) and assets (such as wetlands) is described in Section 3. The hydrological assessment (of ecologically relevant flow statistics) is described in Section 4. Relating the results of the hydrological assessment with the water requirements of key environmental values and assets is described in Section 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.

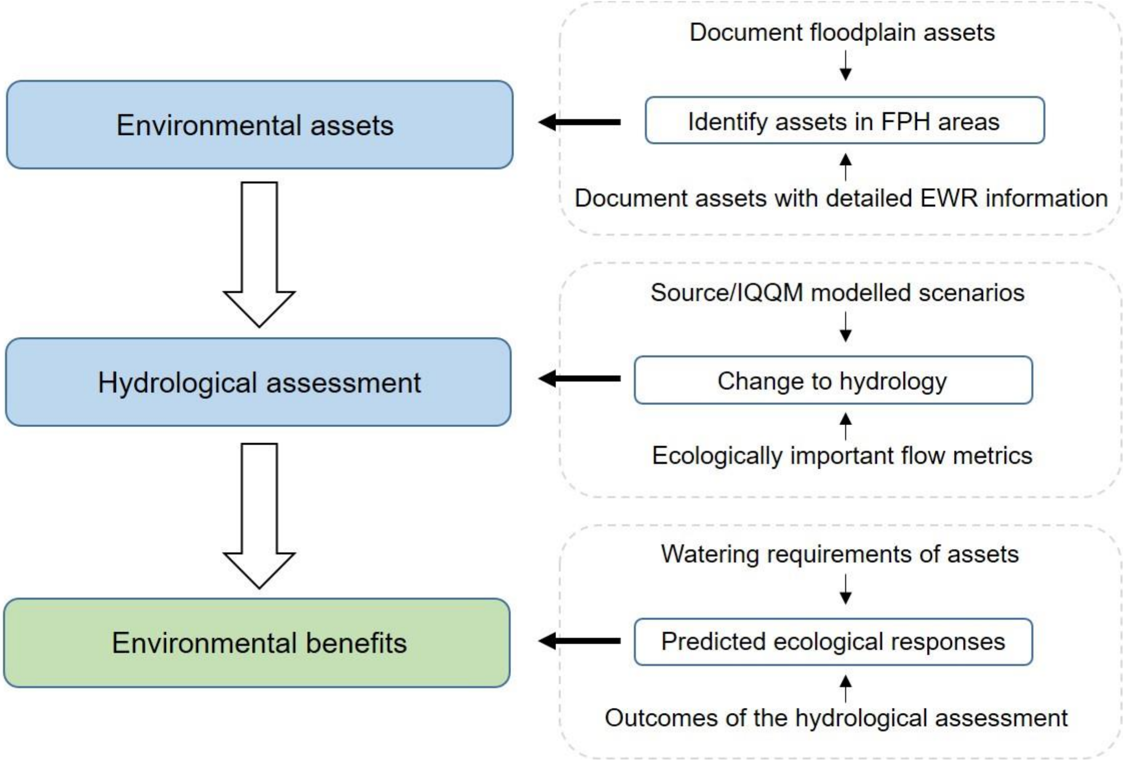

Figure 3 Summary of the approach adopted to identify the environmental outcomes of implementing the NSW Floodplain Harvesting Policy (FPH = floodplain harvesting; Source/IQQM are river system/hydrological models)

1.3 Companion reports

This report is one of a suite of 3 reports that are prepared for each of the 5 NSW northern basin valleys. This report describes an assessment 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 Border Rivers Valley model is described in *Building the river system model for the Border Rivers Valley regulated river system* (DPIE Water 2020a).

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 NSW Border Rivers Regulated River System – Model Scenarios* (DPIE Water 2020b). The three reports together serve to describe how the modelling meets the objectives of the policy.

2 Floodplain harvesting in the Border Rivers

The Border Rivers Valley floodplain is within the NSW Border Rivers catchment and is connected to the Qld Border Rivers catchment. The main rivers are the Severn and Macintyre Rivers in NSW and the Dumaresq and Weir Rivers in Qld. In NSW, the Macintyre River flows along the northern border of the floodplain through Boggabilla, Goondiwindi and down to Mungindi. The major effluents, Whalan Creek and Boomi River, branch off the Macintyre towards the southwest. The only significant tributary downstream of Boggabilla is the Weir River flowing from Qld. The floodplain extends to the township of Mungindi, below which the Barwon-Darling Valley Floodplain begins.

The NSW Border Rivers Valley is regulated by major dams and other instream structures, including Glenlyon Dam, Pindari Dam and Coolmunda Dam. These large regulating structures capture headwater flows and reduce 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 NSW Border Rivers Valley Floodplain including levee banks, earthworks, banks and channels. Works such as these, which affect the distribution of floodwaters, are referred to as flood works. Approximately 55,800 hectares of the floodplain are enclosed by flood works that have current flood work approvals in the proposed Border Rivers Valley Floodplain (DPI Water 2017). 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).

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

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 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 Basin Plan (the Plan). The current portion of floodplain harvesting diversions within the BDL for the Border Rivers is approximately 39 GL. Floodplain harvesting diversions without the policy implemented are estimated at around 44 GL, i.e. 5 GL over the BDL. Implementation of the policy will bring the average annual diversions back in line with the BDL.

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 4 shows the designated Border Rivers floodplain and eligible floodplain harvesting properties. Eligibility of floodplain harvesting properties or works which may subsequently be eligible 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 Section 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 Section 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 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 NSW Border Rivers valley, 43 of the 55 applications for floodplain harvesting access were deemed eligible (DPIE Water 2019a).

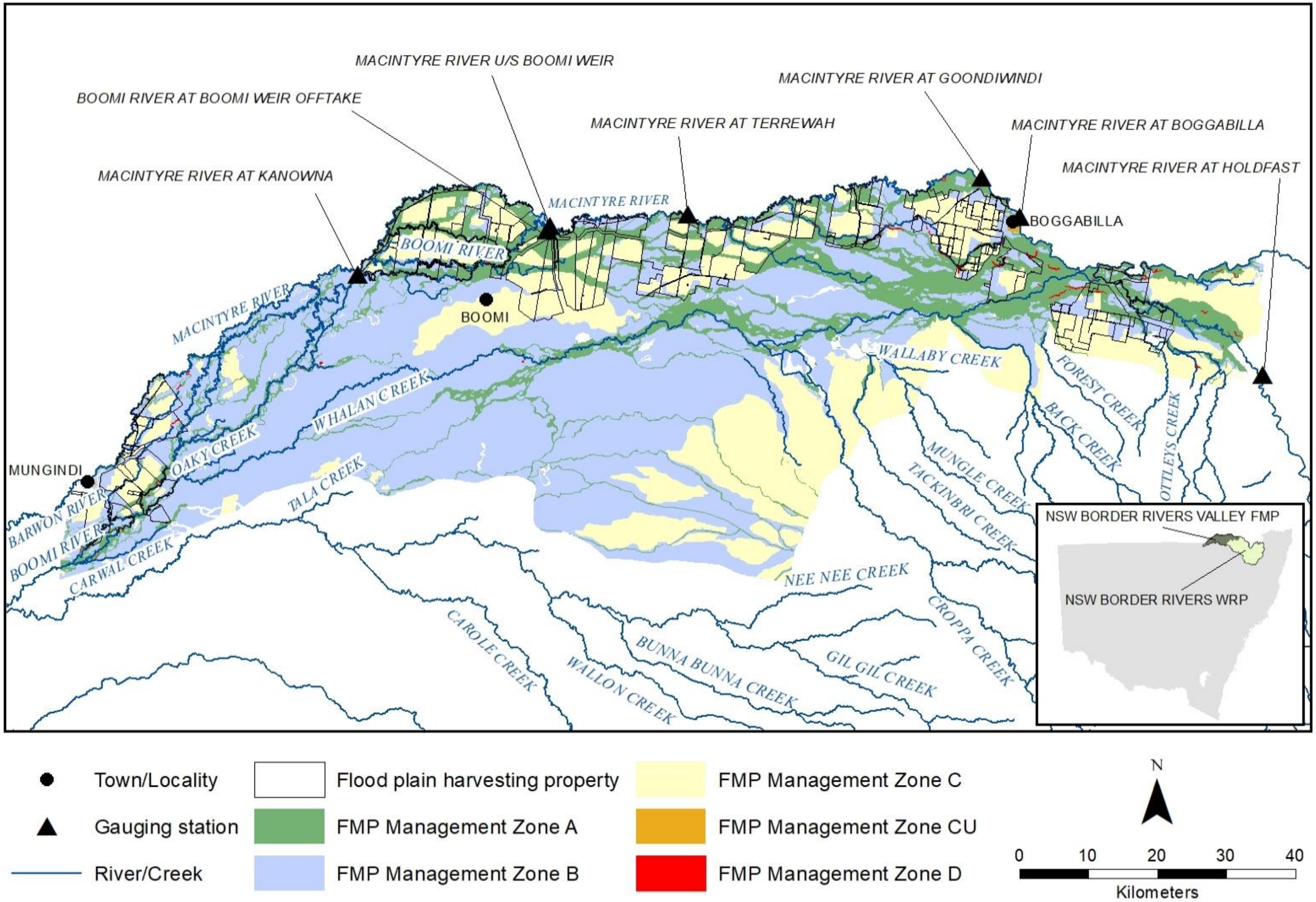

Figure 4 Map of floodplain management zones A, B, C, Cu and D set out in the (draft) NSW Border Rivers Floodplain Management Plan. Only floodplain harvesting properties eligible for floodplain harvesting access licences are shown. FMP= Floodplain Management Plan

3 Environmental assets and values on the floodplain

3.1 Overview of known assets and values

The Border Rivers Valley floodplain is characterised by wetland and lagoon complexes. These wetlands include intermittently connected anabranches 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 specific assets such as nationally important lagoons. A full list of known environmental values in the Border Rivers Valley floodplain, and key geographical assets, is provided in Appendix A and summarised below.

3.1.1 Native fish

At least 12 of the 16 native fish species found in the Border Rivers Valley are recorded or predicted to occur in the various anabranches and wetlands of the Border Rivers floodplain (OEH 2018). 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*), 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 tandanus*; Murray-Darling Basin) (*Fisheries Management Act 1994*). The floodplain also provides critical food resources, drought refuge sites and important habitat for native fish.

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 50 species of waterbirds either recorded or predicted to occur in the Border Rivers Floodplain. A number of these species are listed as vulnerable under the *NSW Biodiversity Conservation Act 2016*, like the magpie goose (*Anseranas semipalmata*) and the brolga (*Grus rubicunda*) (Figure 6). Internationally important species have also been recorded in the floodplain, including the bar-tailed godwit (*Limosa lapponica*) (OEH 2018).

3.1.3 Native vegetation

Several floodplain vegetation species are 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 of the Border Rivers floodplain include river red gum (*Eucalyptus camaldulensis*), coolabah (*Eucalyptus coolabah*), lignum (*Muehlenbeckia florulenta*), river cooba (*Acacia stenophylla*) and marsh club-rush (*Bolboschoenus fluviatilis*), the latter being a key species of the marsh club-rush sedgeland Critically Endangered Ecological Community (OEH 2018, DPIE Water 2019b).

3.1.4 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). By supporting increases in their food sources, increased productivity can be linked to increased populations of larger organisms like fish (Wootton and Power 1993). The Border Rivers floodplains between Goondiwindi and Mungindi contain extensive anabranches and billabongs. These 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).

Figure 5 The unmistakeable Brolga has been recorded in the Border Rivers floodplain and is listed as vulnerable in NSW under the *NSW Biodiversity Conservation Act 2016* [Image: Geoff Whalan]

3.1.5 Wetlands

A nationally and culturally significant wetland system is situated in the Border Rivers catchment to the southwest of Goondiwindi – the Morella lagoon/Boobera lagoon/Pungbougal lagoon (DAWE 2020). Other significant lagoons and wetlands have been identified in the *Water Sharing Plan for the NSW Border Rivers 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 occur 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 zones 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 Border Rivers Valley floodplain is summarised in Figure 6 and the following sub-sections.

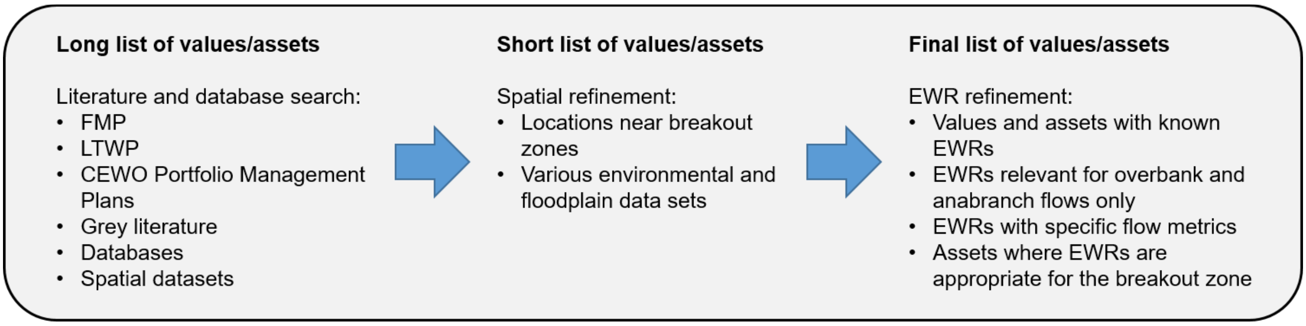

Figure 6 Summary of the approach adopted to identify water-dependent environmental values and assets in floodplain harvesting areas. FMP = Floodplain Management Plan, LTWP = Long-term water plans, CEWO = Commonwealth Environmental Water Office, EWR = environmental water requirement

3.2.1 Literature and database search

A literature and database search was undertaken to identify water-dependent environmental values and assets in the Border Rivers Valley Floodplain. The search included species, populations, communities, ecosystem functions and specific breakout zones (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 Border Rivers Valley Floodplain* (DPI Water 2017)
  - Long-Term Water Plan (OEH 2018)
  - Commonwealth Environmental Water Portfolio Management Plan (CEWO 2018)
  - Environmental Values and Watering Priorities for the Northern Murray Darling Basin (SKM 2009)
  - Risk Assessment for the Border Rivers Surface 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, mapped or predicted to occur within the Border Rivers Valley Floodplain Management Plan boundary.

3.2.2 Spatial refinement

The next step involved identifying those environmental values and assets that occurred within a defined spatial area near the 'breakout zones'[2] as characterised in the river system model. These river system models are the key sources for predicting hydrological changes on the floodplain before and after implementing the policy. An overview of the river system model is provided in Section 4, with more detail in Appendix D and fully described in (DPIE Water 2020a).

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 7). The river system model has configured 17 high flow breakouts, grouped into 9 'breakout zones', associated with a variety of flood runners, anabranches and direct take from the river channel. The end of system

[2] Refer to Appendix D of *Building the Border Rivers Valley river system model* (DPIE Water 2020a) for a description of the derivation of these breakout zones.

(EOS) floodplain breakout represents the breakout zones where most of the changes to floodplain hydrology can be detected within the DPIE Water river system models.

