NSW HEALTHY FLOODPLAINS

Environmental outcomes of implementing the Floodplain Harvesting policy in the Macquarie Valley: Growth in General Security use scenario

Report

March 2021

Published by NSW Department of Planning, Industry and Environment

dpie.nsw.gov.au

Title: Environmental outcomes of implementing the Floodplain Harvesting policy in the Macquarie Valley: Growth in General Security use scenario

Subtitle: Report

First published: March 2021

Department reference number: PUB21/187

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. 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). 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 (LTAAEL) and curtailing future growth. Diversions in the Macquarie Valley have been estimated to be within the LTAAEL. However, there is potential for general security licensed take to grow which would require a reduction in floodplain harvesting take.

Using modelled long-term (1895 to 2019) changes to the hydrology of the floodplain, this report provides an assessment of potential future outcomes for the environment achieved by implementing the policy in the Macquarie Valley if general security use grows to the legal limit for the valley. Key hydrological metrics and environmental water requirements (EWRs) were used to test and identify these outcomes for assets (e.g. locations) and values (e.g. species) including native fish, waterbirds, native vegetation, wetlands and flow-dependent frogs.

Key findings

Our findings are based on the analysis of two river system model scenarios for the Macquarie Valley floodplain. They simulate current conditions with and without the policy implemented and a growth in general security use to the legal limit. We also provide a high-level comparison with the environmental outcomes expected without simulated growth in general security which were assessed in DPIE Water (2021c) (Figure 1, Table 1).

Based on the findings presented in this report and DPIE Water (2021c), implementation of the policy will result in the following:

Scenario	Summary of outcomes
policy implemented and general security use remains at current levels	• Changes to hydrology limited to small improvements in hydrological and environmental outcomes at two of the ten breakout zones[1] • These changes were predominantly increases in the duration (number of flow days) of floods in summer months, total number of events and reduction of time between flow events (inter-event frequency)
policy implemented and general security use grows to the legal limit	• Improvements for hydrological outcomes at seven of the 10 breakout zones • Improved environmental outcomes for key assets and values expected at six of the 10 breakout zones with four zones expected to improve substantially • This includes increase in number of flow events, flow duration and duration of floods, seasonal durations (particularly floods in spring and summer), and reduced period between flow events (inter-event)

[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. A breakout zone can incorporate multiple flow breakouts which are used to assess hydrological changes in a specific area of the floodplain.

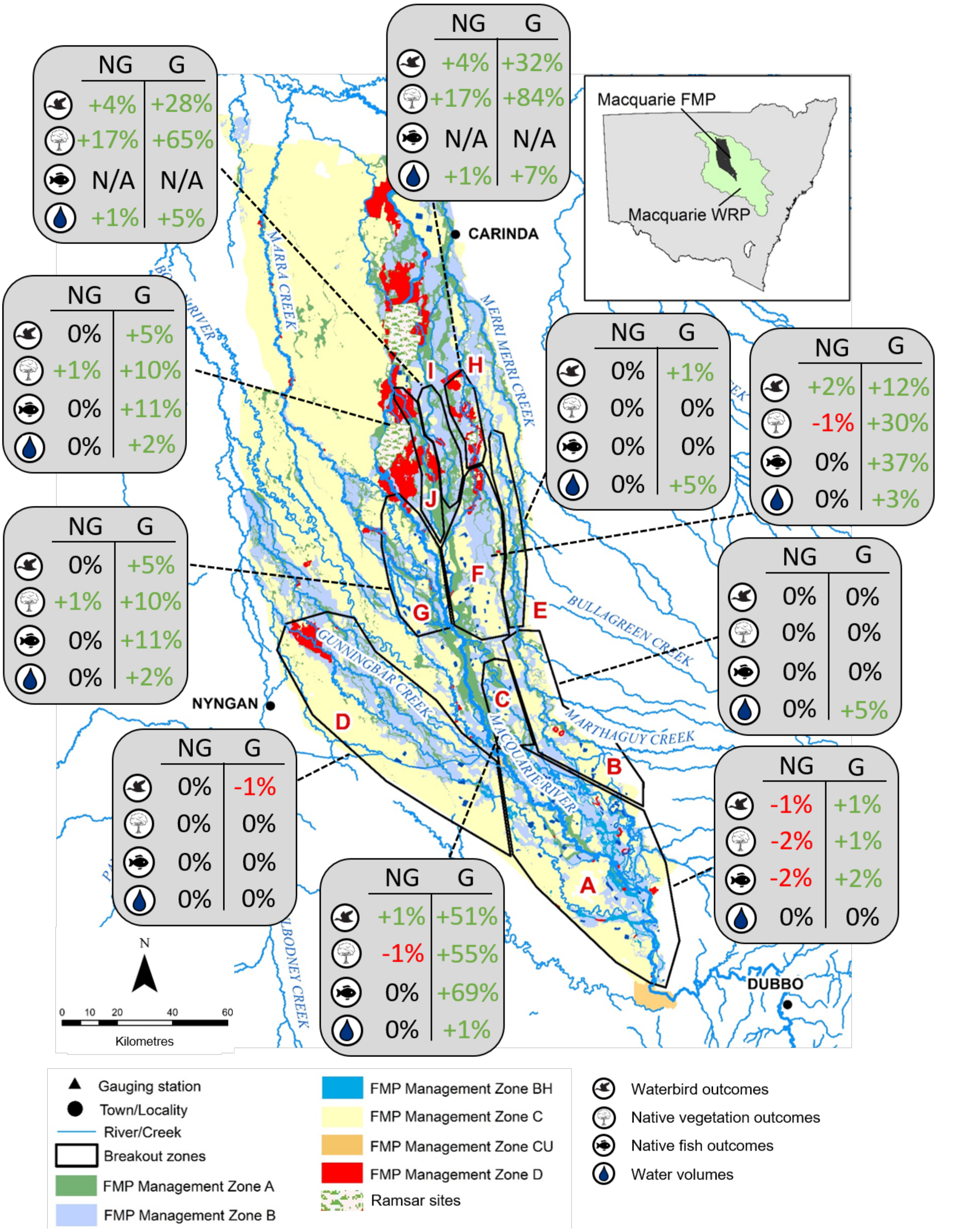


Figure 1 Mapped summary of predicted outcomes for waterbirds, native vegetation, native fish and water volumes for the 10 breakout zones on the Macquarie Valley floodplain. Percent change values show the predicted change from current (no policy) to current with policy implemented for two development scenarios: NG = no growth in general security and G = growth in general security. Values are 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 Trangie, B Marthaguy, C Birchells Plains, D Gunningbar, E Wyndabyne, F Gradgery, G Marebone, H Wilgara, I Glencoe, J Pillicarwarrina. N/A = asset or value was predicted/recorded in the zone.

Table 1 Comparison of outcomes from the implementation of the policy under general security use at current levels and growth within the Plan Limit Compliance Scenario

Values	Policy implemented and general security use remains at current levels	Policy implemented and general security use grows to the legal limit
Hydrology	• Changes to hydrological metrics was primarily to the duration of summer floods and limited spatially with only two breakout zones benefiting from implementation of the policy • These zones were Wilgara and Glencoe • Largest change in mean annual volume was 1% (2 GL) at Wilgara	• The hydrological metrics for duration, frequency and timing are predicted to increase at six breakout zones once the policy is implemented • These zones were Wilgara, Glencoe, Birchells Plains, Marebone, Gradgery and Pillicarwarrina • Largest change in mean annual volume was 7% (12.5 GL) at Wilgara

Values	Policy implemented and general security use remains at current levels	Policy implemented and general security use grows to the legal limit
Fish	• No beneficial change in EWR metrics for fish species where they are known or predicted to occur • Largest change: 1% increase in reproduction frequency EWR for short-moderate lived floodplain specialists	• Short-moderate lived floodplain specialists and flow pulse specialists will benefit the most from the implementation of the policy • Largest change: 51% increase in recruitment timing EWR for short-moderate lived floodplain specialists