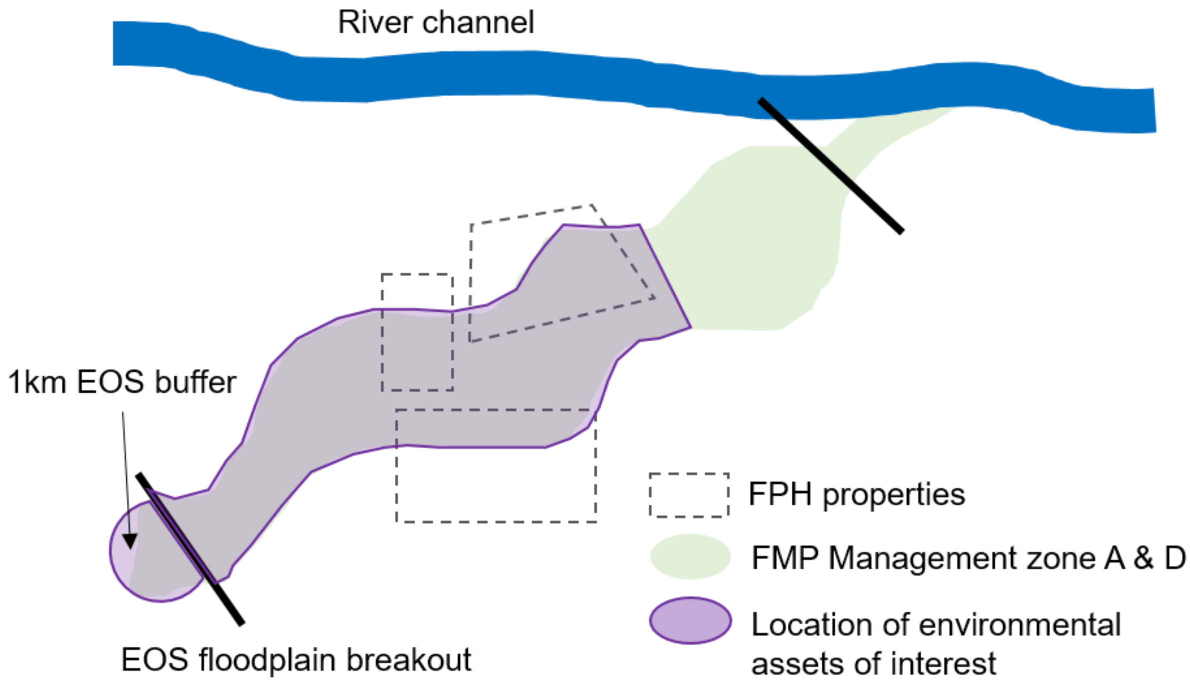

Figure 7 Illustrated depiction of a 'breakout zone'. Breakout zones represent areas where flood waters break out from the river channel onto the floodplain and floodplain harvesting occurs

The upstream and downstream area was restricted by a defined spatial area between the most upstream eligible floodplain harvesting property and a 1 km radius below the end of system floodplain breakout or floodplain harvesting property (whichever was further downstream) in the river system model (Figure 7). Breakout zones provide a high 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 Border Rivers Valley floodplain was split into 9 breakout zones.

The breakout zone, or area of interest, was then further refined[3] to select environmental assets and values which occurred with important *Border Rivers Floodplain Management Plan* (FMP) management zones. Boonal (Zone A) signifies a major flood discharge zone and is of significant importance to floodplain assets. Whalan (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 2017). 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 8 summarises the spatial and EWR refinement process.

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] ArcGIS (10.3.1) was used for this task

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

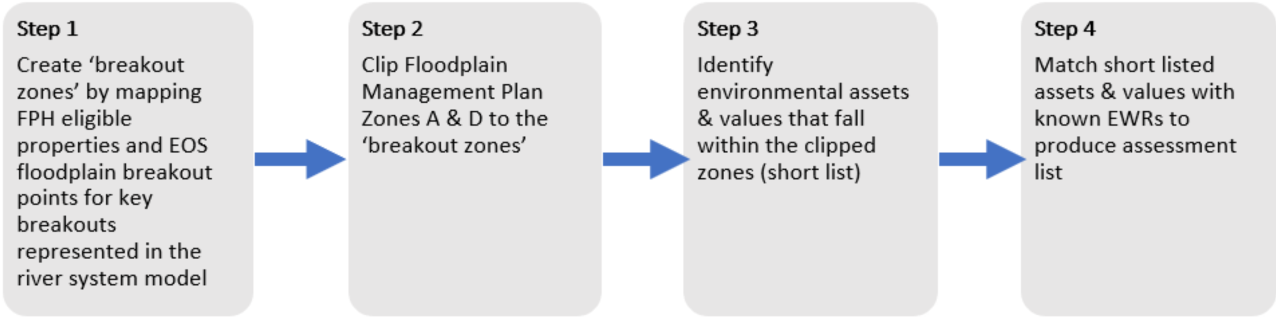

Figure 8 The spatial and EWR refinement process to select environmental assets and values for assessment

3.2.3 Environmental Water Requirement refinement

The last step (Step 4 in Figure 8) 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 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 Border Rivers 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 9 breakout zones on the floodplain (listed in Table 2). These occur from upstream of Boggabilla (at Boonal (A)) to near Mungindi and support a suite of environmental assets and values including threatened plants, animals, communities 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
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) Boonal	Boonal EOS floodplain	Native fish	Eel-tailed Catfish – MDB population (E)3, Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed duck (V)1, brolga, freckled duck (V)1, magpie goose (V)1
		Native vegetation	River red gum, river cooba swamp, coolabah–river cooba–lignum woodland, lignum shrubland wetland, water couch marsh grassland wetland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Boonal Anabranch, Toomelah lagoon, Telephone lagoon, Malgarai lagoon
(B) Boggabilla	End of Boggabilla Breakout	Native fish	Eel-tailed Catfish – MDB population (E)3 Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1

Breakout	Key breakout points	Asset/Value	Characterisation
		Native vegetation	River red gum, coolabah–river cooba–lignum woodland, lignum shrubland wetland, poplar box – coolabah floodplain woodland, water couch marsh grassland wetland river cooba swamp wetland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Morella lagoon, Bora Wetland, Pungbougal lagoon, Poopoopirby lagoon, Maynes lagoon (Yarrangooran lagoon), Gooroo lagoon, Gobbooyallana lagoon (Turkey lagoon), unnamed lagoons 4, 5, 7
(C) Goondiwindi	End of Goondiwindi Breakout	Native fish	Eel-tailed Catfish – MDB population (E)3, Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1, Australian pelican, black swan, great cormorant, grey teal, hardhead, little black cormorant, masked lapwing, musk duck, Pacific black duck, plumed whistling duck, royal spoonbill, whiskered tern
		Native vegetation	River red gum, coolabah open woodland wetland, coolabah–river cooba–lignum woodland, lignum shrubland wetland, river cooba swamp wetland, water couch marsh grassland wetland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Morella lagoon, coolabah lagoon, Boobera lagoon
(D) Whalan	Whalan EOS to Floodplain	Native fish	Eel-tailed Catfish – MDB population (E)3, Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2

Breakout	Key breakout points	Asset/Value	Characterisation
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed Duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1, Australian pelican, black swan, great cormorant, grey teal, hardhead, little black cormorant, masked lapwing, musk duck, Pacific black duck, plumed whistling duck, royal spoonbill, whiskered tern, yellow-billed spoonbill
		Native vegetation	River red gum, coolabah–river cooba–lignum woodland, river cooba swamp, coolabah open woodland wetland, lignum shrubland wetland, water couch marsh grassland wetland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Mundine lagoon, coolabah lagoon, Carbucky lagoon, Boobera lagoon
(E) Tarpaulin (Croppa/ Whalan)	End of Croppa/ Whalan Breakout	Native fish	Eel-tailed Catfish – MDB population (E)3, Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1, grey teal, Pacific black duck, plumed whistling-duck, Australasian darter, little pied cormorant, great cormorant, little black cormorant, pied cormorant, Australian pelican, white-necked heron, little egret, white-faced heron, nankeen night heron, royal spoonbill, white-bellied sea-eagle, Australian wood duck, intermediate egret, unidentified egret
		Native vegetation	coolabah–river cooba–lignum woodland, coolabah open woodland wetland, lignum shrubland wetland, river red gum, water couch marsh grassland wetland
		Wetlands	Wombyanna lagoon, Boomi River billabong, Bonanga billabong
(F) Terrewah	End of Terrewah Breakout	Native fish	Eel-tailed Catfish – MDB population (E)3, Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2

Breakout	Key breakout points	Asset/Value	Characterisation
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed Duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1, grey teal, Pacific black duck, plumed whistling-duck, Australasian darter, little pied cormorant, great cormorant, little black cormorant, pied cormorant, Australian pelican, white-necked heron, little egret, white-faced heron, nankeen night heron, royal spoonbill, white-bellied sea-eagle, Australian wood duck, intermediate egret
		Native vegetation	River red gum, coolabah–river cooba–lignum woodland, lignum shrubland wetland, coolabah open woodland wetland, water couch marsh grassland wetland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Wombyanna lagoon, Boomi River billabong, Bonanga billabong
(G) Boomangera	Boomangera EOS to Floodplain	Native fish	Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, Black-necked stork (E)2, blue-billed duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1, Australian pelican
		Native vegetation	River red gum, coolabah open woodland wetland, coolabah–river cooba–lignum woodland, carbeen +/- coolabah grassy woodland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Boomangera lagoon, unnamed lagoon (Werrina A–E), unnamed lagoon (Boroo) Wombyanna lagoon
(H) Yarrowee	Yarrowee EOS to Floodplain	Native fish	Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1
		Native vegetation	River red gum, coolabah open woodland wetland, coolabah–river cooba–lignum woodland, lignum shrubland, water couch marsh grassland wetland

Breakout	Key breakout points	Asset/Value	Characterisation
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Unnamed lagoon 6
(I) Boomi/ Whalan	Boomi/ Whalan EOS to Floodplain	Native fish	Southern Purple spotted Gudgeon (E)3, Silver Perch (V)2, Olive Perchlet – Western population (E)3, Murray Cod (V)2
		Waterbirds	Australian painted snipe (E)2, black-necked stork (E)2, blue-billed duck (V)1, brolga (V)1, freckled duck (V)1, magpie goose (V)1, Pacific black duck, Australian wood duck, Australian white ibis, plumed whistling-duck
		Native vegetation	River red gum, coolabah–river cooba–lignum woodland, coolabah open woodland wetland, lignum shrubland wetland, water couch marsh grassland
		Important ecological functions	Nutrient, carbon and primary production
		Wetlands	Doondoona lagoon, Marakai wetland, unnamed lagoon (Turrawah A-C), unnamed lagoon (Narrawal B), unnamed lagoon (Hamilton), Goony lagoon, Carwell lagoon

Figure 9 depicts the breakout zones of breakout zones, eligible floodplain harvesting properties and hydrological gauges. Figure 10 to Figure 12 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 (PCT)s were the main focus for these maps.

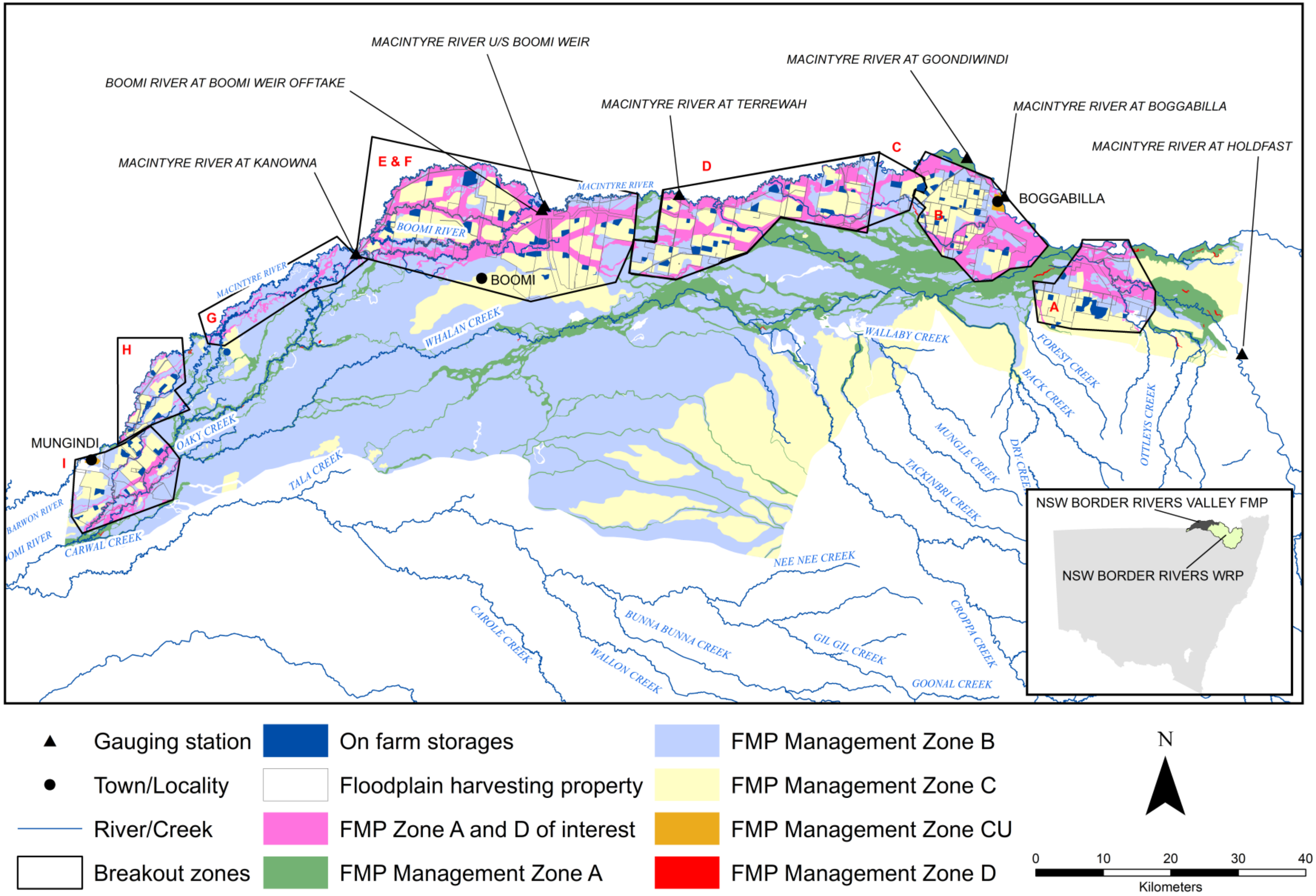

Figure 9 Map of the Border Rivers floodplain showing the Floodplain Management Plan (FMP) zones and the zones of interest used to select environmental assets and values for inclusion in this assessment. Breakout zones from most upstream to most downstream: A Boonal, B Boggabilla, C Goondiwindi, D Whalan, E Tarpaulin (Croppa/Whalan), F Terrewah, G Boomangera, H Yarrowee, I Boomi/Whalan.