Values	Policy implemented and general security use remains at current levels	Policy implemented and general security use grows to the legal limit
Vegetation	• Improvements at Wilgara and Glencoe breakout zones only • Only species that occur in these breakout zones are expected to receive improvements • Largest change: 13% increase in seedling establishment frequency EWR for Coolabah	• Improvements at six of the ten breakout zones • All species assessed are expected to benefit • Largest change: 66% increase in seedling establishment timing EWR for Coolabah

Values	Policy implemented and general security use remains at current levels	Policy implemented and general security use grows to the legal limit
Waterbirds	• Implementing the policy is predicted to provide little to no benefit for colonial-nesting waterbirds • Only small benefits for some EWRs important for non-colonial waterbirds are predicted under the policy	• Improvements to duration and timing EWRs for colonial waterbirds • Wilgara breakout zone is expected to have a substantial increase in the number of flow days in the breeding season for colonial breeding waterbirds • More flow days predicted during non-colonial waterbird breeding periods. • Predicted increase of extra days with flow at six of the ten breakout zones important for breeding
Wetlands	• The outcomes for the greater Macquarie Marshes are minor and limited to Glencoe and Wilgara breakouts zones only • The greatest change is expected at Wilgara breakout zone which incorporates the Wilgara Ramsar site	• The outcomes for the greater Macquarie Marshes are expected to improve at all relevant breakout zones • The greatest change is expected at Wilgara breakout zone which incorporates the Wilgara Ramsar site
Frogs	• The predicted percentage change in achieving frequency metrics for frog EWRs were very low across the floodplain • Wilgara and Glencoe breakout zones are expected to benefit from hydrological changes and predicted to have the greatest percentage change in EWR metrics for summer breeding and flexible breeders	• Flow dependent frogs are a predicted benefit from hydrological changes at six of the 10 breakout zones • Wilgara, Glencoe and Birchells Plains are predicted to have the greatest increase in EWR metrics. These breakout zones will have the greatest outcomes for flow dependent frogs including flexible and summer breeders

Contents

List of figures

List of tables

1 Introduction

1.1 Background

In 2013, the NSW Government introduced the NSW Floodplain Harvesting policy (the policy). 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 aims to manage unconstrained floodplain harvesting by bringing it into a licensing framework.

1.2 Report purpose

This is the second report on the environmental outcomes (i.e. ecological responses) on the floodplain after implementing the policy in the Macquarie Valley. The first report looked at the outcomes of implementing the policy based on the current level of take for general security, Supplementary, High Security, town water supply, stock and domestic and anticipated floodplain harvesting licences (DPIE Water 2021c). However, general security shares in the Macquarie Valley are estimated to be around 11% below the plan limit. This means that in the future, the amount of water accessed under a general security licence could increase. This would require an adjustment to the share entitlements for floodplain harvesting licences in order to keep the valley within the plan limit.

This report considers the predicted environmental outcomes on the floodplain after implementing the policy if there is a growth in general security shares in the future. 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.

1.3 Summary of floodplain harvesting in the Macquarie Valley

The 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 NSW Floodplain Harvesting 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 2012. The implementation of the policy will bring the average annual diversions back in line with the Cap scenario or the Water Sharing Plan Limit[2], which in this case is the smaller long term average total diversion and considered the Plan Limit Compliance Scenario (Table 2). If general security use grows to the legal limit, a reduction in FPH diversions would be required (Table 2).

---

[2] There are two clauses in the Plan Limit definition in the Water Sharing Plan; the Water Sharing Plan limit and the Murray Darling Basin Ministerial Council (MDBMC) Cap on diversions. The Plan Limit Scenario is whichever has lesser long term average total diversions

Table 2 Predicted long term (1895 to 2009) average diversions (GL/year) under the Plan Limit and Current Conditions scenarios to determine growth in use (DPIE Water 2021b)

Diversion component	Long term average under Plan Limit Compliance Scenario (GL/y	Long-term average under Current Conditions Scenario (GL/y)
General and high security	304.0	271.3
Supplementary access	13.6	14.0
Floodplain harvesting		
Overbank flow harvesting	19.1	23.6
Non-exempt rainfall runoff (RR) harvesting	14.1	15.7
Exempt rainfall runoff harvesting	12.9	13.2
Total (less exempt RR)	**350.8**	**324.6**
TOTAL	**363.7**	**337.8**

At the time of writing this report, some floodplain works are still being assessed for eligibility but are not expected to make a substantial difference to the outcomes identified in this report. There has also been an assessment of some eligible works in the Pillicarwarrina breakout zone (Bulgeraga Ck) that were decided post this analysis that will lead to some modest improvements in outcomes for the greater Macquarie Marshes.

More details on floodplain harvesting in the Macquarie Valley are provided in DPIE Water (2021a, 2021b, 2021c).

1.4 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 2. We provide a summarised version of the assessment approach in this report. For further details see the *Environmental Outcomes of implementing the Floodplain Harvesting policy in the Macquarie Valley* (DPIE Water 2021c):

- Chapter 3 describes the Identification of values (such as native fish species) and assets (such as wetlands).
- Chapter 4 describes the hydrological assessment (of ecologically relevant flow statistics).
- Chapter 5 describes how the the results of the hydrological assessment are used to test the environmental water requirements of key environmental values and assets.

The values (e.g. native fish) were selected to ensure that the range of flow requirements needed for assessing environmental responses to changes in flow were captured. The intent was to cover the spectrum of environmental flow dependencies. The approach compares the influence of flow only, all other influences being equal.

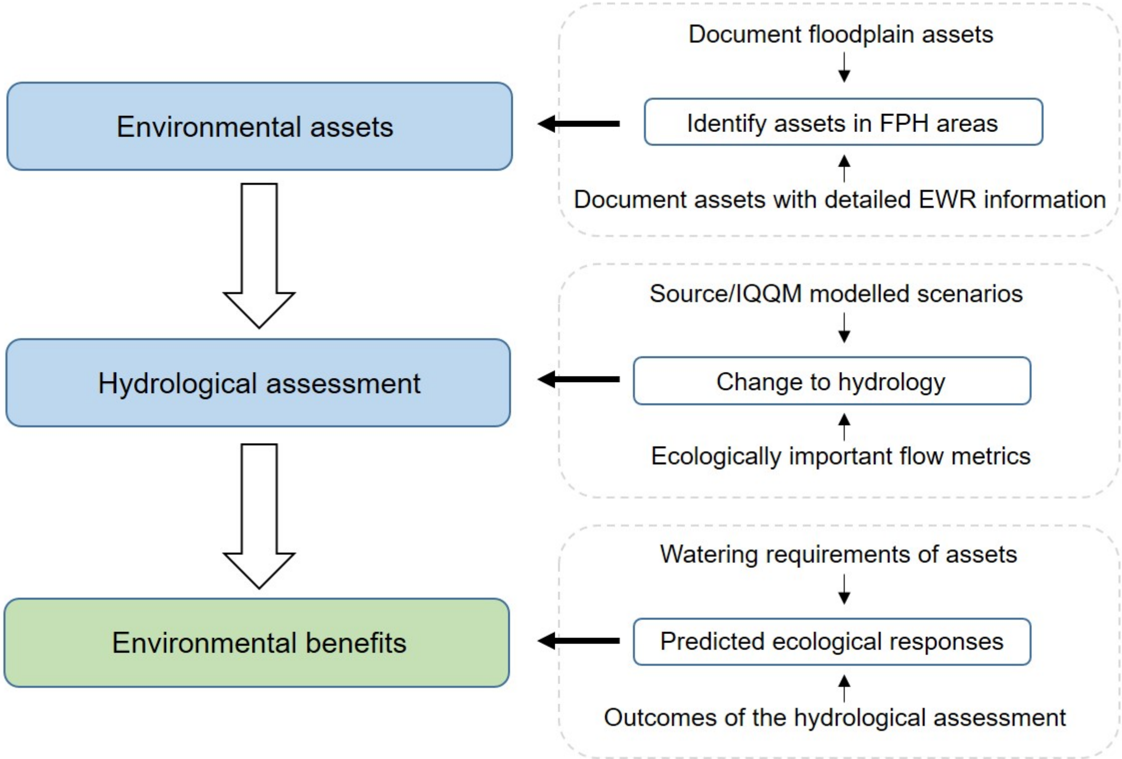


Figure 2 Summary of the approach adopted to identify the environmental outcomes of implementing the NSW Floodplain Harvesting policy (FPH = floodplain harvesting; Source/IQQM are river system/hydrological models)

1.5 Companion reports

This report is one of a suite of four reports that are prepared for the Macquarie Valley. This report describes an assessment of the predicted environmental outcomes from implementing the NSW Floodplain Harvesting policy if there is a growth in general security access. The other three reports are:

1. *Environmental outcomes of implementing the Floodplain Harvesting policy in the Macquarie Valley* (DPIE Water 2021c). This report outlines more detail on the environmental outcomes assessment. Specifically the outcomes of the policy without a growth in general security use. It also provides more detail on the approach, limitations and assumptions which are summarised in this report.
2. *Building the river system model for the Macquarie Valley regulated river system* (DPIE Water 2021a). This report 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.
3. *Floodplain Harvesting Entitlements for the Macquarie Valley regulated river system – Model scenarios* (DPIE Water 2021b). Modelling scenarios have been developed which use the river system model, with two alternate parameter settings that describe: the current condition and the condition with the policy implemented.

The four reports together serve to describe how the modelling meets the objectives of the policy under a variety of scenarios.

2 Environmental assets and values on the floodplain

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 this assessment. This provides greater confidence when predicting the environmental impacts of implementing the policy, as changes to floodplain hydrology can be designated to a breakout zone (area) and therefore restrict the predicted ecological responses of assets to that particular breakout zone.

The approach to identify these values and assets in the Macquarie Valley floodplain is summarised in Figure 3 and in more detail within DPIE Water (2021c).

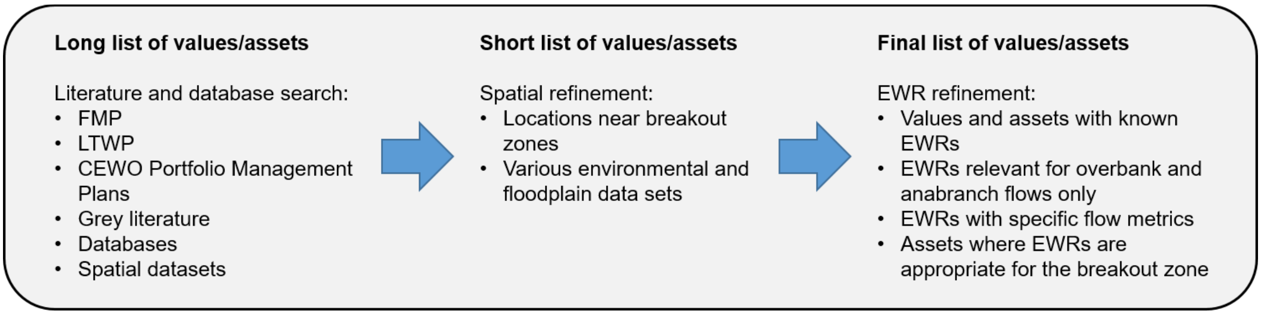


Figure 3 Summary of the approach adopted to identify water-dependent environmental values and assets in floodplain harvesting areas. FMP = Floodplain Management Plan, LTWP = Long-term water plans, CEWO = Commonwealth Environmental Water Office, EWR = environmental water requirement

High level descriptions for assets and values were identified (Table 3) and used to describe the final list of assets and values to be assessed in each of the 10 breakout zones on the floodplain (listed in Appendix A of DPIE Water (2021c)). These occur from downstream of Dubbo and supports a suite of environmental assets and values including threatened plants, animals, communities and functions. The critical components of each asset/value's EWRs are detailed in Appendix C of DPIE Water (2021c).

Figure 4 depicts the breakout zones, management zones, eligible floodplain harvesting properties and hydrological gauges.

Table 3 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
Asset – wetlands	A range of lagoons, billabongs and waterholes known to provide important habitat and refuge for a variety of water-dependent communities
Asset – flow-dependent frogs	Predicted distributions, recorded and known observations of a variety of flow-dependent frog species

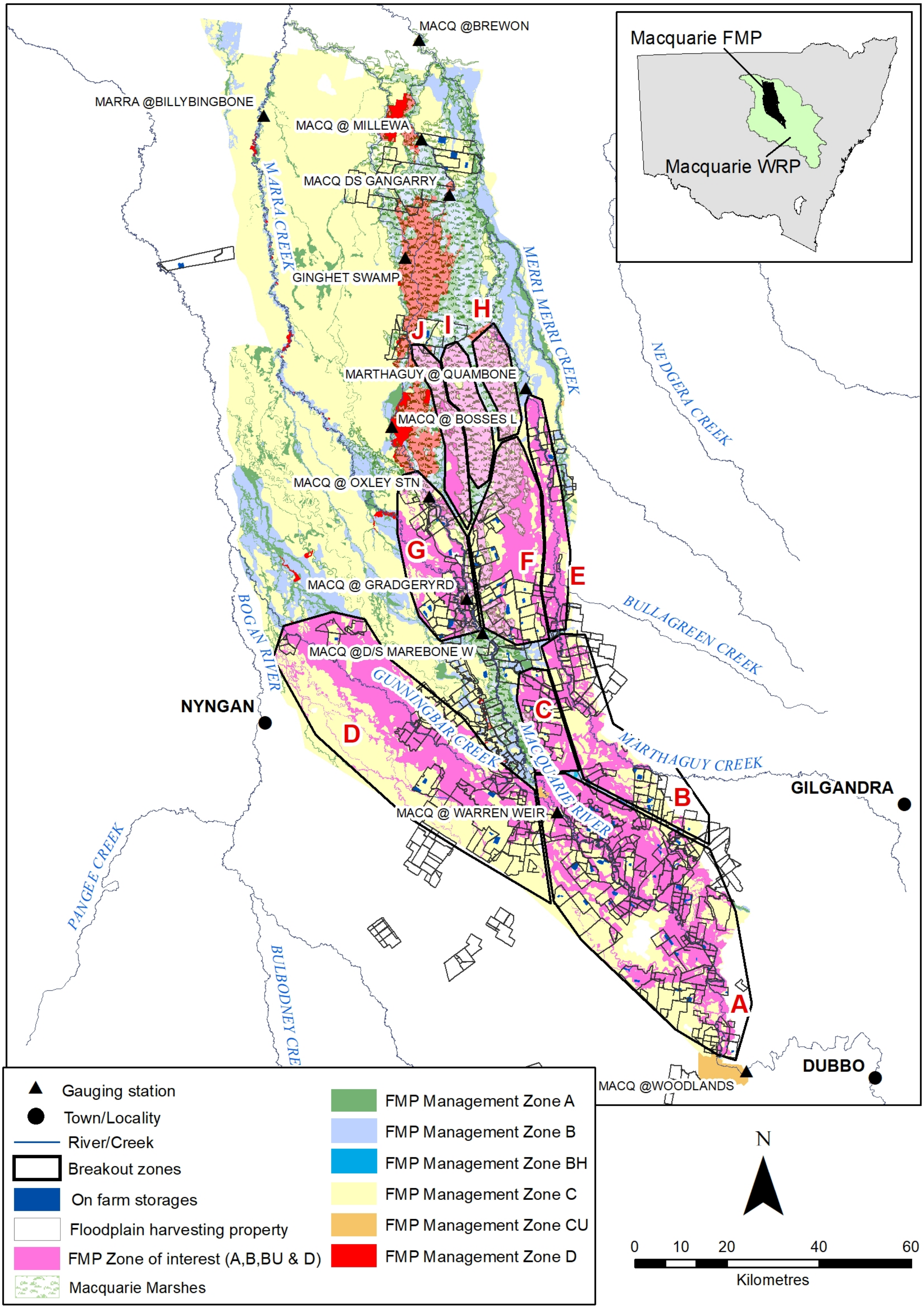


Figure 4 Map of the Macquarie floodplain showing the Floodplain Management Plan (FMP) zones and the zones of interest used to select environmental assets and values for inclusion in this assessment. Breakout zones from most upstream to most downstream: A Trangie, B Marthaguy, C Birchells Plains, D Gunningbar weir, E Wyndabyne, F Gradgery, G Marebone, H Wilgara, I Glencoe, J Pillicarwarrina.