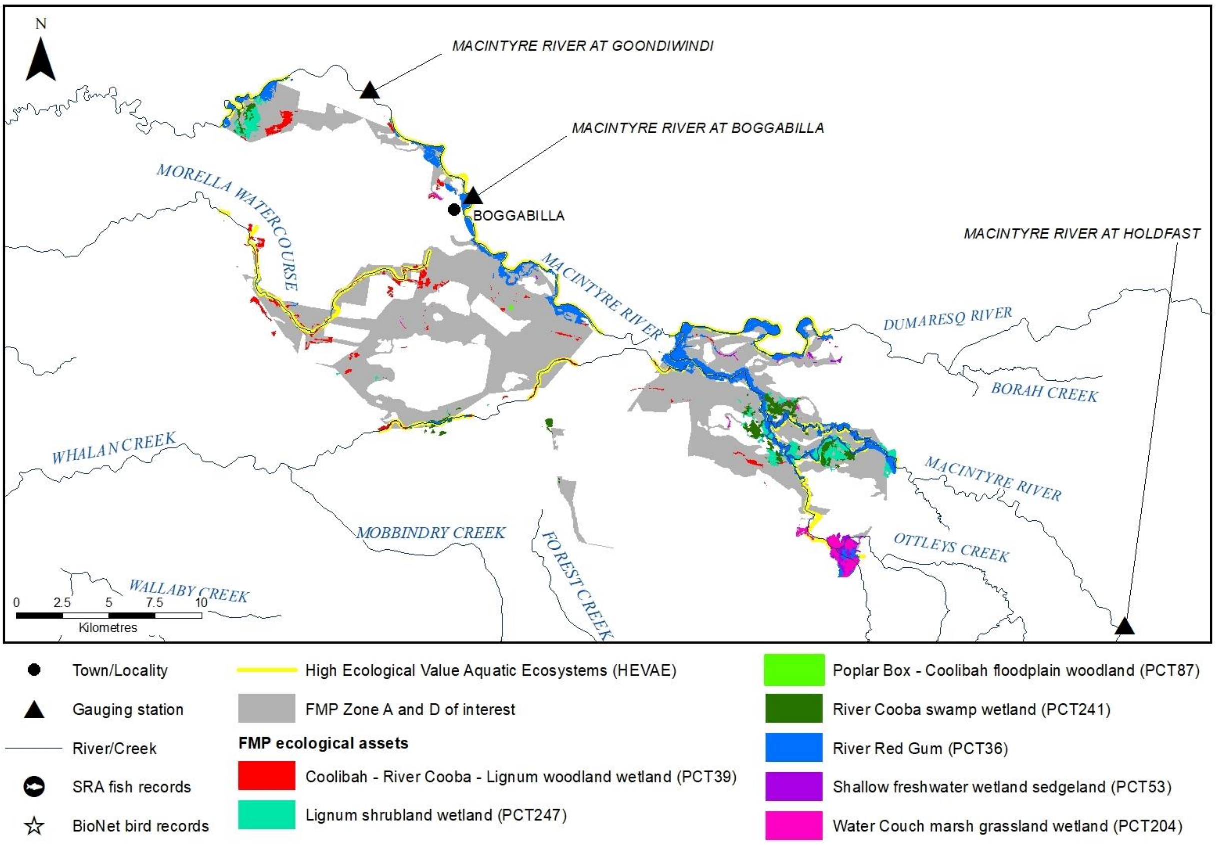

Figure 10 Location of selected water-dependent environmental assets and values at breakout zones A Boonal and B Boggabilla. Appendix B details data sources that were not able to be presented

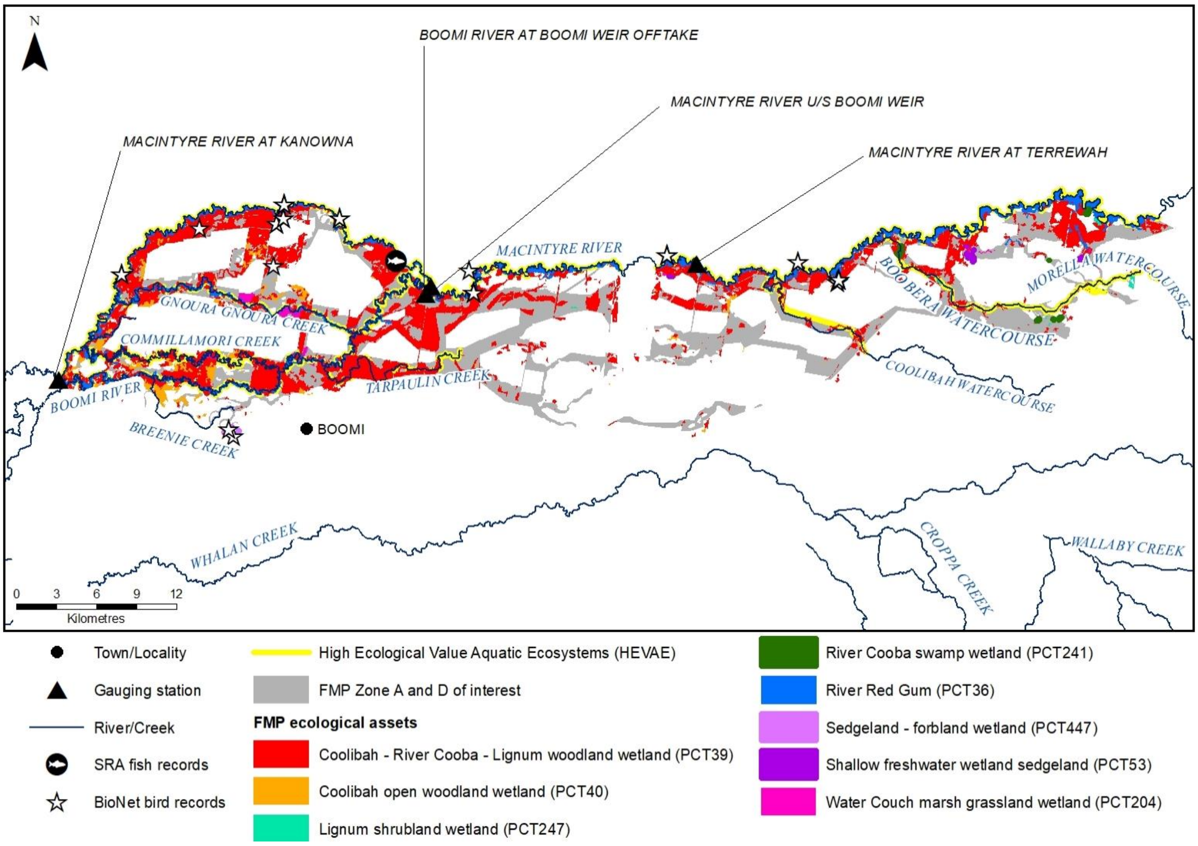

Figure 11 Location of selected water-dependent environmental assets and values at breakout zones C Goondiwindi, D Whalan, E Tarpaulin (Croppa/Whalan) and F Terrewah. Appendix B details data sources that were not able to be presented

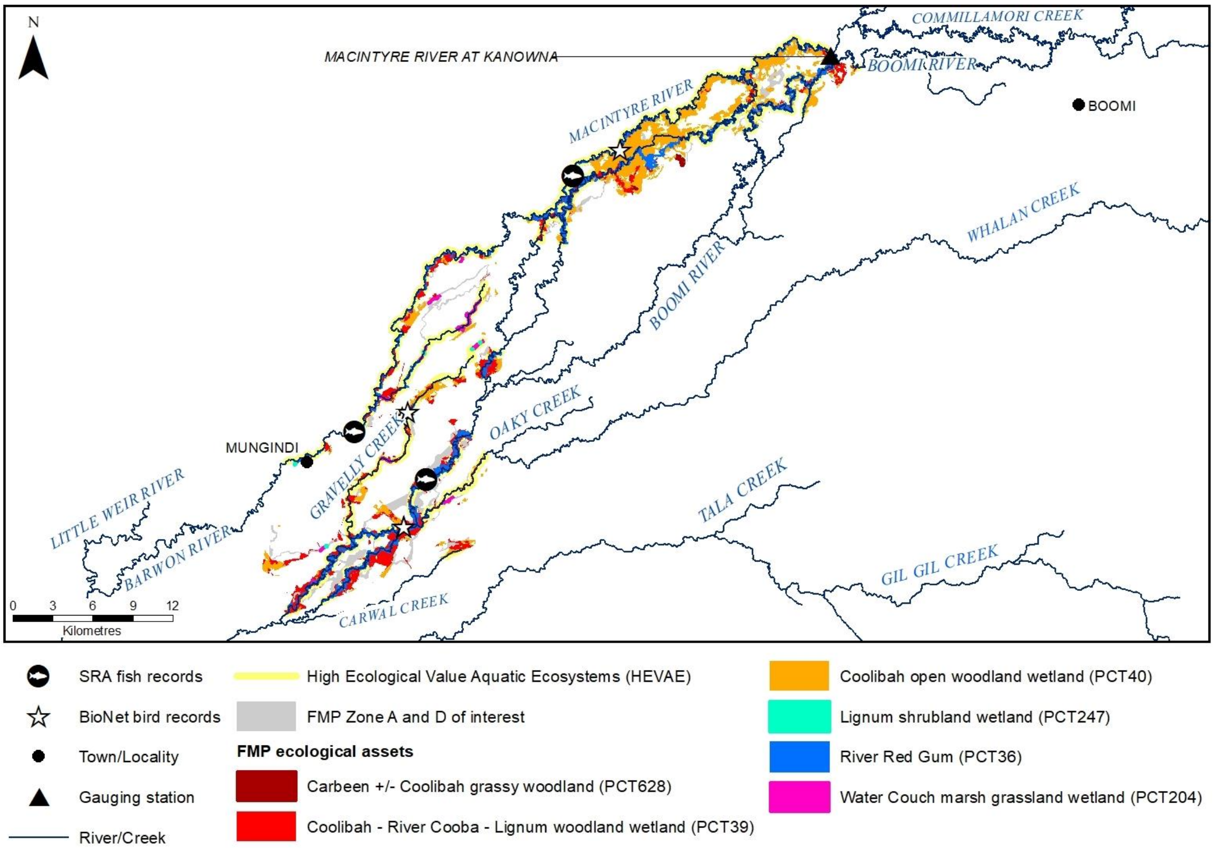

Figure 12 Location of selected water-dependent environmental assets and values at breakout zones G Boomangera, H Yarrowee and I Boomi/Whalan. Appendix B details data sources that were not able to be presented

4 Hydrological changes on the floodplain

4.1 River system model overview

Implementation of the *NSW Floodplain Harvesting Policy* (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 DPIE Water. Further information can be found for each model in the companion Model Build reports for each valley (e.g. *Building the river system model for the Border Rivers Valley regulated river system* (DPIE Water 2020a).

River system models have been used for many decades to determine water availability, flows and diversions under varying climate conditions, as a critical step in informing the development of water sharing arrangements. The Border Rivers Valley model is designed to support contemporary water management decisions in the Border Rivers, 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 and estimating Plan limits
- to determine volumetric entitlements for floodplain harvesting consistent with the 2013 policy.

4.1.1 Modelling platform

The Border Rivers Valley river system model is built using the Source software platform which has been adopted as Australia's National Hydrological Modelling Platform. Source simulates flows through a system, whether those flows are water, sediment, contaminants, water accounts or water trade. It provides sufficient functionality to simulate the process of water moving out onto floodplains. Source models are built from components which are linked, through adding nodes and links, to represent the system to be modelled. There are many types of nodes to represent places where water can be added, diverted, stored, and recorded (for reporting) in a model, including:

- 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 can be configured to correctly represent the system, a process known as parameterisation (DPIE Water 2020a). 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 13 shows the key components of a reach water balance. The Environmental Outcomes reports primarily use 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 performances against observed data over the period of calibration. The NSW Border Rivers model was validated between the period 01/07/2004 to 30/06/2013 (DPIE Water 2020a).

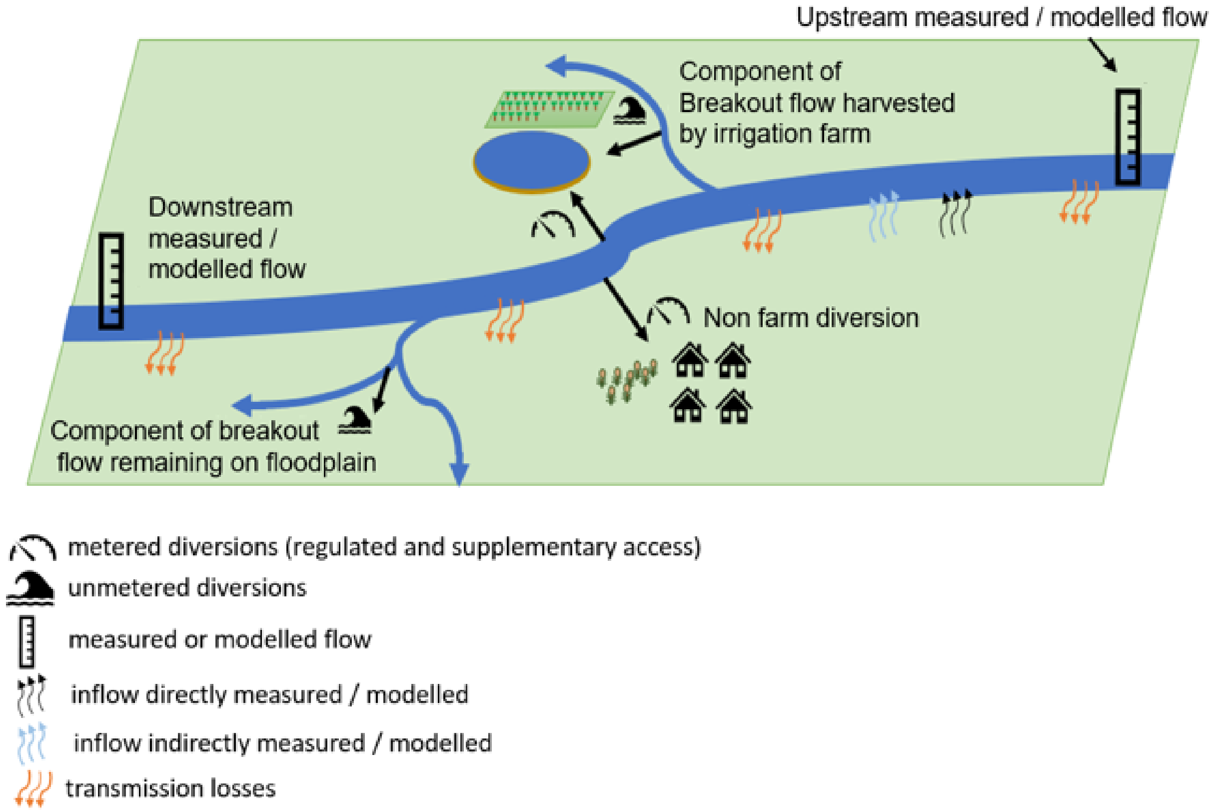

Figure 13 Reach water balance components [Source: Figure 3, DPIE Water 2020a]

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

> "Fixed development conditions: including catchment and landuse, 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 2020a).

These scenarios are detailed in the companion Scenarios report (DPIE Water, 2020b).

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. to stop off allocation water going down the breakout, to represent the virtual storage)

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

- all the 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 7). This is a reporting point in the model, and not an actual gauge.

4.1.4 Available hydrological data

Change in floodplain harvesting pre- and post-implementation of the policy was assessed under two model scenarios:

- current conditions, that is without the policy implemented; the Current Conditions Scenario
- current conditions with floodplain harvesting entitlements and accounting applied; the Plan Limit Scenario.

Both scenarios are required to identify hydrological changes due to implementing the policy and flow-on environmental floodplain benefits or disadvantages. Each scenario contains:

- modelled daily time-series flow data (in ML/day) for important gauging stations (gauge nodes) in the valley
- modelled daily time-series flow data (in ML/day) (via a Source 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 7. More details on the modelling are provided in Appendix D and the companion Model Build and Scenarios reports (DPIE Water 2020a, DPIE Water 2020b).

All modelled flow data cover the period from 1895 to 2019.

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). Native fish biomass, health and abundance can increase with the magnitude, duration and inundation of a flood (Bunn et al. 2006) whilst inundation extent, duration and variability (i.e. regularity or frequency) are critical to maintain and improve floodplain vegetation species. For example, river red gum forests can survive for long periods without inundation but require periodic flooding (every 1 to 3 years), a flood inundation duration of 2 to 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 fall 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, EES 2020). For example, the most common timing for spawning of floodplain specialist fish in the northern basin is September to October. Improving magnitude and duration of floods during these periods would therefore achieve the greatest outcomes for these fish (NSW Department of Primary Industries 2015). These hydrological features are also important for a number of other ecological functions on the floodplain and in the river channel. Therefore, identifying and describing the changes to key metrics of each hydrological feature is the first step in assessing environmental outcomes of implementing the policy.

Flow metrics that describe the ecologically relevant hydrological features of the floodplain have been adapted from Richter et al. (1996) and Leigh and Sheldon (2008) and are shown in Table 3. A mix of summary, parametric and non-parametric measures has been selected to describe these features. Non-parametric measures (such as **medians**) are appropriate for many flow regimes due to the less frequent floods and more frequent low flows; while **totals** and parametric measures (such as **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). Using totals (e.g. total duration of summer events) avoids the impact of zeros on the mean and median. Where medians were used, 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.

Table 3 Hydrological feature, period of interest and hydrological metrics adopted to describe magnitude and duration of flood events. Seasonality (timing), frequency and variability are incorporated into each hydrological feature. [1]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 interevent 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

For annual, seasonal and event time periods, magnitude (volumes and flow rates) will be described by mean, medians and totals, as well as by skewness 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 predict environmental outcomes on the floodplain.

4.2.2 Methods to quantify changes

The model Current Conditions and Plan Limit scenarios are the primary source of information used to quantify changes in floodplain flows due to implementing the policy. The hydrological metrics listed in Table 3 were calculated for each modelled flow series[6]. As the end of system (EOS) floodplain breakout flow is the modelled time series where detectable impacts of floodplain harvesting are evident, the analysis is restricted to this model node for each breakout zone.

A comparison of results for the EOS floodplain breakout under these two scenarios was undertaken for the period 1895 to 2019 (Figure 14, Table 4). The Plan Limit Scenario 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 2019. Running over such a long period ensures that multiple dry and wet periods and climate extremes are captured in the modelling and provides a measure of change under similar climatic conditions when the policy is implemented. Further detail on the limitations and approach used to quantify hydrological changes can be found in Appendix D .

[6] 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.

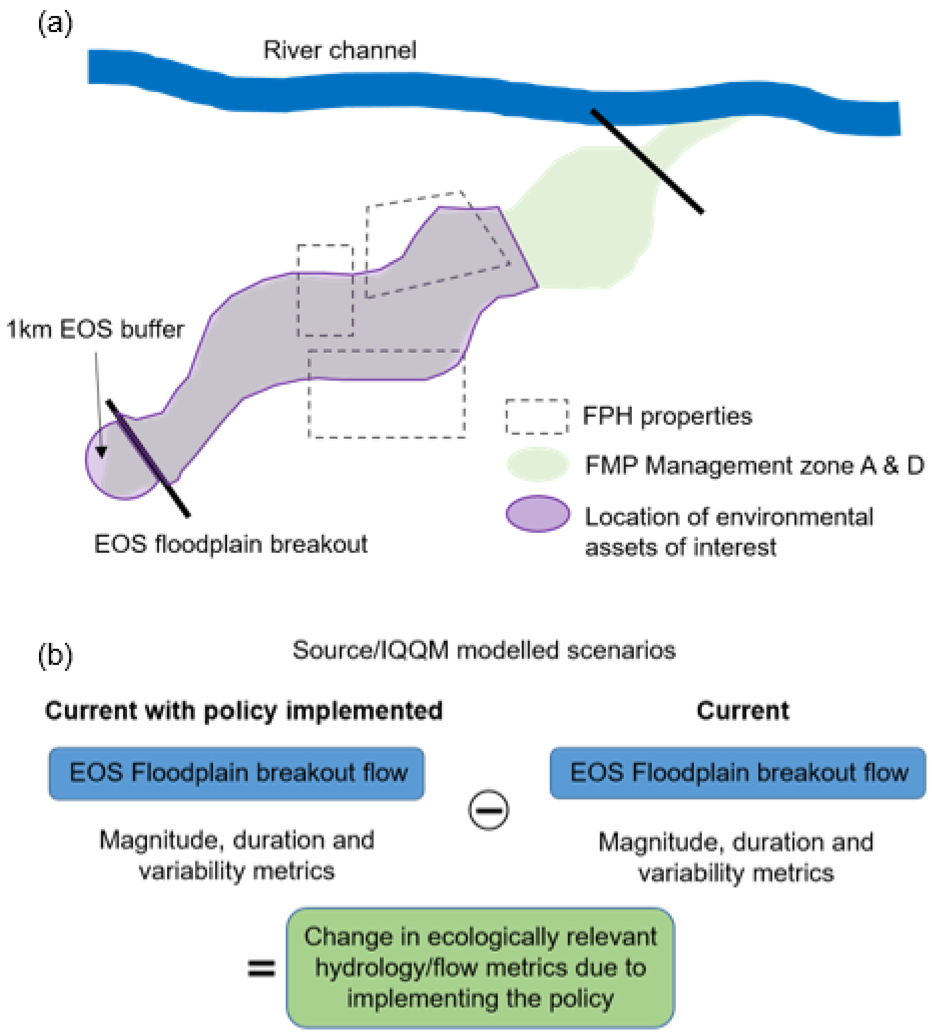

Figure 14 Diagram showing the relevance of the river system model end of system (EOS) floodplain breakout (a) to environmental assets and values and how this model breakout (b) was used to identify changes to floodplain hydrology

4.3 Hydrological outcomes

4.3.1 Changes to floodplain hydrology

Modelling indicates that implementation of the policy will result in changes to key hydrological features of the floodplain. Change in each of the 9 breakout zones with the policy implemented, expressed as percentage change from without the policy implemented, is provided in Table 4. Results are broken down into the key hydrological features of magnitude, duration and event frequency and discussed 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 Border Rivers Valley floodplain.

Results presented are modelled long-term (over the period 1895 to 2019) changes to the hydrology of the floodplain that would occur under the policy.

Magnitude

Total and **mean annual volumes** are predicted to increase in all breakout zones after implementation of the policy. In total, during flood years (i.e. excluding non-flood years) the policy is predicted to allow 15 GL in mean annual volumes to return to the floodplain across all breakout zones. Boomi/Whalan (I) is the only breakout zone not predicted to see an increase of 10% or more in mean annual volume of breakout EOS flow. The largest percent increase in mean annual volume is at Boggabilla (B) (49%, 1.2 GL) and the largest volume increase is at Terrewah (F) (4.6 GL, 15%). The smallest relative increase (2%) is 0.9 GL at Boomi/Whalan (I).

Total seasonal volumes are also predicted to increase at the majority of breakout zones: the largest in autumn (196% at Boggabilla (B)), winter (88% at Boonal (A)) and summer (38% at Boggabilla) (B). Total spring volume is predicted to increase by 3 to 9% across 6 of the 9 zones with no change or a small reduction in the other 3.

Median event magnitudes, which provide a measure of change in flow rates (ML/day) during flood events, are predicted to increase by 24% at Boggabilla (B) and 18% at Whalan (D), with very little change predicted at the other 7 breakout zones.

Whilst a number of improvements are predicted for total seasonal volumes and median event magnitudes, this is not consistent across the floodplain with some zones predicted to have very little change, particularly at Boomi/Whalan (I), the most downstream breakout zone near Mungindi.

Duration

Total number of flow days is predicted to increase in all breakout zones (Table 4). Days with flow almost double at Whalan (D) and Boggabilla (B), with increases of 716 (93%) and 666 (86%) flow days respectively.

Seasonal changes to flood durations vary with the season and breakout zone. Four zones have predicted increases in the number of flow days during spring that are above the average of 4%. The largest is a predicted 15% increase in spring flood durations at Goondiwindi (C). Changes to total summer days with flow vary from increases of 91% (172 more days) at Whalan (D) to 2% (7 extra days) at Boomi/Whalan (I). All breakout zones are predicted to have more days with flow in summer months after implementation of the policy, with an average of 20% increase across all breakout zones. The biggest improvements are predicted at Whalan (D) (91%) and Boggabilla (B) (72%). The other season predicted to receive longer flood durations is autumn, with some increases as much as 475 more flow days (257% more) at Boggabilla (B). All breakout zones except Boomi/Whalan (I) are predicted to receive more days with flow in autumn.

Event based metrics

The **number of flood events** between 1895 and 2019 are predicted to increase across all zones by 30% on average (Table 4). The largest relative increases in number of events are 3 at Boonal (A) (30%), 11 at Whalan (D) (24%) and 17 at Terrewah (F) (23.3%). The mean duration between events (**inter-event period**) is predicted to reduce at all breakout zones, with the largest being an average reduction of 900 days (-25%) between events at Boonal (A). The reduced inter-event period and associated rise in number of events will result in more events reaching floodplain assets and values with shorter periods between each flood event.

Modelled outcomes for the **rise and fall** statistics of flood events vary by breakout zone and flow metric of interest (Table 4). All 9 breakout zones are predicted to have increases in total duration of the rising limb of flood events. The largest change is a total increase of 101 days (35%) in rising limb duration at Whalan (D). The mean **rate of rise** decreased across most breakout zones with the greatest change a reduction in the rate of rise by approximately 100 ML/day (-29.9%) for flood events at Whalan (D). The duration of the **falling** limb of events is predicted to change by less than 3% at all breakout zones.

Table 4 Percentage change in ecologically relevant flow metrics after implementation of the policy. Values are averaged over the simulation period. EC = Event created, i.e. there was no event before implementation of the policy. Only flows >1 ML/d were considered flowing days. *Negative % change is a positive outcome for the value or asset as the mean period between floods (inter-event period) has reduced.

Hydrological feature	Flow metric	Boonal A	Boggabilla B	Goondiwindi C	Terrewah F	Boomangera G	Yarrowee H	Whalan D	Tarpaulin E	Boomi/ Whalan I	Average
Magnitude	Mean of annual volume (flood years only)	14%	49%	12%	15%	12%	15%	33%	13%	2%	18%
	Ratio of median to mean annual volume	-14%	-34%	-12%	-14%	-12%	-15%	-26%	-13%	-4%	-16%
	Total autumn volumes	EC	196%	30%	29%	27%	29%	163%	29%	1%	63%
	Total winter volumes	88%	20%	1%	1%	2%	-1%	15%	-2%	1%	14%
	Total spring volumes	0%	3%	9%	8%	-1%	3%	5%	4%	0%	3%
	Total summer volumes	7%	38%	12%	21%	18%	22%	23%	19%	1%	18%
	Median of event magnitude	1%	24%	2%	1%	0%	3%	18%	2%	0%	6%
Duration, frequency and timing	Total flow days	25%	86%	15%	15%	9%	13%	93%	11%	1%	30%
	Number of events	30%	19%	8%	23%	11%	14%	24%	9%	3%	16%
	Total autumn days with flow	EC	257%	35%	41%	23%	29%	240%	13%	0%	32%
	Total winter days with flow	20%	18%	3%	4%	5%	3%	22%	-1%	-1%	4%
	Total spring days with flow	0%	9%	15%	4%	-1%	1%	15%	8%	0%	4%

Hydrological feature	Flow metric	Boonal A	Boggabilla B	Goondiwindi C	Terrewah F	Boomangera G	Yarrowee H	Whalan D	Tarpaulin E	Boomi/ Whalan I	Average
	Total summer days with flow	26%	72%	18%	20%	12%	18%	91%	21%	2%	20%
	Mean inter-event period*	-25%	-14%	-8%	-19%	-10%	-13%	-15%	-8%	-2%	-13%
	Total duration of rises	32%	29%	17%	18%	10%	10%	35%	8%	1%	18%
	Mean rate of rise	-16%	-6%	-2%	-1%	0%	-4%	-30%	9%	5%	-5%
	Total duration of falls	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean rate of fall	-2%	-6%	13%	3%	-1%	12%	-56%	14%	0%	-3%

5 Predicted ecological outcomes

The results presented in this section are based on long-term (1895 to 2019) simulated hydrological changes where the policy is implemented across the entire record. 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 for environmental purposes is predicted to increase annually and in each season, with the biggest relative increases in autumn followed by summer (Figure 15). The mean annual predicted increase in volumes (across all breakout zones) is 1.7 GL, with up to 4.6 GL returned to the Terrewah (F) breakout zone (F) alone. Improvements are also predicted for **event durations** in all seasons. The biggest predicted increases in flood durations are in autumn and summer. Enhanced summer flood volumes and durations will provide benefits to a broad range of assets and values in the Border Rivers as this is a warm and biologically active period. The **number of events** increases by 16% on average. In addition, the **inter-event period** reduces by up to 89 days for half of the breakout zones. In the Boonal (A) breakout zone, the mean inter-event period reduces to 7.5 years from more than 10 years. The combination of more flood events with reduced inter-event periods should improve the flooding frequency for most floodplain assets and values.

In general, the increased volume, number and duration of events passing through floodplain harvesting areas are predicted to contribute to downstream benefits for other regions of the Border Rivers, including the Barwon-Darling.

Returning water use back to the long-term average extraction limit and curtailing future growth in floodplain harvesting through the policy will also provide improvements in reliability of environmental provisions of the (draft) Floodplain Management Plan for the Border Rivers Valley Floodplain 2018. This is predicted to benefit most water-dependent floodplain environmental assets and values in the NSW Border Rivers.

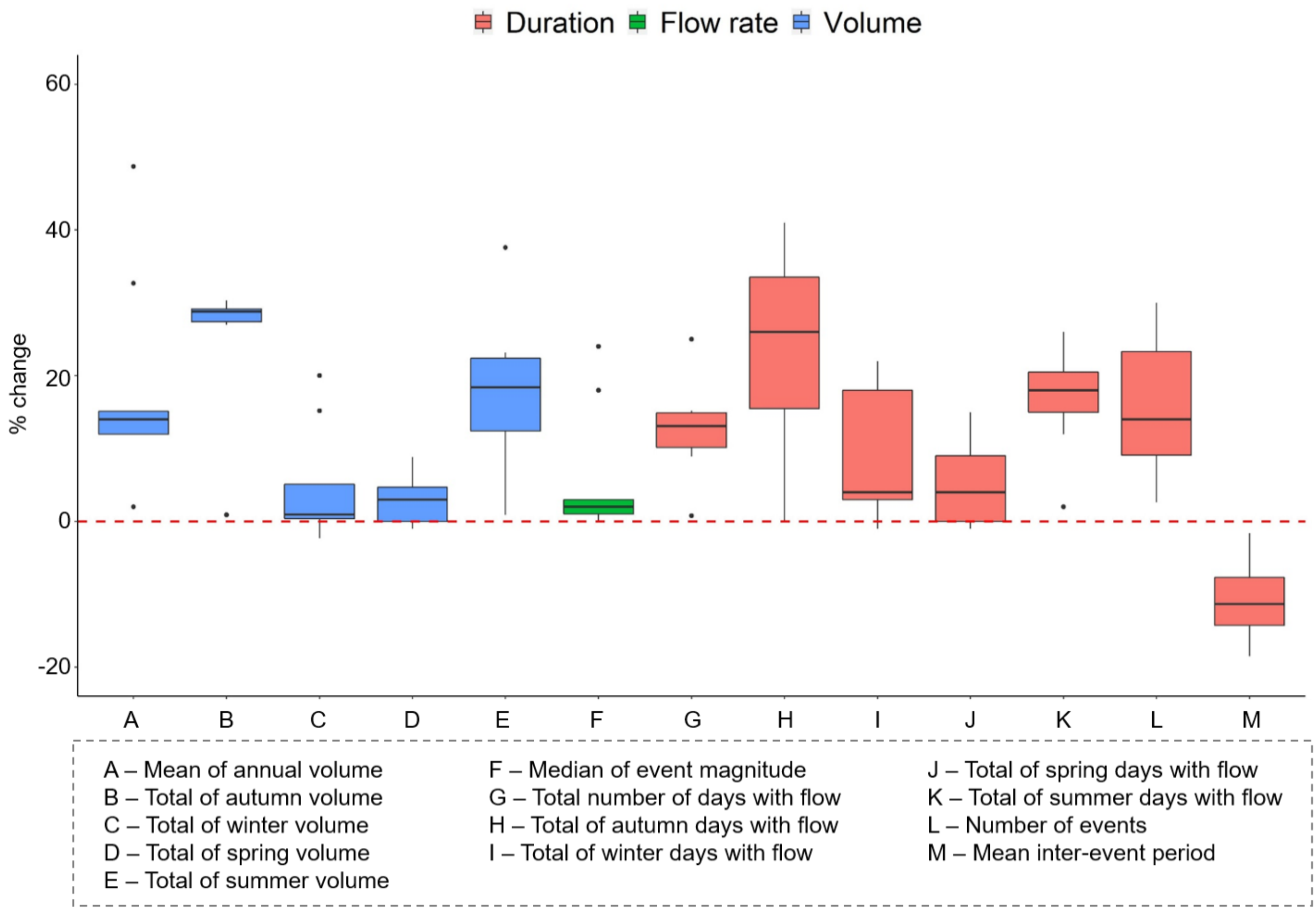

Figure 15 Box plot of percentage change in key hydrological metrics after implementing the policy in the Border Rivers Valley. Data represents the medians (bold line inside box), 25th and 75th percentiles (bottom and top of box), minimum and maximum (bottom and top whisker notches) and outliers (points), averaged over the simulation period across the 9 breakout zones

5.2 Assessment approach

Understanding the summary statistics for hydrological changes in Section 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 (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 *Assumptions and limitations* (Section 5.3) below.