3 Hydrological changes on the floodplain

3.1 Available hydrological data

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

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

Both scenarios are required to identify hydrological changes due to implementing the policy if a growth in general security occurs to the maximum legal limit. This is also used to assess the flow-on environmental outcomes on the floodplain. 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) to floodplain breakout zones, and an end-of-system (EOS) reporting node
- more details on the modelling are provided in the companion Model Build and Scenarios reports (DPIE Water 2020a, DPIE Water 2020b). All modelled flow data covered the period from 1895 to 2019.

3.2 Quantifying changes to floodplain hydrology

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). 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 4. Further details on these metrics is provided in DPIE Water (2021c).

The model **Current Conditions with Growth** and **Plan Limit with Growth** scenarios are the primary source of information used to quantify changes in floodplain flows due to implementing the policy in this report. The hydrological metrics listed in Table 4 were calculated for each modelled flow series[3]. 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.

---

[3] 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.

Table 4 Hydrological feature, period of interest and hydrological metrics adopted to describe magnitude and duration of flow 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 flow 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 flow 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

A comparison of results for the EOS floodplain breakout under these two scenarios was undertaken for the period 1895 to 2019 (Figure 5, Table 5).

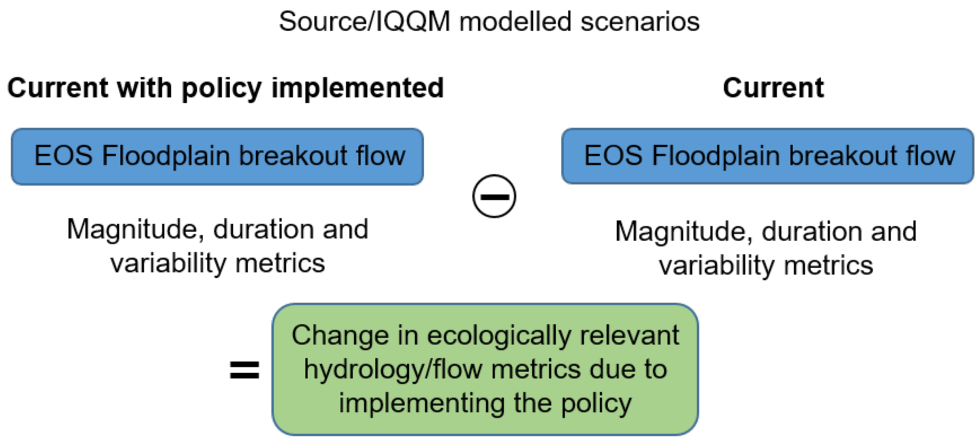


Figure 5 Summary diagram of how modelled breakouts were used to identify changes to floodplain hydrology and assess predicted ecological outcomes

3.3 Hydrological outcomes

3.3.1 Changes to floodplain hydrology

Modelling indicates that the implementation of the policy will result in changes to key hydrological features of the floodplain. This varied with location on the floodplain and the metric of interest. The outcomes are represented as a percentage change from the current scenario to the scenario with the policy implemented for each breakout zone (Table 5). There were a number of improvements to ecologically relevant floodplain metrics. These are broken down into the key hydrological features below. These interpretations are limited to the modelled outcomes for the end of system breakouts but provide indicative modelled outcomes for a variety of areas on the Macquarie Valley floodplain.

The 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

In total, during flood years (i.e. years when there are overbank flows and excluding non-flood years) the policy is predicted to allow an average increase of 3% in **mean annual volumes** to return to the floodplain across all breakout zones in the Macquarie Valley floodplain. The largest percent increase in total volume is 7% (767 GL) and mean annual volume is 7% (12.5 GL) at the Wilgara breakout zone. The lowest in total volume and mean annual volume was at Gunningbar breakout zone which had no change in any metrics.

With the exception of the Gunningbar breakout zone, and Trangie which is only expected to have a 1% increase in one season, all breakout zones are predicted to receive some increase in **total seasonal volumes** (Table 4). This varied across breakout zone and seasons. The largest percent increases are predicted at Wilgara (23%, 271GL) in summer and Marthaguy (16%, 6 GL) in autumn, Glencoe (15%, 230 GL) in summer and Wyndabyne (15%, 4GL) over the modelled 124 year period. Across the floodplain total summer volumes will have the highest average increase (8%) and winter the lowest (1%).

Median event magnitudes provide a measure of change in flow rates (ML/d) during flow events. There is a 4% increase in average median event magnitude across all breakout zones. The highest percentage change is expected in Wyndabyne breakout zone (18%). Small changes are predicted in Glencoe and Birchells Plains breakout zones (4%, and 9%) respectively and <1% change in other breakout zones (Table 5).

Duration

Based on the modelled scenarios, the **total number of flow days** across the entire record is predicted to increase across the floodplain (16%). However, breakouts zones Gunningbar and Marthaguy are expected to have no change and Wydnabyne and Trangie breakout zones only minor increases (<3%). Total days with flow improve most at the Birchells Plains (42%, 1035 total flow days) and Wilgara (31%, 1250 total glow days) over the modelled period. Gradgery, Marebone, Glencoe and Pillicarwarrina are predicted to have moderate increases (16% to 19%). The breakout zone variability in total flow days suggests that specific breakout zones should receive longer flood durations whilst others will remain relatively unchanged once the policy is implemented.

Seasonal flood durations in general are expected to have greatest changes in summer (39%) and autumn (28%) with small increase predicted spring (12%) and minor increases in winter (6%) (Table 5). The greatest increase in durations is at Birchells Plains (108%, 488 total flow days) and Wilgara (79%, 468 total flow days) breakout zones in summer over the modelled period.

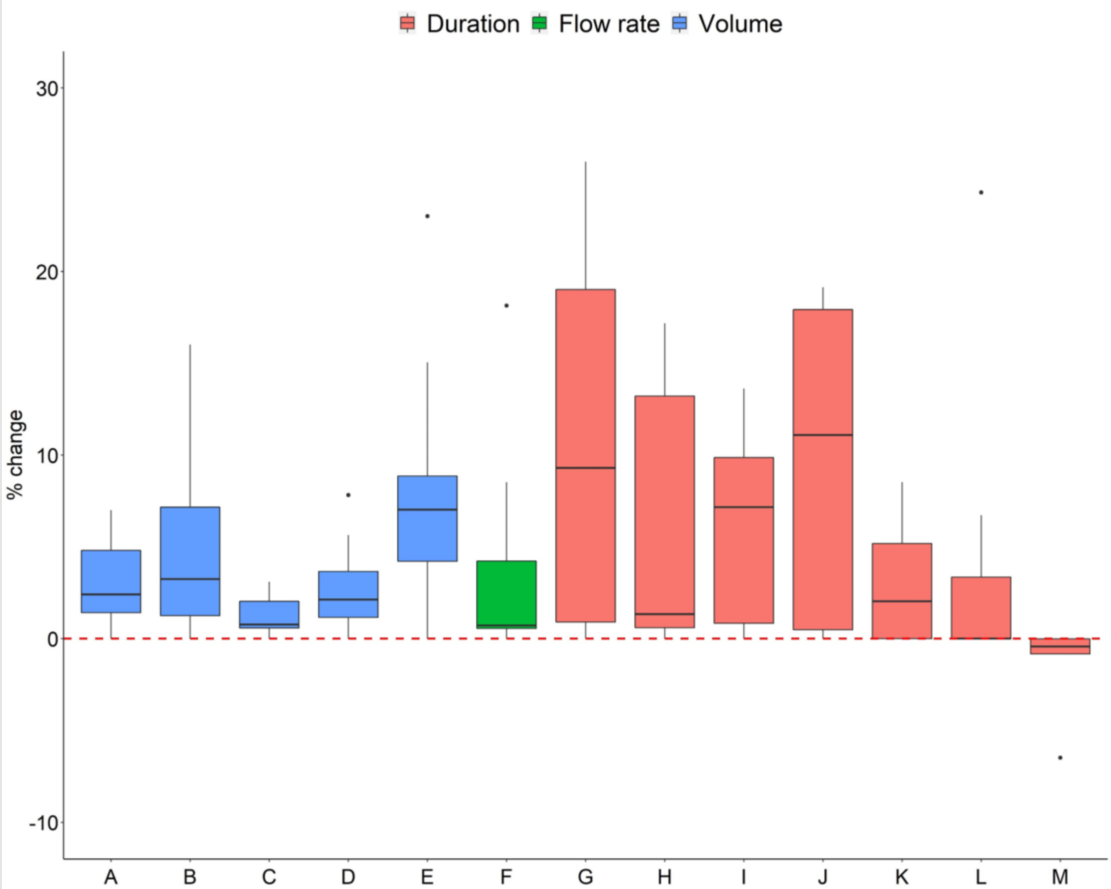
No change is expected at Gunningbar and only minor increases expected in Trangie, Marthaguy and Wyndabyne breakout zones (Table 5). The predicted increases were variable across the seasons and breakout zones with six of the ten sites expected to see beneficial change over all seasons (Table 5).