For the majority of environmental values, EWRs were grouped into two common themes: (1) maintenance and (2) regeneration/reproduction. 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). 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.

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[7]. As flow 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 a spell length or period of 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. The month of, season of, days between, and years between events were then generated from the spell length data[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 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 has 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 C . 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 and wetlands 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 , expert opinion and a documented understanding of 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 improvement in meeting 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 vegetation species are under significant stress due to climatic conditions such as 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

[7] 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.

community can be spatially variable. For example, lignum can occur in dense stands or intergrade into different communities such as coolibah 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 volumes of water returned to 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 for areas outside the identified breakout zones (e.g. downstream benefits) 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 Border Rivers Long term Watering Plan Part B (OEH 2018) suggests a >27,000 ML/day event at the Macintyre @ Goondiwindi (416201A) flow gauge for three days will achieve a small overbank event. This is expected to provide a sufficient inundation period for a range of environmental values. 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 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 under 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, 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 month8. The data were interpreted as a % change in the number of flow days per month, after implementing the policy. Figure 16 represents the summary statistics (median, 25th and 75th percentiles) across all 9 breakout zones. Percent change results are in Table 5.

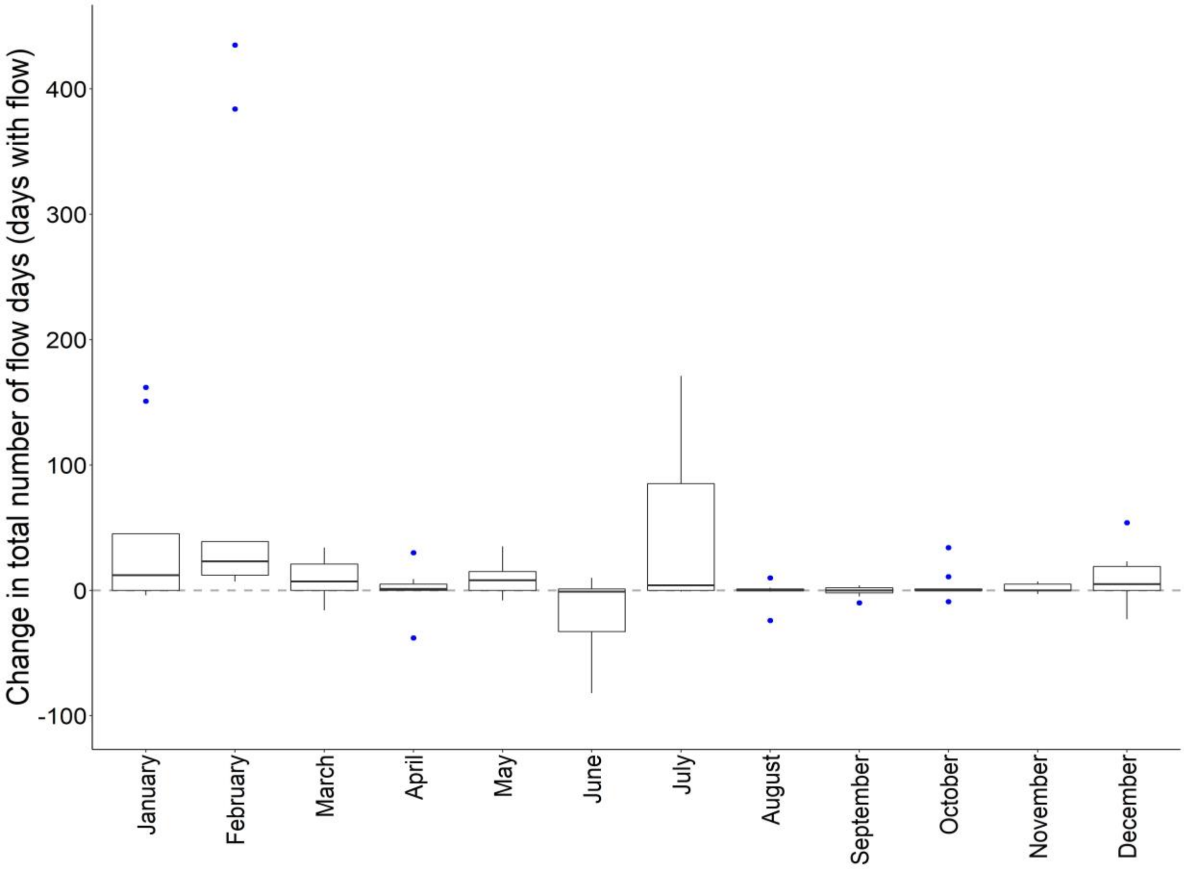

Figure 16 Box plot of change in total number of flow days in each month after implementing the policy in the Border Rivers Valley. Values are averaged over the simulation period across all 9 breakout zones. Number of flow days is based on modelled flow >1 ML/day. Boxes show the medians (bold line inside box), 25th and 75th percentiles (bottom and top of box), minimum and maximum (bottom and top whiskers) and outliers (points) for the 9 breakout zones

[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.

Table 5 Percentage change in duration (total number of flow days in each month) for each breakout zone after implementing the policy. Values are averaged over the simulation period. EC = Event created i.e. there was no event before implementation of the policy. Only flows > 1 ML/day were considered flow days. Su=Summer; Au=Autumn; Wi-Winter; Sp=Spring

Hydrol feature	Breakout zone	Su Jan	Su Feb	Au Mar	Au Apr	Au May	WI Jun	WI Jul	Wi Jul	SP Sep	SP Oct	Sp Nov	Su Dec
Duration	A Boonal	0	62	0	0	0	EC	0	0	0	0	0	0
	B Boggabilla	191	518	16	-34	EC	-32	59	10	-100	25	0	56
	C Goondiwindi	9	24	115	3	22	1	5	-2	3	54	-4	42
	D Whalan	114	474	-19	41	32	-55	285	-20	22	0	27	415
	E Tarpaulin	14	22	20	3	8	0	-1	2	0	0	18	32
	F Terrewah	6	61	162	11	18	9	-1	0	4	12	-2	31
	G Boomangera	35	6	41	17	24	-57	121	0	-1	0	0	10
	H Yarrowee	-3	20	-25	2	-17	-24	89	4	-6	-14	8	-50
	I Boomi/Whalan	0	3	3	0	0	-2	0	0	0	0	0	0

The median number of flow days across all zones is predicted to increase in 6 of the 12 months – January, February, March, May, July, December – and remain relatively unchanged in the other 6 months (Table 5, Figure 16). The largest increases in number of flow days are predicted for the summer months. There are a number of breakout zones which have large increases, represented by outliers in Figure 16. For example, the Boggabilla (B) and Whalan (D) breakouts have an increase of 384 (+518%) and 435 (+474%) days with flow in February respectively. These 2 breakout zones have the best predicted outcomes for enhanced number of flow days across most months (Table 5). Whilst the majority of months either have positive outcomes or no change to the number of flow days on the floodplain, some have negative outcomes for certain months (Table 5). For example, 5 of the 9 breakout zones have a reduced number of days with flow in June. In some breakout zones, this reduction is as much as 57% (e.g. Boomangera). Surprisingly, the change to number of flow days is not consistent across months at all zones. The Yarrowee (H) and Whalan (D) breakouts have reductions in flow days during March whilst most other breakout zones have increases in flow days. The Boonal (A), Yarrowee (H) and Boomi/Whalan (I) breakouts are not predicted to receive large improvements in the durations of floods, as measured by flow days on the floodplain (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.

5.5 Native fish

5.5.1 Metrics

The key fish values used in this assessment are the Eel-tailed Catfish, Southern Purple spotted Gudgeon, Silver Perch, Olive Perchlet 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 2019). At least one species from each guild has been recorded or predicted to occur in all of the breakout zones. Eel-tailed Catfish occur in 6 of the 9 breakout zones (Table 2). The fish guilds and species are:

- flow dependent specialists, such as Silver Perch
- generalists, which include a number of species such as Bony Herring that benefit from improved floodplain outcomes
- short-moderate lived floodplain specialists such as Olive Perchlet
- in-channel specialists such as the iconic Murray Cod (Figure 17) and Eel-tailed Catfish.

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, duration and timing (seasonality) needed to maintain native fish
- reproduction – the flood frequency required to provide sufficient reproduction opportunities
- recruitment – the timing (seasonality) of flood events required for effective 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 spawning 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 Murray Cod give insight to potential benefits for Eel-tailed catfish). The majority of native fish EWRs were sourced from the *Fish and Flows in the Northern Basin* (NSW Department of Primary Industries 2015, 2019) and the *Long Term Water Plans* developed by DPIE EES (OEH 2018).

In total, 11 EWR metrics and 34 tests were undertaken for native fish.

Figure 17 The iconic Murray Cod, a species which would be impacted by changes to floodplain harvesting practices [Photo: Guo Chai Lim]

5.5.2 General hydrological impacts

Impacts of implementing the policy vary across the breakout zones, with some areas seeing large improvements and others having small negative outcomes. Overall, the predicted improvements in key hydrological metrics should provide future benefits for native fish. The **number of flood events** are predicted to increase and the **inter-event period** to reduce across all areas, both of which are critical for improving fish outcomes. Increased **total, spring and summer volumes** and increased **total spring and summer flow durations** (Table 4) should provide benefits and improvements for all in-stream fish guilds. Boosts in volumes and flow durations to the Border Rivers floodplain will potentially provide increased longitudinal and lateral movement of organisms including downstream benefits in the Barwon-Darling.

Median **event magnitudes** (ML/day) are predicted to remain unchanged for most areas of the floodplain, with two breakout zones increasing by 18% (Boomangera (G)) and 24% (Boggabilla (B)). Increases in event magnitudes or discharge velocities could provide important thresholds (0.3–0.5 metres/second) for riverine specialists like Murray Cod.

5.5.3 Impacts on fish guild-specific EWRs

On average across the floodplain, there are improvements in the number of EWRs achieved for the majority of EWR metrics important for native fish (Table 6, Figure 18). Of the 34 metrics tested, 23 are predicted to improve by 10% or more. However, these changes vary drastically across the floodplain. For example, achievement of the duration required for egg development in flow dependent specialists like **Silver Perch** increases by 18% on average but reduces by 15% in one zone and increases by 48% in another (Table 6).

Only 3 EWR metrics have reduced frequencies:

- the timing of recruitment opportunities for generalists (-9%)
- the timing of recruitment for flow dependent specialists (-1%)
- the timing of flows important for spawning in small-moderate floodplain specialists (-3%).

Breakout zone specific outcomes for native fish EWRs are summarised in Section 9.

River specialists like **Murray Cod** are likely to benefit the most from the implementation of the policy, however a range of positive outcomes are predicted for all the listed native fish guilds in the Border Rivers valley floodplain. Along with these direct benefits, indirect benefits or undesirable outcomes from improvements in 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 EWRs for native fish in the Border Rivers Valley floodplain after implementing the policy. Values represent average, minimum and maximum predicted outcomes, averaged over the simulation period across the 9 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 dependent specialists	River specialist Murray Cod
Duration	Egg development	+15% (0, +43)	+18% (0, +47)	+18% (-15, +48)	+23% (0, +71)
	Maintenance	+11% (-4, +43)	+13% (-15, +47)	+18% (0, +48)	+18% (0, +71)
Frequency	Maintenance	+23% (+2, +100)	+27% (+2, +100)	+27% (+2, +100)	+27% (+2, +100)
	Maintenance (interflow)	+27% (+2, +100)	+27% (+2, +100)	+27% (+2, +100)	+27% (+2, +100)
	Reproduction	+10% (0, +42)	N/A	+7% (0, +27)	+7% (0, +27)
	Reproduction (interflow)	+27% (+2, +100)	+7% (0, +27)	N/A	N/A
Timing	Maintenance	N/A	+11% (-6, +33)	+11% (-6, +33)	+11% (-6, +11)
	Recruitment	+5% (-40, +67)	-9% (-25, 0)	-1% (-6, +33)	+44% (-9, +300)
	Spawning	-3% (-20, +4)	N/A	+11% (-7, +33)	+16% (-5, +42)
	Spawning habitat	+13% (-11, +40)	+11% (-6, +33)	N/A	N/A
	Food, refugia	+18% (-5, +50)	N/A	N/A	N/A

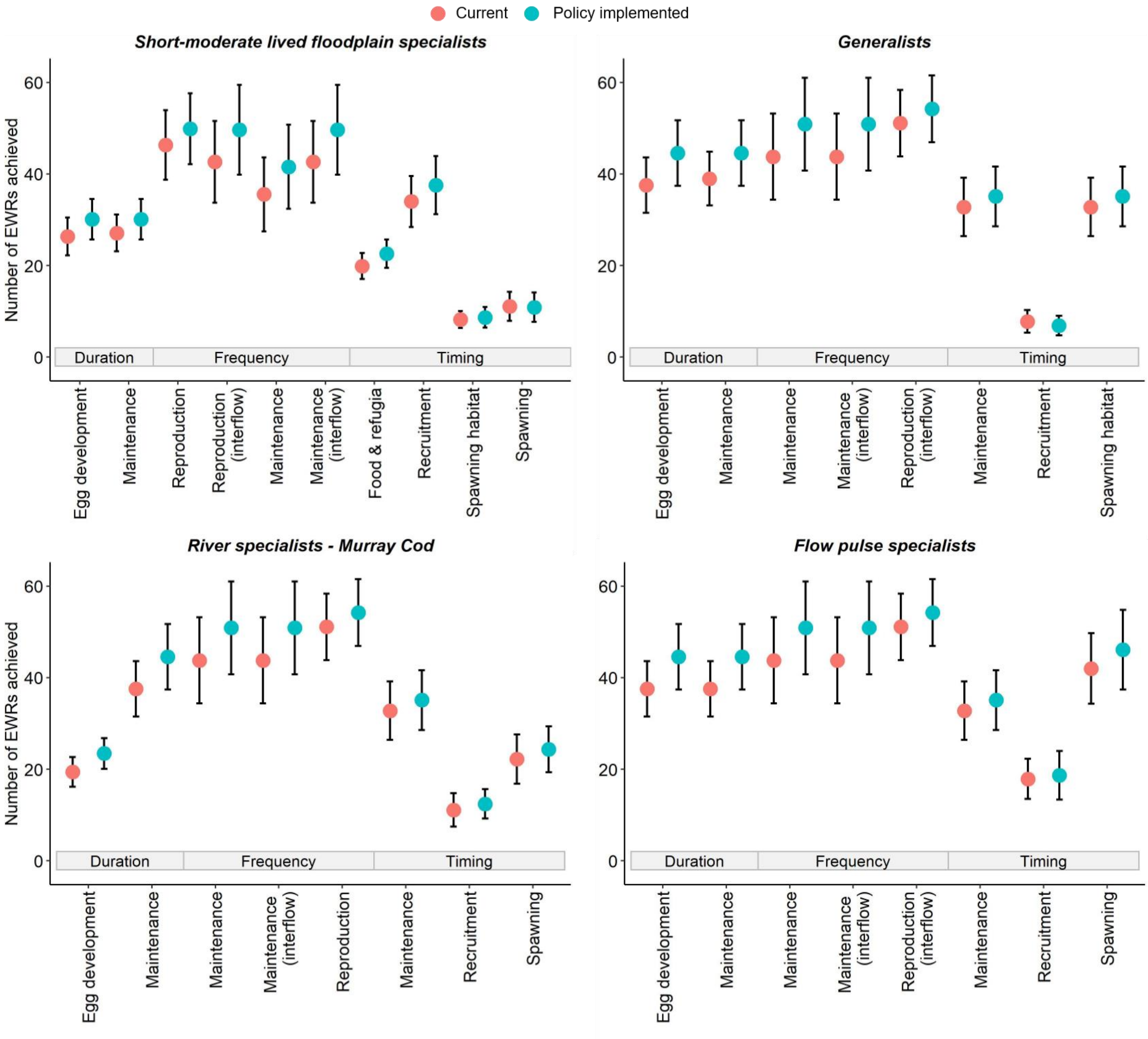

Figure 18 Average number of EWRs achieved for native fish with the policy (Policy implemented) and without the policy (Current) in the Border Rivers over the 124 year simulation period and across the 9 breakout zones. The grey horizontal rectangles identify the hydrological feature (duration, frequency, timing) and the x axis labels are the EWR metric. Error bars represent the standard error, *n* = 9

5.6 Native vegetation

5.6.1 Metrics

The key water-dependent native vegetation values used in this assessment are key species in the plant community types (PCTs) from Table 2. These are lignum, coolabah (flood-dependent woodland), river cooba, river red gum and water couch (non-woody wetland). These species represent 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. Specific values for each EWR metric vary for each native vegetation species (detailed in Appendix C). Most 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 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.