Event based metrics

The **number of flow events** between 1895 and 2019 are predicted to increase at half of the breakout zones with Marthaguy, Gunningbar, Wyndabyne, Marebone and Pillicarwarrina breakout zones expected to have no change (Table 5). The highest percentage increase is at Wilgara (147%, 162 events), Glencoe (60%, 62 events) and Birchells Plain (49%, 81 events) breakout zones over the modelled period.

The mean duration between events (**inter-event period**) is predicted to have the highest reductions at Wilgara and Glencoe breakout zones (-61% and -40%) respectively. This equates to a reduction in 220 days at Wilgara and 150 days at Glencoe between events over the modelled period. Only Birchells Plains, Gradgey, Wilgara, Glencoe are expected to have any changes in interevent period that could benefit ecology (Table 5).

Modelled outcomes for the rise and fall statistics of flow events vary by zone and flow metric of interest (Table 5). Across all breakout zones there is expected to be an average increase of 15% for the **duration of the rising limb**. Birchells Plains, Gradgery, Wilgara and Glencoe are expected to increase (17% to 81%) in rising limb duration. Of the remaining break out zones, decreases are expected at Marthaguy, Marebone and Pillicarwarrina, no change at Gunningbar and Wyndabyne, and only small increase at Trangie. The **mean rate of rise** is expected to decrease across the floodplain by -6% (average across zones). This appears to be driven by decreases in Birchells Plains (-51%), Wilgara (-33%), Glencoe (-18%) and Gradgery (-14%) breakout zones (Table 5). The **duration of the falling limb** of events and **rate of fall** was variable across the breakout zones however overall is expected to decrease across all zones with -5% and -9% average percent change respectively. The largest percentage change was a -51% decrease in mean rate of fall at Birchells Plains breakout zone (Table 5).



A – Mean of annual volume
B – Total of autumn volume
C – Total of winter volume
D – Total of spring volume
E – Total of summer volume
F – Median of event magnitude
G – Total number of days with flow
H – Total of autumn days with flow
I – Total of winter days with flow
J – Total of spring days with flow
K – Total of summer days with flow
L – Number of events
M – Mean inter-event period

Figure 6 Box plot of percentage change in key hydrological metrics after implementing the policy with the growth in general security scenarioin the Macquarie 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 10 breakout zones

Table 5 Percentage change in ecologically relevant flow metrics after implementation of the policy with the growth in general security scenario. 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	(A) Trangie (%)	(B) Marthaguy (%)	(C) Birchells Plains (%)	(D) Gunningbar (%)	(E) Windabyne (%)	(F) Gradgery (%)	(G) Marebone (%)	(H) Wilgara (%)	(I) Glencoe (%)	(J) Pillicarwarrina (%)	Average (%)
Magnitude	Mean of annual volume (flood years only)	0	5	1	0	5	3	2	7	5	2	3
	Ratio of median to mean annual volume	3	9	57	0	61	15	36	68	40	36	32
	Total autumn volumes	0	16	3	0	15	4	1	8	5	1	5
	Total winter volumes	1	3	0	0	3	1	1	2	1	1	1
	Total spring volumes	0	3	1	0	3	4	1	8	6	1	3
	Total summer volumes	0	4	4	0	5	9	9	23	15	9	8
	Median of event magnitude	0	1	9	0	18	1	1	5	1	1	4
Duration, frequency and timing	Total flow days	3	0	42	0	1	16	19	31	26	19	16
	Number of events	7	0	49	0	0	24	0	147	60	0	29
	Total autumn days with flow	0	1	70	0	1	44	17	71	58	17	28
	Total winter days with flow	2	0	14	0	1	5	10	11	10	10	6
	Total spring days with flow	3	0	34	0	0	11	18	19	17	18	12
	Total summer days with flow	9	0	108	0	4	31	51	79	56	51	39

Environmental outcomes of implementing the Floodplain Harvesting policy in the Macquarie Valley: Growth in General Security use scenario

Hydrological feature	Flow metric	(A) Trangie (%)	(B) Marthaguy (%)	(C) Birchells Plains (%)	(D) Gunningbar (%)	(E) Windabyne (%)	(F) Gradgery (%)	(G) Marebone (%)	(H) Wilgara (%)	(I) Glencoe (%)	(J) Pillicarwarrina (%)	Average (%)
	Mean inter-event period*	-6	0	-34	0	0	-21	-1	-61	-40	-1	-16
	Total duration of rises	4	-6	81	0	0	17	-7	41	23	-7	15
	Mean rate of rise	0	7	-51	0	6	-14	22	-33	-18	22	-6
	Total duration of falls	0	0	0	0	0	-1	-25	-2	-1	-25	-5
	Mean rate of fall	0	15	-49	0	4	-13	-1	-30	-18	-1	-9

3.3.2 Case study of hydrological changes

An analysis of the modelled hydrological changes for total annual volumes for a 10 year period with a number of consecutive floods (1970-1979), and hydrographs over a period with lower (1970-1971) and higher (1973-1974) total volumes were used to highlight changes over a decade and within flow events (Figure 7). Two breakout zones were selected to highlight the potential changes in a zone with the relatively little change (Trangie breakout zone) and one with some expected changes (Wilgara breakout zone).

There are only small changes in total annual volume predicted for the Trangie breakout zone with greatest increase of 4 GL in 1974. However, there was a 3 GL decrease in 1978. In most years there is no change with an overall total increase of 8 GL over the ten-year period. In comparison, Wilgara breakout zone is predicted to have greater change in total annual volumes. The greatest increase was in 1970 and 1973 (43 GL), with a total increase of 185 GL over the ten-year period.

The hydrograph for the Trangie breakout zone for the period 1970-1971 shows little change after the policy is implemented, with only a minor increase in flow days (1 day) predicted. However, an additional 14 flow days for the period 1973-1974 with 2 flow days in winter and 12 flow days in summer were predicted. Wilgara breakout zone in general has higher daily volumes after the implementation of the policy. There is an increase of 68 flow days over spring and summer and a 3 flow day increase at the tail end of the recession for the 1970-1971 period. In comparison the 1973-1974 period had 14 additional flow days. The predicted hydrological changes associated with policy implementation show that the increase in volume and flows days is associated with increase in daily flow volume, low magnitude flow events, and a slight increase in flow days on the recession of large events. Flow days in particular were observed to have the greatest increase in 1970-1971 and was associated with low magnitude events that were not apparent in the current scenario without the policy implemented.