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

Figure 19 Coolabah, a species of eucalyptus tree, is an important component of multiple plant community types on the Border Rivers Valley Floodplain [Photo: David Carr]

[9] The reason for this substitution is set out in Section 5.3. In short, duration of flood water on the floodplain is not modelled.

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 15). Predicted increases in the **total 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 spring and summer volumes and flow durations are likely to be particularly important, as many species require flood events over the warmer months to enable seedling establishment and to avoid desiccation.

The **duration of floods** required for most vegetation values varies but is often at least two months of inundation. Substantial improvements in the substitute indicator, i.e. change in the **number of flow days** during important months or seasons, are evident during summer (Figure 16). Boggabilla (B) and Whalan breakouts had the biggest predicted increases in the number of flow days between December and February with at least 50% more (up to 518% in February for Boggabilla (B)) days with flow (Table 5). Summer is a critical period for maintenance, regeneration and reproduction for most vegetation values including river red gum, lignum, coolabah and water couch.

Based on the median across all breakout zones, very small changes are predicted for the **number of flow days** in September to November indicating minimal improvement for spring flood durations (Figure 16, Table 5). Spring is also a critical month for most native vegetation species. The best and worst predicted results are 54% more flow days in October at Goondiwindi (C) and 100% less flow days during September at Boggabilla (B) (Table 5). Events during autumn and winter months are important for lignum dispersal and post-flood recession germination (Roberts and Marston 2011). Predicted changes to flow days in autumn and winter months are variable, both across months and breakout zones (Figure 16, Table 5). March, May and July are all predicted to have more flow days across the floodplain as a whole, however this varies with the breakout zone on the floodplain. For example, Yarrowee (H) had 25%, 17% and 24% predicted reductions in March, May and July respectively (Table 5). Flow days during April and August are not predicted to change compared to June which is predicted to have reduced flow days at 5 of the 9 breakout breakout zones. Fewer flow days during any autumn and winter months are likely to have negative effects for vegetation values, particularly lignum.

5.6.3 Impacts on native vegetation specific EWRs

Modelling indicates that implementation of the policy in the Border Rivers will result in an overall increase in the achievement of all the EWRs of key native vegetation species (Table 7, Figure 20), showing no reduction in the rate of achievement (all average % changes positive or zero).

However, predicted changes varied greatly across the floodplain. For example, achievement of the frequency required for maintenance of **mature coolabah wetland** increased by 188% in one breakout zone but only increased by 3% in another. The greatest predicted increases in average EWR achievement are the event frequency required for maintenance of **water couch** (77%) and for seedling establishment of **river red gum** (112%). Breakout zone specific outcomes for native vegetation EWRs are summarised in Section 6.

Improvements to native vegetation will likely have flow on benefits for other environmental values on the floodplain, including waterbirds, native 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.

Table 7 Percentage change in frequency of achieving EWRs for native vegetation in the Border Rivers Valley floodplain after implementing the policy. Values represent average, minimum and maximum predicted outcomes, averaged over the simulation period across the 9 breakout zones. Minimum and maximum are shown in parentheses. *n* represents the sample size or the number of breakouts in which a value was present. N/A = not applicable

Hydro feature	EWR metric	Lignum n = 9	Coolabah n = 9	River cooba n = 9	River red gum n = 9	Water couch n = 8
Frequency	Maintenance	+46% (+3, +188)	Wetland +46% (+3, +188) Woodland +37% (+3, +161)	+34% (0, +179)	Forest +51% (+4, 195) Woodland +46% (+3, +192)	+77% (0, +268)
	Seedling establishment	+47% (+6, +220)	+45% (+6, +213)	N/A	+112% (+38, +268)	N/A
Timing	Maintenance	N/A	N/A	N/A	+35% (+4, +206)	+31% (0, +206
	Seedling establishment	N/A	+35% (+4, +206)	N/A	+35% (+4, +206)	N/A
	Seedling maintenance	N/A	N/A	N/A	+35% (+4, +206)	N/A
	Seedling dispersal	+26% (0, +75)	N/A	N/A	N/A	N/A

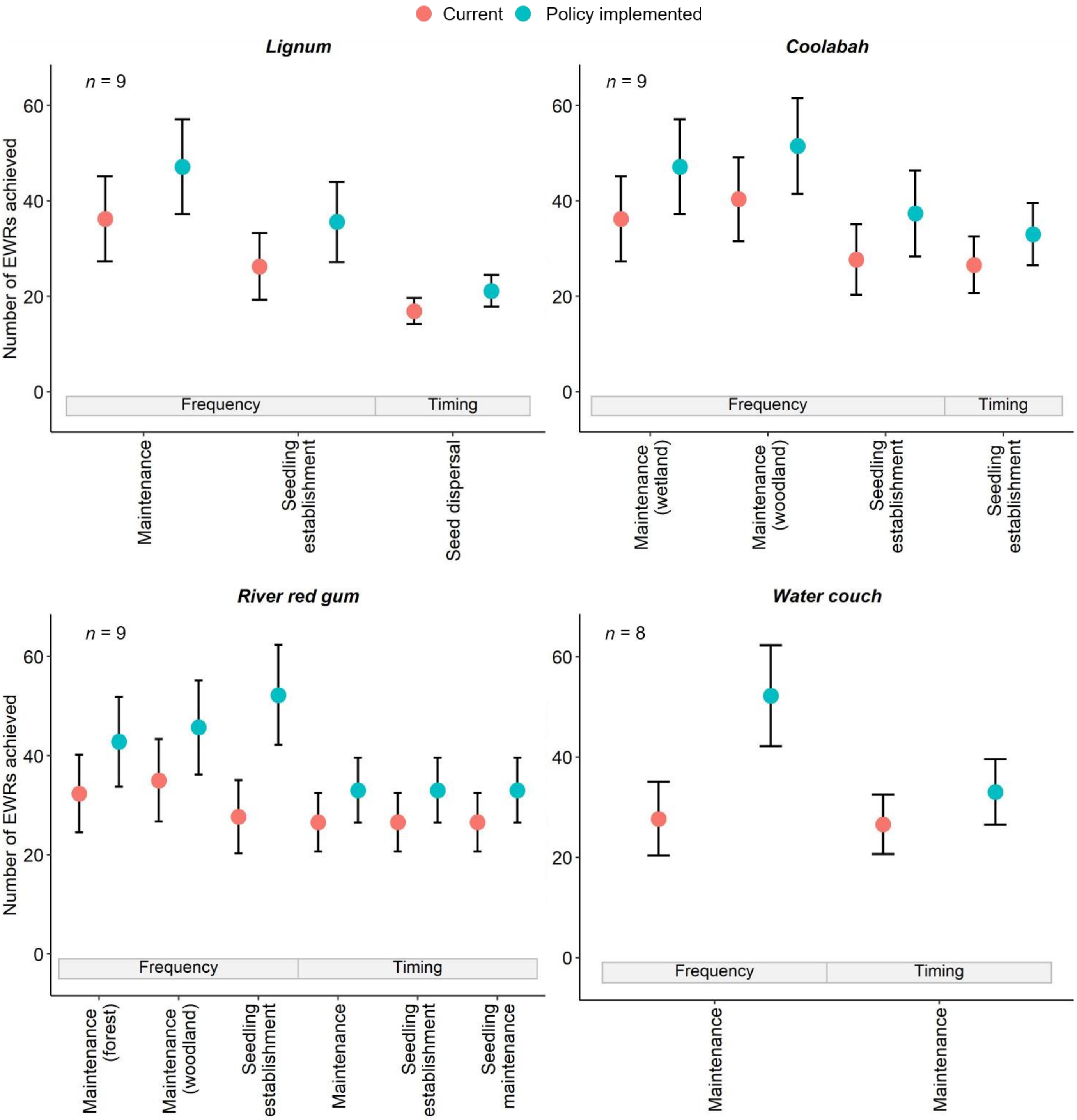

Figure 20 Average number of EWRs achieved for native vegetation (lignum, coolabah, river red gum, water couch) with (Policy implemented) and without (Current) the policy implemented in the Border Rivers over the 124 year simulation period and across the 9 breakout zones. The grey horizontal rectangles represent the hydrological feature whilst the x axis labels are the EWR metric. Error bars represent the standard error

5.7 Waterbirds

There are 25 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 Border Rivers LTWP (OEH 2018), Scott (1997), Kingsford et al. (2014) and Brandis and Bino (2016).

Not all of these species were recorded in all 9 breakout zones. However, due to the highly mobile nature of waterbirds, achievement of EWRs was assessed for waterbirds across all 9 breakout zones. As there was a lack of species-specific EWRs for the Border Rivers valley (apart from duration EWRs in Brandis and Bino 2016), we generalised outcomes for all waterbirds. Although several colonial waterbird species are predicted, known or recorded in the Border Rivers, limited established breeding colonies have been recorded in this region over recent years (OEH 2018). Therefore, this report does not assess EWR outcomes for colonial waterbirds but includes potential outcomes for habitats and resources for colonial waterbirds.

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 overbank threshold, frequency and duration for each overbank event. **Five flood frequencies** were assessed:

- 4 year maximum inter-event period, 1 in 3 years, 1 in 5 years (for breeding outcomes), 1 in 7 years, 1 in 10 years.

Three timing metrics were selected:

- August to December for building fat reserves for breeding
- winter for winter breeding floods
- summer for summer breeding floods.

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.

Details of the EWR values used are provided in Appendix C .

In total, 8 water requirements for non-colonial waterbirds 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 worldwide (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 (Table 4, Figure 15). The **frequency of flood events** is predicted to increase, meaning more floodwater can be expected to make it through the floodplain harvesting areas, improving longitudinal connectivity. In addition, the **inter-event period** reduced 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 47% in some areas (e.g. Boggabilla (B)). While considerable improvements in hydrological features are expected, the greatest seasonal improvements are expected in autumn and summer with minimal improvements in flood volumes predicted for winter and spring. Greater improvements in spring would be desirable as this season is important for waterbird breeding.

The changes in **total number of flow days in each month** are shown in Table 5 and Figure 16. August to December is considered an important period for waterbirds to gather resources and improve condition before breeding (Scott 1997, OEH 2018). The total number of flow days, a measure of the change in flood durations is only predicted to improve for November and December. In some breakout zones, the number of days with flow during December is predicted to increase by more than 400% (at Whalan (D)) breakout zone (Table 5). The **median of total flow days** across the 9 breakout zones for August to October remained relatively unchanged (Figure 16). One of the largest reductions is a 100% drop at Boggabilla (B) for the total number of flow days during September (Table 5).

The number of flow days during **winter months** such as June is predicted to reduce by up to 57% in 5 of the 9 breakout zones. Flow days during July increased substantially (greater than 50%) in 4 breakout zones while remaining relatively unchanged in the other 5 zones. The total number of flow days during August is not predicted to change much across the floodplain (Figure 16). In contrast, the **summer months** are all expected to have increased number of flow days across the floodplain with improvements of up to 518% at Boggabilla (B) during February.

In general, implementation of the policy should improve temporal variability, flood frequency, volume and number of flow days to provide broad-scale benefits for waterbirds in the Border Rivers. However, the minimal improvement in flow days and volumes during winter and spring (in some cases reduced number of flow days) may be a constraint to achieving improved waterbird outcomes in the Border Rivers.

5.7.3 Impacts on waterbird specific EWRs

The outcomes for waterbirds varies across the 9 breakout zones, but on average, implementing the policy is predicted to provide beneficial outcomes for non-colonial waterbirds. The average number of events which achieved the frequency requirements for waterbirds increases by more than 20% with policyimplementation (Table 8, Figure 21). The average number of events which meet the **inter-event frequency** (no more than 4 years between events) is predicted to improve by 27% with the **1 in 5 year flood frequency** increasing by 44% on average (Table 8).

The achievement of appropriate **flood timing in August–December** remains relatively unchanged (+4%). This indicates that the policy will not provide benefits for waterbird feeding in a period in which waterbirds are likely to access resources and fatten up before breeding (Scott 1997). In addition, predicted **winter breeding flood** events for some waterbird breeding triggers slightly decreased (-1%). This suggests that the outcomes for flow duration in winter months will vary among months, but are unlikely to benefit waterbirds in any substantial way. **Summer breeding flood** events are predicted to increase, with an average increase in summer floods of 34%. Breakout zone specific outcomes for waterbird EWRs are summarised in Section 6.

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, the predicted improved outcomes for native vegetation should have a range of flow-on effects for waterbirds. More frequent flooding at appropriate times (coolabah EWRs predicted to be achieved 35–47% more often) should improve coolabah tree outcomes 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. lignum) are crucial for waterbirds, and the predicted positive outcomes for these values may benefit waterbirds on the Border Rivers valley floodplain.

Table 8 Percentage change in frequency of achieving EWRs for non-colonial nesting waterbirds in the Border Rivers Valley floodplain after implementing the policy. Values represent average, minimum and maximum predicted outcomes, averaged over the simulation period across the 9 breakout zones. Minimum and maximum are shown in parentheses

Hydrological feature	EWR metric	EWR detail	Non-colonial nesting waterbirds
Frequency	Maintenance (interflow)	No greater than 4 years between events	+27% (+3, +167)
	Maintenance, survival and breeding opportunities	1 in 3 years	+32% (+4, +133)
		1 in 5 years	+44% (+18, +167)
		1 in 7 years	+23% (+3, +60)
		1 in 10 years	+29% (+10, +60)
Timing	Fat reserves before breeding	August–December	+4% (-5, +13)
	Winter breeding floods	Winter	-1% (-20, +11)
	Summer breeding floods	Summer	+34% (0, +86)

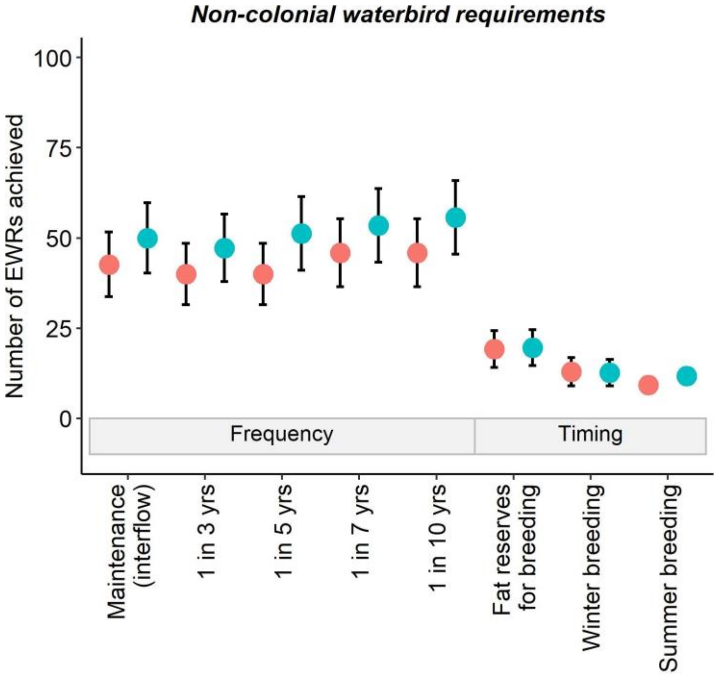

Figure 21 Average number of EWRs achieved for non-colonial waterbirds with (Policy implemented) and without (Current) the policy implemented over the 124 year simulation period and across the 9 breakout zones. The grey horizontal rectangles represent the hydrological feature whilst the x axis labels are the EWR metric. Error bars represent the standard error, n = 9

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 **frequency of events** required to prevent DOC build up and potential blackwater events (EES 2020)
- 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, total volume, total summer volumes and duration of events** (Table 4, Figure 15) should all provide beneficial outcomes for primary and secondary productivity as well as nutrient supply. Reduced **inter-event periods** should increase DOC supply from anabranches on the floodplain.