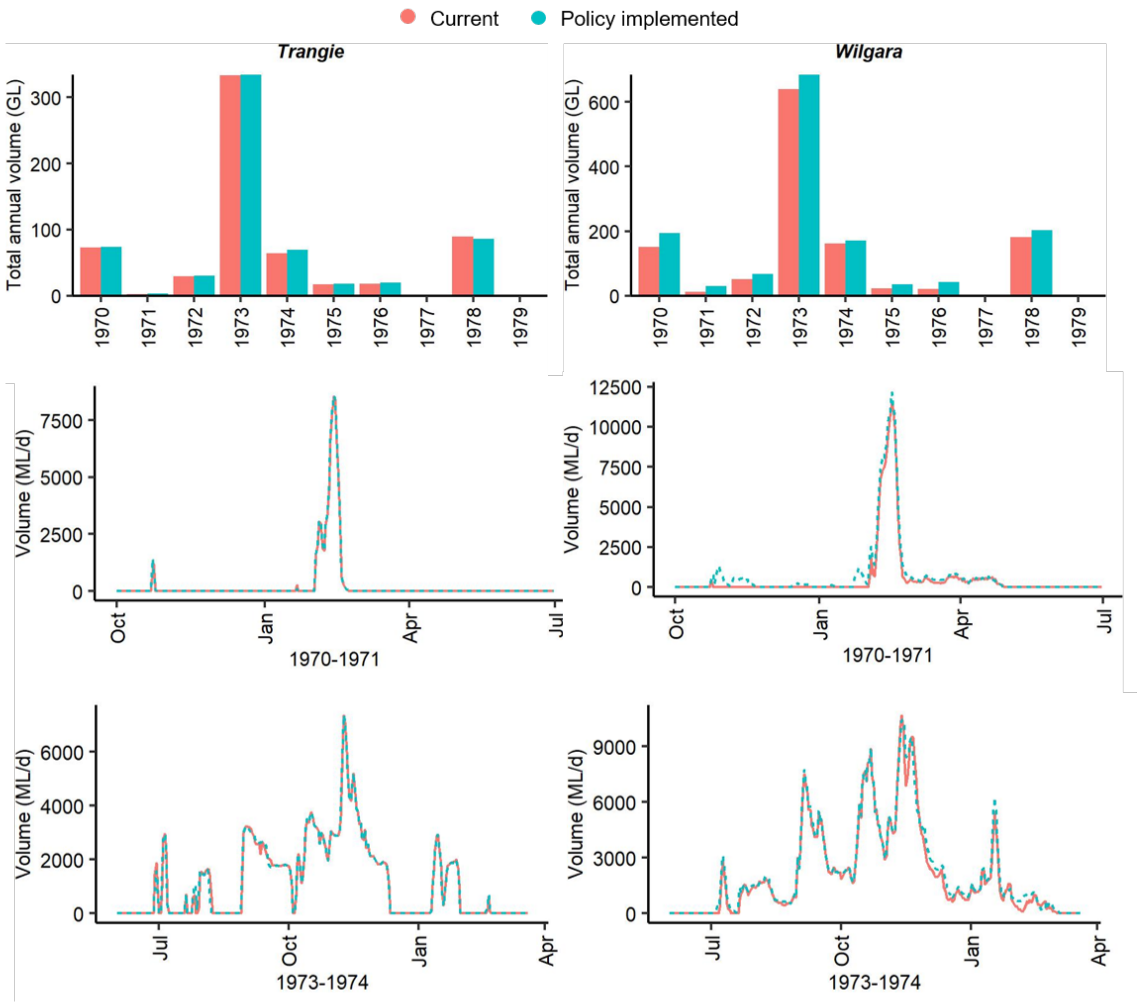


Figure 7. Modelled total annual volumes (GL/year) 1970-1979 and floodplain breakout volume (ML/d) during 1970-71 and 1973-1974 at the breakout zone with the smallest (Trangie) and largest (Wilgara) predicted hydrological change. Data represents the volumes remaining after FPH diversions have been applied.

4 Predicted ecological outcomes

The results presented in this chapter 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.

4.1 Assessment approach

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 Appendix C of DPIE Water (2021c)). 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 Compliance Scenario) and without (Current Conditions Scenario) (EWR values are listed in Appendix C, DPIE Water (2021c)). This involved first identifying all flow events, including the event duration, in the modelled flow data4. 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 flow 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[4]. 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 C of DPIE Water (2021c). Key outcomes are summarised for native fish, waterbirds, native vegetation, flow-dependent frogs and wetlands in this Chapter.

4.2 Assumptions and limitations

The predicted ecological outcomes are based on the best available information and are assessed from EWRs sourced from previous studies listed Appendix C of DPIE Water (2021c), expert opinion and a documented understanding of the impacts of hydrological changes on water-dependent floodplain environmental assets and values. There is a detailed explanation of the assumptions and limitations associated with this assessment in DPIE Water 2021c (Section 5.2 and Appendix D).

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. These should be treated as a tool for decision making, not as a measure of actual outcomes which will be observed in the future. A

[4] 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.

range of factors may inhibit modelled and predicted outcomes becoming observed outcomes. Some of these are discussed below.

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.

4.3 Native fish

4.3.1 Metrics

Fourteen different fish species were either predicted or recorded across the 10 breakout zones. 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). Not all breakout zones had predicted or recorded observations of a native fish species from each fish guild (DPIE Water 2021c) This assessment only considered the outcomes for each fish guild if it occurred in the breakout zone. The fish guilds, species and relevant breakout zones are summarised below:

- flow dependent specialists, such as Silver Perch, Spangled Perch and Golden Perch. Species from this guild were recorded in breakout zones A, B, C, D, E, F, G and J.
- generalists, which include a number of species such as Bony Herring and Australian Smelt that benefit from improved floodplain outcomes. Representative species from this guild were identified in breakout zones A, B, D, G, and J.
- short-moderate lived floodplain specialists such as Olive Perchlet. Predicted to occur in breakout zones A, C, D, F, G and J.
- in-channel/river specialists such as the iconic Murray Cod (Figure 8) and Eel-tailed Catfish. The relevant breakout zones for this fish guild are A, B, D, E, F, G and J.

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 flow events required for effective recruitment
- spawning, habitat and food – native fish often require flow events during specific seasons due to seasonality preferences for spawning. This also relates to the timing of flow events for spawning habitat, food resources and refugia for recruits.

Specific EWRs were not available for all fish species. However, the outcomes for a native fish guild can provide some insight into the implications for other species within that guild (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 (DPIE EES 2019a, 2019b).

In total, 10 EWR metrics and 30 tests were undertaken for native fish.

Figure 8 The iconic Murray Cod, a species which would be impacted by changes to floodplain harvesting practices [Photo: Guo Chai Lim]

4.3.2 Impacts on fish guild-specific EWRs

On average across the floodplain there are improvements predicted in the number of EWRs achieved for most metrics important for native fish (Table 6). Based on the 30 individual metric tests, only the recruitment EWR metric for generalists is predicted to have no change. The changes vary across the floodplain with no change, negative change and positive changes expected at some breakout zones, Some zones are expected to have large increases, for example 142% maximum for the floodplain specialists recruitment metric in one zone (Table 6). The minimums are driven by outcomes at the Trangie, Gunningbar, Marthaguy and Wyndabyne breakout zones which also had the lowest percentage changes in hydrology metrics (Table 5).

It is predicted that short-moderate lived floodplain specialists and flow pulse specialists will benefit the most from the implementation of the policy. Riverine specialists are expected to have moderate improvements, and generalists to have only minor improvements (Table 5).

Birchells Plains and Gradgery breakout zones are expected to benefit short-moderate lived floodplain specialists and flow pulse specialists the greatest. Birchells Plains breakout zone is expected to have an average 66% increase for flow pulse specialists and 71% increase for floodplain specialists in reaching EWRs. Gradgery is expected to have an average 35% increase for flow pulse specialists and 40% increase for floodplain specialists in reaching EWRs. Riverine specialists are expected to receive the greatest benefit at Gradgery breakout zone with 35% increase in reaching EWRs. Generalists percentage increase was predominately low across the breakout zones with the highest percentage increase of 7% predicted at Marebone and Pillicarwarrina.

Native fish on Birchells Plains that are known or predicted to occur include flow pulse specialists Silver Perch and flood plain specialist Olive Perchlet. Silver Perch, Oliver Perchlet and riverine specialist Trout Cod are known or predicted to occur at Gradgery breakout zone. As such, these species are expected to benefit the most from the policy under this scenario particularly at Birchells Plains and Gradgery breakout zones. Trout Cod is also predicted to have some benefit (16% increase in EWRs) at Marebone and Pillicarwarrina breakout zones. Riverine specialist Murray Cod are known or predicated to occur at Gunningbar and Marthaguy. These breakout zones are expected to have negligible change in hydrological metrics and EWR’s, therefore is expected there will be no ecological benefit to this threatened species. Small changes are only predicted for generalists, the benefit of which will be limited to Marebone and Pillicawarrina breakout zones.

Table 6 Percentage change in frequency of achieving EWRs for native fish in the Macquarie Valley floodplain after implementing the policy with the growth in general security scenario. Values represent average (minimum and maximum) predicted outcomes, averaged over the simulation period across the relevant breakout zones for each fish guild (See Section 4.3.1). S-M FP = short-moderate lived floodplain; N/A = no EWR available; *n* = number of breakout zones assessed

Hydro feature	EWR metric	S-M FP specialists (*n* = 6)	Generalists (*n* = 5)	Flow dependent specialists (*n* = 7)	River specialist Murray Cod (*n* = 7)
Duration	Egg development	32% (0, +86)	4% (0, +9)	12% (0, +50)	21% (0, +52)
Frequency	Maintenance	19% (0, +56)	4% (0, +10)	13% (0, +51)	7% (0, +29)
	Maintenance (interflow)	17% (0, +52)	4% (0, +10)	13% (0, +52)	7% (0, +29)
	Reproduction	17% (0, +50)	N/A	12% (0, +49)	7% (0, +28)
	Reproduction (interflow)	17% (0, +52)	4% (0, +10)	N/A	N/A
Timing	Maintenance	N/A	3% (0, +7)	15 (0, +70)	7% (0, +34)
	Recruitment	51% (+3, +142)	0% (0, 0)	23% (0, +121)	11% (-1, +50)
	Spawning	9% (0, +43)	N/A	15% (0, +70)	11% (-2, +43)
	Spawning habitat	22% (0, +72)	3% (0, +7)	N/A	N/A
	Food, refugia	21% (0, +88)	N/A	N/A	N/A

4.4 Native vegetation

4.4.1 Metrics

The key water-dependent native vegetation values used in this assessment are listed by their plant community types (PCTs) (DPIE Water 2021c). Seven vegetation species were selected for this assessment. They 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. The vegetation species and associated breakout zones used to assess vegetation specific outcomes are:

- black box which was found in 10 breakout zones (zones A-J),
- coolabah (woodland and wetland) found in 3 breakout zones (zones H-J),
- lignum shrubland in 5 breakout zones (zones A, B, D, F and J),
- river red gum (forest and woodland) which was found in 10 breakout zones (zones A-J),
- cumbungi found in only one breakout zone (zone G),
- river cooba found in all 10 breakout zones, and
- water couch (non-woody wetland) present in 5 breakout zones (zones F-J).

This assessment tested native vegetation EWRs based on two key hydrological features – **frequency and timing of flow 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 Appendix C of DPIE Water (2021c)). Most EWR values were sourced from (Roberts and Marston 2011, DPIE EES 2019a).

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[5]. The full list of key months/seasons is Appendix C of DPIE Water (2021c). 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.

[5] The reason for this substitution is set out in Section 5.2. In short, duration of flood water on the floodplain is not modelled.

Figure 9 Cumbungi, an emergent aquatic plant, is an important component of plant communities on the Macquarie Valley Floodplain [Photo: Ed Dunens]

4.4.2 Impacts on native vegetation specific EWRs

Modelling indicates that implementation of the policy in the Macquarie Valley will result in an overall increase of all the tested native vegetation EWRs (Table 7). Of the 24 metrics tested, 19 are expected to have an average increase ≥ 10%. The best outcomes for all native vegetation values is predicted to be the result of increased flood frequency and reduced periods between floods as well increases in timing of flows at certain times of the year depending on the species. Under the implemented policy scenario all species recorded an average increase in the frequency and timing required for maintenance and seedling establishment related EWRs.

The predicted change varied across the floodplain. The breakout zones with the highest average increase in EWR metrics were Wilgara (84%), Glencoe (65%) and Birchells Plains (55%) (Table 7). These breakout zones also had the greatest change in hydrology metrics (Table 5). Conversely the breakout zones with the least change in hydrology metrics, Trangie, Wyndabyne and Marthaguy, and Gunningbar, had either no change or negligible change in EWR metrics (≤1%). The remaining breakout zones are expected to have moderate increase of average EWR metrics (10%-30%).

All species assessed are expected to increase in EWRs. Coolibah is expected to have the greatest average increase (52%) in EWRs at Wilgara, Glencoe and Pillicarwarrina breakout zones. Other notable increases are Water Cooch, River Redgum and Black Box (Table 7). However, this varies spatially across the floodplain. While there are average increases in most breakout zones, four of the 10 sites are expected to have no beneficial change to any vegetation.

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 Macquarie Valley floodplain after implementing the policy with the growth in general security scenario. Values represent average (minimum and maximum) predicted outcomes, averaged over the simulation period across the relevant breakout zones identified in Section 4.4.1. *n* represents the sample size or the number of breakouts in which a value was present. N/A = no EWR available; *n* = number of breakout zones assessed

Hydro feature	EWR metric	Lignum (n = 5)	Coolabah (*n* = 3)	River cooba (*n* = 10)	River red gum (*n* = 10)	Black box (*n* = 10)	Water couch (*n* = 5)	Cumbungi (*n* = 1)
Frequency	Maintenance	Small shrubs 9% (0, +31)	Wetland 49% (+10, +78)	23% (0, + 75)	Forest 28% (0, 95)	26% (0, +86)	44% (+12, +93)	13%
		Large shrubs 8% (0, +28)	Woodland 45% (+9, +72)		Woodland 25% (0, +88)	N/A		
	Seedling establishment	10% (0, +36)	58% (+12, +93)	N/A	28% (0, +93%)	27% (0, +93)	N/A	12%
	Maintenance (interflow)	N/A	45% (+9, +72)	N/A	24% (0, +78)	N/A	N/A	N/A
Timing	Maintenance	N/A	N/A	N/A	31% (0, +103)	N/A	31% (0, +59)	11%
	Seedling establishment	8% (0, +34)	66% (+7, +103)	N/A	18% (0, 62)	23% (0, +103)	N/A	N/A
	Seedling maintenance	N/A	N/A	N/A	31% (0, +103)	N/A	N/A	N/A
	Seedling dispersal	7% (0, +21)	N/A	N/A	N/A	N/A	N/A	N/A

4.5 Waterbirds

There were 26 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. Eighteen colonial waterbird species have either been recorded or predicted to occur in any one breakout zone.

4.5.1 Metrics

This assessment focussed on environmental water requirements to **maintain habitat and provide breeding opportunities for colonial and non-colonial nesting waterbirds**. Metrics assessed for waterbird outcomes were **floods volumes, frequency of floods, flood duration** and **timing of floods**. Metrics used in this report were adapted from peer-reviewed scientific literature and the NSW Long-Term Water Plans specific for the Macquarie-Castlereagh valley (DPIE EES 2019a).

Colonial-nesting waterbirds

Below are summaries of the **environmental water requirements** for breeding outcomes of **colonial waterbirds** with a description of the metric assessed in this report.

Duration metrics

- the number of flow days above 1,250 ML/d (50 days or more) and 1,500 ML/d (40 days or more) at Oxley station flow gauge (421022) required to achieve the highest breeding probability (Bino et al. 2014). This EWR relates to flood duration and flow rate at specific locations in the valley.
    - metric is the number of floods with more than 40 days with flow (with and without the policy implemented) occurring in the breakout zone which includes Oxley station flow gauge (421022) and those breakout zones downstream from that gauge
- July and December is a period critical for breeding events (Arthur et al. 2012, Bino et al. 2014) and longer flood durations are important for breeding success.
    - metric is the total number of flow days in the months between July and December.

Frequency and flood volume metrics

- Analyses of historical flows and colonial waterbird breeding in the Northern Basin established that breeding events are linked to large floods (Brandis and Bino 2016), Specifically, flow volumes in the 3 months before breeding (September–November) (Kingsford and Auld 2005a).
    - metric is the difference (with and without the policy implemented) in cumulative volume of flow events which occurred in the 3 months before September, October and November.