Whilst there are a number of improvements in relevant hydrological metrics for these values, greater outcomes could be achieved if the timing or seasonality of these improvements were changed. For example, the largest relative increase in flood volumes is predicted for autumn months, with only modest improvements in spring and **summer**. Spring and summer are periods when the best productivity outcomes would be achieved.

5.8.3 Impacts on specific EWRs for ecosystem functions

Modelling indicates that implementation of the policy in the Border Rivers Valley will result in mixed outcomes, with both beneficial and negative outcomes predicted for key ecosystem function EWRs (Table 9, Figure 22).

On average, there is a small increase (23%) predicted for the achievement of **'best' events** (i.e. flood event lasts longer than 2 weeks) which would provide the best productivity outcomes, particularly for aquatic insects. Achievement of these EWRs is enhanced by the average increase of 21% in events occurring in summer, a highly productive period for aquatic ecosystems. In contrast, the frequency of **'better' events** (i.e. event lasts for 1–2 weeks) is predicted to reduce by 2% on average, and by up to 60% at Boggabilla (B). **'Reduced' events** (i.e. event lasts for less than a week) are known to provide high DOC concentrations from anabranches. The frequency of these events is predicted to increase by an average of 16%, with some areas remaining unchanged and others increasing by 64%.

The event frequency required to **reduce DOC build up** on floodplains and prevent the associated blackwater events is also predicted to be met more often (by 20% on average). This outcome is highly variable with some areas predicted to have increased achievement of this EWR by up to 60%.

A negative percentage change (a 13% decrease on average) for **inter-event period** is a positive outcome as it indicates that the mean and/or median period between floods (inter-event period) has reduced. The reduced inter-event period will provide more frequent wetting and drying cycles and provide greater levels of productivity.

Table 9 Percentage change in frequency of achieving EWRs for ecosystem functions in the Border Rivers floodplain after implementing the policy. Values represent average, minimum and maximum predicted outcomes, averaged over the simulation period across the 9 breakout zones. Minimum and maximum are shown in parentheses

Hydrological feature	EWR metric	% change
Duration	Reduced productivity outcomes (<1 week)	+17% (-9, +50)
	Better productivity outcomes (1–2 weeks)	-2% (-60, +60)
	Best productivity outcomes (>2 weeks)	+23% (-4, +81)
	High dissolved organic carbon concentrations	+16% (0, +43)

Hydrological feature	EWR metric	% change
Frequency	Prevent blackwater and carbon build-up	+20% (0, +60)
	Anabranch wetting and drying cycles (inter-event frequency/period)	-13% (-2, +25)
Timing	Better outcomes (summer)	+21% (0, +64)

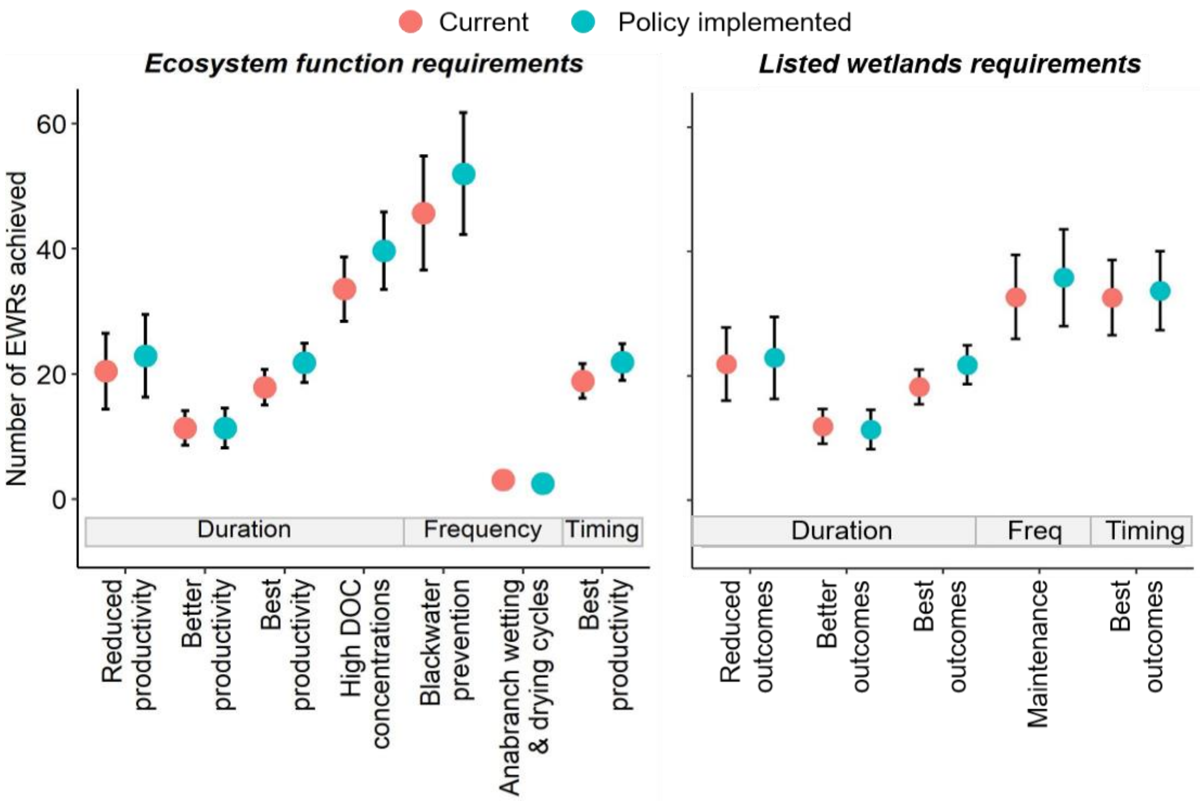

Figure 22 Average number of EWRs achieved for identified ecosystem functions and wetlands with (Policy implemented) and without (Current) the policy implemented over the 124 year simulation period and across the 9 breakout zones. The grey horizontal rectangles represent the hydrological feature whilst the x axis labels are the EWR metric. Error bars represent the standard error, *n* = 9

5.9 Wetlands

A variety of wetlands occur on the Border Rivers Floodplain. These include significant anabranches, lagoons, wetlands, watercourses and billabongs. The full list of wetlands identified on the floodplain is included in Appendix A . Some examples include the nationally important Morella watercourse, Boobera lagoon and Pungbougal lagoon. These wetlands are of cultural significance and provide significant refugia and habitat for a myriad of aquatic species.

5.9.1 Metrics

Specific, documented EWRs for Border River wetlands are rare, with only the required frequency of flood events defined by one source (DPI Water 2017). To identify the impact of changes in other hydrological features (duration and timing), this report includes an assessment of **flood durations,** with longer events being linked to more beneficial outcomes for the identified wetlands. The assessment uses similar metrics as for important ecosystem functions:

- **duration**
    - reduced (days with flow <1 week)
    - better (1–2 weeks of days with flow)
    - best (>2 weeks of days with flow).
- the **frequency** required for wetland maintenance
- seasonal timing: **spring–summer floods** as these warmer months align with key water requirements of other values which inhabit these wetlands such as native fish and vegetation.

The EWR metrics were assessed across all 9 breakout zones. Details of the EWR are provided in Appendix C .

5.9.2 General hydrological impacts

Modelling suggests that implementation of the policy should increase flood volumes across the Border Rivers floodplain (Table 4). **Median annual volume** in the Boggabilla breakout zone (B) is predicted to increase by 49%. This area includes the Morella lagoon, Morella watercourse and Bora wetland, among other wetlands. The **number of flood events** is also predicted to increase for all breakout zones of the Border Rivers.

The increased volumes and number of flood events should provide beneficial outcomes for these wetlands.

5.9.3 Impacts on specific EWRs for wetlands

The predicted impacts on wetlands is similar to those for key ecosystem functions. Modelling indicates that implementation of the policy will slightly improve the frequency required to maintain floodplain wetlands and the **frequency of 'best' events** (i.e. last longer than 2 weeks) (Table 10, Figure 22). Beneficial changes of +17% and +13% are identified in the achievement of **short events** (i.e. event lasts less than 1 week) and the timing of **spring and summer flood** events respectively. As with most of the environmental values and assets assessed in this report, the variability around these results is large. For example, spring and summer events are not predicted to change at Boomangera breakout (G) but are predicted to increase by 41% at Whalan (D) breakout zone. **'Better'** flood events (i.e. event lasts for 1 to 2 weeks) are predicted to decrease by 2%.

It is difficult to suggest whether the policy provides overall beneficial outcomes for the wetlands based on the EWR metrics assessed. It is likely that the small increases in achieving most of the EWRs tested will result in some beneficial outcomes for wetlands.

Table 10 Percentage change in frequency of achieving EWRs for wetlands in the Border Rivers floodplain after implementing the policy. Values represent average, minimum and maximum predicted outcomes, averaged over the 124 year simulation period across the 9 breakout zones. Minimum and maximum are shown in parentheses

Hydrological feature	EWR metric	% change
Duration	Reduced wetland outcomes (<1 week)	+17% (-9, +50)
	Better wetland outcomes (1–2 weeks)	-2% (-60, +60)
	Best wetland outcomes (>2 weeks)	+23% (-4, +81)
Frequency	Maintenance	+21% (0, +67)
Timing	Best outcomes (spring & summer)	+13% (0, +41)

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 9 breakout zones (Table 10). Summarised outcomes for these 3 key value categories at each breakout zone provide an assessment of breakout zone specific outcomes on the NSW Border Rivers 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 assets and values, implementing the policy resulted in modelled improvements at most breakout zones, with some breakout zones predicted to see greater improvements than others.

In total, 11 **native fish** EWRs were tested for each fish guild (Table 6). Minor to moderate increases in EWR achievement are predicted for all 4 native fish guilds at 8 of the 9 breakout zones. In contrast, at Yarrowee (H), the number of EWRs met is predicted to decrease slightly (-2%) for short-moderate lived floodplain specialists, generalists and flow dependent specialists. In-channel specialists (i.e. Murray Cod) at Boggabilla (B) are predicted to receive the most benefits (+65%).

Up to 6 different EWRs were assessed for **native vegetation** (Table 7). On average, all native vegetation values are predicted to have either a positive or neutral change in EWR achievement at all breakout zones. The greatest improvements are predicted for Terrewah ((F), e.g. a 237% average increase in EWR achievement for water couch) and Whalan ((D), e.g. a 43% average increase for river cooba). For Boggabilla (B), EWRs of several species are predicted to be met by events which did not exist under the Current Conditions scenario.

For **waterbirds**, 8 different EWRs were tested for non-colonial nesting waterbirds (Table 8). The average change in the number of EWRs predicted to be met increased for all 9 zones. The smallest predicted improvements are +6% at Goondiwindi (C) and +5% at Boomi/Whalan (I) breakout zones. The largest predicted improvements for waterbird EWRs are +68% at Boonal (A) and +41% at Whalan (D). Although the achievement of waterbird EWRs is predicted to improve at all breakout zones on average, there are some EWRs that are predicted to decrease in breakout zones. For example, the timing of winter floods in the Boggabilla breakout zone decreases by 20%.

Overall, implementation of the policy is likely to have positive outcomes for the majority of breakout zones and environmental values when average changes in EWR achievement for all environmental asset categories are considered. In contrast, policy implementation is likely to result in comparatively fewer benefits for native fish at the Yarrowee (H) and Boomi/Whalan (I) breakouts. The smallest improvements for waterbirds are at Goondiwindi (C) and Boomi/Whalan (I) breakouts. For native vegetation, Goondiwindi (C) and Tarpaulin (E) have the smallest positive outcomes. This suggests that a greater focus on these areas may be required in the future or that modelled return flows need to be incorporated into the river system models to detect impacts in these breakout zones.

Table 11 Percentage change in the number of EWRs met for a given environmental value after implementation of the policy for the 9 breakout zones of the Border Rivers 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. Minimum and maximum are shown in parentheses. 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 asset	Boonal A	Boggabilla B	Goondiwindi C	Terrewah F	Boomangera G	Yarrowee H	Whalan D	Tarpaulin E	Boomi/Whalan I
Native fish	Short-moderate lived floodplain specialists	+36% (0, +100)	+14% (-40, +42)	+11% (-4, +24)	+16% (0, +21)	+12% (-8, +23)	-2% (-14, +11)	+32% (-20, +67)	+9% (0, +15)	+2% (0, +6)
	Generalists	+33% (0, +100)	+10% (-25, +29)	+7% (-14, +22)	+13% (-13, +22)	+11% (-7, +21)	-2% (-20, +5)	+33% (0, +48)	+11% (0, +23)	+3% (0, +5)
	Flow pulse specialists	+33% (0, +100)	+14% (-33, +29)	+12% (0, +22)	+16% (+8, +22)	+14% (0, +21)	-2% (-14, +5)	+30% (-7, +48)	+11% (0, +23)	+3% (0, +5)
	River specialist – Murray Cod	+31% (0, +100)	+65% (+5, +300)	+8% (-9, +36)	+13% (0, +22)	+14% (0, +21)	+5% (-6, +25)	+41% (+7, +71)	+16% (+6, +29)	+2% (0, +5)
	Average of all native fish guilds	**+33%**	**+26%**	**+10%**	**+14%**	**+13%**	**0%**	**+34%**	**+12%**	**+2%**
Waterbirds	Non-colonial nesting waterbirds	+68% (0, +167)	+29% (-20, +86)	+6% (-8, +24)	+14% (0, +25)	+20% (+4, +33)	+15% (-5, +50)	+41% (0, +83)	+15% (+11, +23)	+5% (0, +20)
Native vegetation	Lignum	+64% (+25, +100)	+30% (+26, +36)	+12% (+9, +17)	+161% (+75, +220)	+3% (0, +6)	+29% (+23, +35)	+39% (+25, +46)	+14% (+11, +16)	+3% (0, +6)
	Coolabah	+65% (+33, +100)	+22% (+5, +29)	+8% (+4, +11)	+192% (+161, +214)	+4% (+3, +6)	+21% (+12, +26)	+40% (+36, +46)	+11% (+6, +15)	+4% (+3, +6)
	River cooba (only 1 EWR tested)	0%	+31%	+9%	+179%	+3%	+25%	+43%	+11%	+3%
	River red gum	+78% (+33, +133)	+29% (+5, +95)	+12% (+4, +38)	+212% (+192, +268)	+23% (+3, +118)	+26% (+12, +69)	+49% (+39, +95)	+19% (+6, +73)	+23% (+3, +118)

Asset/value category	Environmental asset	Boonal A	Boggabilla B	Goondiwindi C	Terrewah F	Boomangera G	Yarrowee H	Whalan D	Tarpaulin E	Boomi/Whalan I
	Water couch	0% (0, +42)	+50% (+5, +42)	+2% (0, +42)	+237% (+206, +42)	Not present	+6% (0, +12)	+67% (+39, +95)	+3% (0, +6)	+61% (+5, +118)
	Average of all native vegetation	**+41%**	**+32%**	**+9%**	**+196%**	**+19%**	**+21%**	**+48%**	**+11%**	**+19%**

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

These data are based on available literature and spatial datasets.

Table 12 Legend for Table 13

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)
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

Table 13 Recorded water-dependent floodplain environmental assets and values and where the information was sourced from

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), water couch marsh grassland (PCT204), sedgeland – forbland wetland (PCT 447) • 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) • 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
Important lagoons and wetlands (FMP, WSP listed)	WSP, SKM, FMP	• Barden Lagoon, Bonanga Billabong, Boobera Lagoon, Boomangera Lagoon, Boomi River Billabong, Boonal Anabranch, Bora Wetland, Callandoon/Dingo Anabranch, coolabah Lagoon, Doondoona Lagoon, Gobbooyallana Lagoon (Turkey Lagoon), Gooroo Lagoon, Kildonan Lagoon, Malgarai Lagoon, Malgarai Overflow, Marakai Wetland, Maynes Lagoon, Morella Lagoon Poopoopirby Lagoon, Pungbougal Lagoon, Rainbow Lagoon, Serpentine Lagoon, Telephone-Malgari Lagoon, unnamed lagoon - Myall Park, unnamed lagoon - Spring Creek, unnamed lagoon - Hamilton, unnamed lagoon (Narrawal A & B), unnamed lagoon (Turrawah A, B & C), unnamed lagoons 1, 4, 5, 6 & 7 Mundine lagoon, Carbucky lagoon, unnamed lagoon (Werrina A–E), unnamed lagoon (Boroo) Wombyanna lagoon, unnamed lagoon (Hamilton), Goony lagoon, Carwell lagoon
Native vegetation	LTWP, SKM, HEVAE	• River red gum, black box, coolabah, lignum, non-woody wetland, braid fern (E)[2], *shrub sida* (E)[2], *cyperus conicus* (E)[2]

Asset type	Source	Specific asset
Native fish	LTWP, SRA Fish dataset, HEVAE, SKM	• Flow dependent specialists – Golden Perch, Silver Perch (V)[2], Spangled Perch • Generalists – Australian Smelt, Carp Gudgeon, Mountain Galaxias, Flathead Gudgeon, Murray-Darling Rainbowfish, Bony Herring, Unspecked Hardyhead • Short-moderate lived floodplain specialists – Southern Purple Spotted Gudgeon (E)[3], Olive Perchlet – Western population (E)[3], Rendahl's Tandan, Flathead Galaxias • In-channel specialists – Murray Cod (V)[2], River Blackfish, Eel-tailed Catfish – MDB population (E)[3], Darling River Hardyhead
Water birds	LTWP, BioNet, HEVAE, SKM	• Ducks – Australasian grebe, Australasian shoveler, chestnut teal, freckled duck (V)1, great crested grebe, grey teal, hardhead, hoary-headed grebe, musk duck, Pacific black duck, pink-eared duck, blue-billed duck (V)1 • Herbivores – Australian wood duck, black-tailed native-hen, black swan, dusky moorhen, Eurasian coot, plumed whistling-duck, purple swamphen, magpie goose (V)[1] • Large waders – black-necked stork (E)[2], brolga (V)[1], royal spoonbill, yellow-billed spoonbill, Australian white ibis • Piscivores – Australian gull-billed tern (C), whiskered tern, Australasian darter, little pied cormorant, great cormorant, little black cormorant, pied cormorant, Australian pelican, white-necked heron, little egret, white-faced heron, nankeen night heron, white-bellied sea-eagle, intermediate egret • Shorebirds – Australian painted snipe (E)[2], banded lapwing, black-fronted dotterel, black-winged stilt, Latham's snipe (J,K), marsh sandpiper (C,J,K), masked lapwing, red-capped plover, red-kneed dotterel, red-necked avocet, sharp-tailed sandpiper (C,J,K), Caspian tern
Other threatened biota	SKM, HEVAE, DPI Fisheries	• River snail (E)[3]
Groundwater recharge	FMP	• Key areas of groundwater recharge on the floodplain
Functions	LTWP, SKM	• Nutrient, carbon and primary production

Appendix B Datasets used to refine environmental assets and values in the Border Rivers Valley

Table 14 Datasets used to refine assets and values and their source

Dataset	Year	Source	Reference	Details
Border Rivers cross section breakouts	2019	DPIE Water	DPIE Water modelling team (2019)	Identifies key breakout points where the river system models will have representative flow data for base case and implementation
Border Rivers Flood Management Plan Management Zones	2017	DPIE EES	NSW Office of Environment and Heritage Floodplain Management Plans NSW Office of Environment and Heritage (2017) 59-61 Goulburn Street Sydney 2000	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
Border Rivers Flood Management Plan (2018) Vegetation wetlands composite	2019	DPIE EES	NSW Office of Environment and Heritage, (2015) BRG-Namoi Regional Native Vegetation Mapping. EcoLogical Australia (2009) Upgrade of Vegetation Mapping in the Border Rivers-Gwydir Catchment. EcoLogical Australia (2015) Development of a Biodiversity Prioritisation Plan for the North West LLS Hudson & Bacon (2009) Culturally significant lagoons and salt affected sites project Water Sharing Plan for the NSW Border Rivers Unregulated & Alluvial Water Sources (2012)	Composite map of wetlands and vegetation plant community types (PCT) in the Border Rivers
Border Rivers Flood Management Plan (2018) Flood dependent composite	2019	DPIE EES		Mapped distribution of flood dependent plant community types (PCT) and important lagoons, billabongs, watercourses and wetlands in the Border Rivers

Dataset	Year	Source	Reference	Details
Border Rivers Flood Management Plan threatened fish distributions (MaxEnt)	2019	DPI Fisheries	NSW DPI Fisheries Fish Community Status and Threatened Species data. NSW Department of Industry (2016) 161 Kite Street Orange 2800 http://www.dpi.nsw.gov.au/fishing/species-protection/threatened-species-distributions-in-nsw	MaxEnt predicted distributions of threatened fish species in the Border Rivers FMP. Species include: Eel-tailed Catfish, Olive Perchlet, Purple-spotted Gudgeon and the river snail
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
BioNet	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

Dataset	Year	Source	Reference	Details
LTWP planning unit records	2019	DPIE EES	DPIE Conservation and Biodiversity (2019). Long-term Water Plan for the NSW Border Rivers Water Resource Plan Area. NSW Office of Environment and Heritage, Goulburn St, Sydney.	Appendix B of the LTWP lists the relevant assets and values in each planning unit. Assets and values from the following planning units were included in the original set of assets and values: (10) Yetman, (11) Ottleys Creek, (12) Confluence of Macintyre & Dumaresq, (13) Macintyre Floodplain u/s Boomi, (14) Whalan Creek & Croppa Creek, (15) Macintyre River & Boomi River Floodplain
Flood-dependent fauna (Fish) - Key Fish Habitat	2017	DPI Fisheries	NSW DPI Fisheries	Spatially representing Key Fish Habitat within the Floodplain Management Plan boundary

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

Table 15 Footnotes for Table 16

Footnotes
[1] (Roberts and Marston 2011), [2] (OEH 2018), [3] (Scott 1997), [4] (NSW Department of Primary Industries 2015), [5] (Kingsford et al. 2014), [6] (SKM 2009), [7] (DPI Water 2017), [8] (McGinness and Arthur 2011), [9] (Reid et al. 2016), [10] (Brandis and Bino 2016), [11] (NSW Department of Primary Industries 2019), [12] (Ballinger et al. 2005), [13] (Boulton and Lloyd 1992)
N/A = No detail or unable to assess accurately, y = years, m = months, d = days

Table 16 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[11,7] Max inter-event period of 4 years[2,11]	$\leq 2^y$ $\leq 4^y$	3-5 years in 10[4,2] Max inter-event period of 4 years[2,11]	≥ 3 in 10^y $\leq 4^y$
	Duration	>10 days[11]	$\geq 10^d$	>10 days to allow egg development[2,4,11]	$\geq 10^d$
	Timing	October to April for spawning habitat[2,11] 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

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Generalists	Frequency	1 in 3-5 years[11] Maximum interflow period of 5 years[11]	≥1 in 5[y] ≤5[y]	2 in 10 years[11]	≥2 in 10[y]
	Duration	5 days[11]	≥5[d]	5 days[11]	≥5[d]
	Timing	Spring to summer[11]	Spr-Sum	September to February flows enhance spawning and provide habitat and resources for recruitment[4]	Sep-Feb
	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]	Spr-Aut with an event no more than 2 months prior
Flow pulse specialists	Frequency	1 in 3-5 years[11] Maximum interflow period of 5 years[11]	≥1 in 5[y] ≤5[y]	2-3 in 10 years[4]	≥2 in 10[y]
	Duration	>5 days[11]	≥5[d]	5 days[4,11]	≥5[d]
	Timing	Spring to summer[11]	Spr-Sum	Spring to autumn[4]	Spr-Aut
	Other	Velocities of 0.3 $m.s^{-1}$ required for ideal habitat[11]	N/A	Rapid recession assists with egg dispersal[4] Subsequent events enhance recruitment and dispersal outcomes[4]	N/A

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
In-channel specialist: Murray cod	Frequency	1 in 3-5 years[11] Maximum interflow period of 5 years[11]	≥1 in 5[y] ≤5[y]	2 in 10 years	≥2 in 10[y]
	Duration	>5 days[11]	≥5[d]	>14 days to allow egg development and hatching[4]	≥14[d]
	Timing	Spring to summer[11]	Spr-Sum	Winter and spring rises triggers spawning[4]	Win-Spr
	Other	Velocities of 0.3 $m.s^{-1}$ required for ideal habitat[11]	N/A	Subsequent events enhance recruitment and dispersal outcomes[4]	Win-Spr with an event no more than 2 months prior
Waterbirds					
All waterbird species	Frequency	In line with key habitat requirements[5]	N/A	LTWP 1 in 5 years[2,10]	≥1 in 5[y]
	Duration	1 in 3 years – equivalent to a small overbank[2] 4 year maximum inter-event period[2] 1 in 7 years – frequency for a larger overbank[2] 1 in 10 years – minimum frequency for a large overbank[2] In line with key habitat requirements[5] Longer durations are generally more beneficial for vegetation and waterbird condition[2]	≥1 in 3[y] ≤4[y] ≥1 in 7[y] ≥1 in 10[y]	Spring flood: 5-7 months[3,5] Winter flood: 6-10 months[3] **inundation duration cannot be assessed. Improved number of flow days during these seasons used as a substitute*	Total number of flow days in Spr Total number of flow days in Win
	Timing	In line with key habitat requirements[5]	N/A	Late winter to early summer preferable to provide adequate food for fat reserves[3,2]	Aug-Dec
	Other	In line with key habitat requirements[5]	N/A	Rate of fall can trigger nest abandonment in some species[3,2]	N/A

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Native vegetation					
Shrublands					
Lignum (shrubland wetlands) *Muehlenbeckia florulenta*	Frequency	Every 2-5 years is ideal. Lower flood frequencies (i.e. less than 1 in 5 years) reduce Lignum cover Over watering is detrimental to Lignum shrublands[1]	≥1 in 5[y]	Seedlings watered once per 12 to 18 months over first three years: desirable[1]	≥1 in 1.5[y]
	Duration	Durations can vary from 3 months up to 7 months[1]	≥3[m]	Dispersal of seeds important (float for at least 5 days) 4-6 weeks for seedling establishment[1]	≥5[d] ≥28[d]
	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] Seedling establishment before or during summer[1]	Aut-Win Spr-Sum
	Other	Depth Not critical, generally less than 1 m.[1]	N/A	Germination temperature dependent (15-30°C) Depth shallow (5 to 15 cm).[1] Flowering triggered by flooding which can occur within four weeks of flooding	N/A

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Forest and woodlands					
Coolabah *Eucalyptus Coolabah*	Frequency	Wetland: Every 5-10 years in 10[2] Woodland: 1 year in 10[1,2]	≥2 in 10^{y} 1 in 10^{y}	Small inundations in the first and second year improve seedling establishment[1]	≥1 in 2^{y}
	Duration	Wetland: 3 to 7 months[2] Woodland: 1 month[2]	≥3^{m} ≥1^{m}	Unknown	N/A
	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]	Sep-Dec
	Frequency	Once every 3-7 years[1]	≥1 in 7^{y}	Not known	N/A
River cooba *Acacia stenophylla*	Duration	2-3 months, slightly tolerant of water logging Floods less than 5 days unlikely to be effective[1]	≥3^{m} ≤5^{d}	Flooding is important but the specific requirements are not known[1]	N/A
	Timing	Not critical[1]	N/A	Not known	N/A
	Frequency	Forests: every 1-3 years Woodlands: every 2-4 years[1]	≥1 in 3^{y} ≥1 in 4^{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
River red gum *Eucalyptus camaldulensis*	Duration	Forests: 5-7 months Woodlands: 2-4 months Variability around these numbers is ok[1]	≥5[m] ≤2[m]	4-6 weeks is ideal[1]	≥28[d]
	Timing	Not critical but the best outcomes during spring-summer[1]	Spr-Sum	Flood in August-November[2] Flood recession in spring-summer to provide warm moist conditions for germination and seeding growth[1]	Spr-Sum
	Other	N/A	N/A	Shallow depths are desirable but where this is unknown, duration is critical[1]	N/A
	Frequency	Wetland: Every 5-10 years in 10[2] Woodland: 1 year in 10[1,2]	≥2 in 10[y] 1 in 10[y]	Small inundations in the first and second year improve seedling establishment[1]	≥1 in 2[y]
Wetland and floodplain non-woody vegetation					
Water couch (*Paspalum distichum*)	Frequency	Every 1-2 years	≥1 in 2[y]	Not known	N/A
	Duration	5-8 months	≥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]

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
Important ecosystem functions					
Productivity	Frequency	Every 8-10 years to avoid building of carbon and potential blackwater events[2] Reduced duration and increased inter-event duration (i.e. zero flow days) are detrimental to the wetting and drying cycles of anabranches[9]			< Mean and median duration between events[y]
	Duration	Longer durations and greater volumes will provide the best outcomes[2,12,13]: 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[8]			$\leq 7^{d}$, $\geq 7^{d}$-$<14^{d}$ $\geq 14^{d}$ $\geq 6^{d}$
	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.[6]			Sum
	Other	Flows must return to the river at some point to increase in-channel benefits for fish and other organisms			N/A
Wetlands					
Floodplain watercourses (billabongs, lagoons, lagoons, lakes)	Frequency	Annual or near annual[7]			
	Duration	Longer durations are generally more beneficial. 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)			

Asset	Hydro feature	Maintenance	Value used	Regeneration/Reproduction	Value used
	Timing	Any time, but flooding during warmer months aligns with key requirements of vegetation, fish and waterbirds which inhabit these watercourses			
	Other	A range of other values use these floodplain watercourses			

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 two modelling scenarios (with and without policy implemented) 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 2020a) and described in detail in the Scenarios report (DPIE Water 2020b). 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 comparing the results of the two model scenarios.

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 2019.

D.1.3 Relating floodplain harvesting take to quantified changes

In addition to providing the two modelled daily flow time series, DPIE Water 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 2020b).

D.2 Assumptions and limitations

It is important to acknowledge that the outcomes are predictions based on modelled hydrological data for the period from 1895 to 2019, and the following must be kept in mind when interpreting results:

- Predicted outcomes are restricted by the uncertainty and limitations of the hydrological models and should only be used as a guide to potential outcomes.
- Return flows from the floodplain to downstream waterways are not included in the hydrological models which limits the interpretation of downstream outcomes. As downstream return flows are likely to be improved by the policy, it is possible that the current report underestimates any environmental benefit that might accrue.
- Flood inundation duration and inundation spatial extent cannot be assessed using the available hydrological models.

- The adopted approach assumes that meeting an environmental water requirement (EWR) is a positive outcome for an environmental asset or value. In reality, this could be influenced by a range of other factors not incorporated into this report.
- Outcomes are only estimated for those breakout zones within ‘breakout zones’ with licensed floodplain harvesting entitlements and modelled hydrological data.

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.

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 DPIE EES. 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 Macquarie 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. DPIE Water 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 returned to 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 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 (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 continues to ensure licensed diversions are adhered
- Lawful structures that allow licenced 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 17 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 18 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 2020b))
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
NSW Border Rivers WSP	Shortened term for the Water *Sharing Plan for the NSW Border Rivers Regulated River Water Source 2009*
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 2020b))
the policy	Shortened term for the *NSW Floodplain Harvesting Policy*