Timing metric

- metric is the number of floods occurring between July and December

Other (based on native vegetation outcomes)

- The requirements to maintain critical breeding habitat (native vegetation) to improve breeding success for colonial waterbirds. The vegetation species include lignum (*Muehlenbeckia florulenta*) and river red gum (*Eucalyptus camaldulensis*). Both of these are important for breeding success of colonial waterbirds (Bino et al. 2014).
    - metrics are the outcomes for the lignum and river red gum from Section 4.4

Non-colonial waterbirds

Environmental water requirements for **breeding outcomes** of non-colonial waterbirds are summarised below, together with a short description of the associated metrics.

Timing and duration metrics

- The timing and duration of flows are critical for breeding events (DPIE EES 2019b).
  - metric 1 is the number of flow days in spring and summer for ideal breeding conditions
  - metric 2 is the number of flow days in autumn and winter for opportunistic breeding conditions
  - metric 3 is the number of flow events occurring in spring and summer for ideal breeding conditions
  - metric 4 is the number of flow events occurring in autumn and winter for opportunistic breeding conditions.

Other (based on native vegetation outcomes)

- The requirements to maintain critical breeding habitat (native vegetation) to maintain non-colonial waterbirds. The vegetation species include: lignum (*Muehlenbeckia florulenta*) and river red gum (*E. camaldulensis*) (DPIE EES 2019b)
  - metrics: outcomes for lignum and cumbungi from Section 4.4

Not all species were recorded in all breakout zones. However, due to the highly mobile nature of waterbirds, achievement of the waterbird EWRs was assessed for all species based on the colonial and non-colonial grouping. Only breakout zones which captured the key hydrological changes in the northern, southern and eastern management regions outlined in (Bino et al. 2014) were assessed for colonial waterbirds. This included an area where up to 16 waterbird breeding colonies have been recorded (Bino et al. 2014). The breakout zones assessed for colonial waterbird outcomes were E Wyndabyne, F Gradgery, G Marebone, H Wilgara, I Glencoe, and J Pillicarwarrina. Outcomes for non-colonial waterbirds were assessed for all 10 breakout zones.

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.

Further details of the EWR values used are provided in Appendix C of DPIE Water (2021c).

4.5.2 Impacts on waterbird specific EWRs

Colonial waterbirds

The outcomes varied across the six breakout zones where colonial waterbirds are known to breed, but on average, implementing the policy is predicted to provide benefit to duration and timing EWRs for colonial waterbirds (Table 8). The total number of flow days between July and December, an important breeding period is expected to improve by 13% on average across the breakout zones. This equates to an average of 379 more flow days at the 6 breakout zones across a 124 year period and is considered an improvement for colonial waterbird breeding outcomes. Improved flow duration in December is the primary driver of these changes. The Wilgara breakout zone is expected to have a substantial increase in the number of flow days in the breeding season (+617 days, +20%) and is the standout for improved colonial waterbird outcomes in this valley. This breakout zone is located within the Macquarie Marshes and contains the Wilgara Ramsar wetland site.

There is a slight predicted increase to the frequency of floods which have a minimum of 40 flow days (+3%) and also a small change to the three month cumulative volumes important for significant colonial waterbird breeding events (+2%) (Table 8).

Along with these direct measures, changes to key habitats (e.g. native vegetation) indirectly influence waterbird outcomes, either positively or negatively. For example, the predicted outcomes for native vegetation should have a range of flow-on effects for waterbirds.

Table 8 Percentage change in achievement of EWRs for colonial nesting waterbirds in the Macquarie Valley floodplain after implementing the policy with the growth in general security scenario. Values represent average (minimum and maximum) predicted outcomes, averaged over the simulation period across the 6 breakout zones (E-J).

Hydrological feature	EWR metric	EWR detail	Colonial nesting waterbirds (*n*= 6)
Duration	Breeding	Number of flow days between July and December	+13% (+1, +20)
Frequency	Breeding	Number of floods with at least 40 days of flow	+3% (0, +19)
Frequency and flood volume	Breeding: 3 month volume prior to breeding	Cumulative 3 month volume of floods before Sep (Aug, July and June)	+1.5% (+1, +3)
		Cumulative 3 month volume of floods before Oct (Sep, Aug and July)	+1% (+0, +3)
		Cumulative 3 month volume of floods before Nov (Sep, Aug and July)	+2.3% (+1, +4)
Timing	Breeding	July–December	+31% (0, +67)

Non-colonial waterbirds

The outcomes varied across the 10 breakout zones where non-colonial waterbirds are known to occur. On average, implementing the policy is predicted to benefit duration breeding condition EWRs important for non-colonial waterbirds (Table 9). The total number of flow days for ideal breeding conditions increased by an average of 20% or 376 days across the 10 breakout zones. This is primarily due to a large predicted increase of extra days with flow at six of the ten breakout zones. Specifically for the Birchells (799 days, 58%), Glencoe (823 days, 29%) and Wilgara (834 days, 34%) breakout zones. Opportunistic breeding outcomes are expected to increase by 12% with Birchells the key breakout zone of improvement (515 more days, 29%).

There is also a predicted increase to the timing of flow events occurring in spring-summer (+31% on average) and autumn-winter (+14% on average). There is improvements in achieving lignum and cumbungi EWRs documented in section 4.4. These range from 7% to 13% depending on the metric of interest. This has the potential to improve critical breeding habitat for non-colonial waterbirds on the Macquarie valley floodplain.

Table 9 Percentage change in achievement of EWRs for non-colonial nesting waterbirds in the Macquarie Valley floodplain after implementing the policy with the growth in general security scenario. Values represent average (minimum and maximum) predicted outcomes, averaged over the simulation period across the 10 breakout zones (A-J).

Hydrological feature	EWR metric	EWR detail	Non-colonial nesting waterbirds (*n*= 10)
Duration	Breeding: ideal conditions	Total number of flow days during spring and summer	+20% (0, +58)
	Breeding: conditions for opportunistic breeding	Total number of flow days during autumn and winter	+12% (0, +29)
Timing	Breeding: ideal conditions	Number of spring and summer flow events	+31% (0, +103)
	Breeding: conditions for opportunistic breeding	Number of autumn and winter flow events	+14% (-11, +48)

4.6 Wetlands: Macquarie Marshes

A variety of wetlands occur on the Macquarie Valley floodplain, including numerous significant anabranches, lagoons, wetlands, watercourses and billabongs. Of particular importance is the greater Macquarie Marshes, which includes Ramsar listed areas of wetlands of international significance (Department of Agriculture, Water and the Environment 2020). The four Macquarie Marshes Ramsar sites cover approximately 10% of the area of the greater Macquarie Marshes. These sites include the southern and northern sections of the Macquarie Marshes Nature Reserve, U-block and part of the private property Wilgara. The Marshes support important flow-dependent flora and fauna species including one of the largest colonial waterbird breeding sites in Australia (DPIE EES 2019a).

Other significant lagoons and wetlands have been identified in the Macquarie Valley but were not assessed in this report.

4.6.1 Metrics

EWRs for the Macquarie Marshes were sourced from Part B of the Macquarie-Castlereagh LTWP (DPIE EES 2019b). Only EWRs from appropriate planning units in the Macquarie-Castlereagh LTWP Part B that included the wetlands of interest assessed in this report were used in this assessment. These outcomes were not directly targeted for the wetlands themselves, but aimed to provide environmental outcomes for the values that each wetland or group of wetlands supports. These values included native fish, native vegetation, waterbirds, and flow-dependent frogs. For example, overbank and wetland events are listed as supporting a broad range of foraging habitats for waterbirds in the Macquarie Marshes. Therefore, **overbank** and **wetland** flows were included as EWRs of interest for the Macquarie Marshes, along with any other important EWRs listed for this wetland system. As mentioned in the waterbirds section, this report incorporates modelled nodes on the floodplain and not gauging station nodes. Therefore, frequency EWRs were simplified to reflect a change in achieving different flood frequencies for the Macquarie Marshes in specific breakout zones. The metrics included:

Frequency metrics

- frequency of flow events of 2, 5, 6, 7, 8 and 9 years in 10 years, and
- the frequency that the maximum inter-event period was satisfied (4 and 5 years maximum between floods).

Duration metric

- the duration of floods (number of flow days) between August and March.

Timing metric

- the number of floods occurring between August and March.

Details of the EWRs are provided in Appendix C of DPIE Water (2021c).

The selected **frequency and timing** EWR metrics from the Macquarie LTWP were only assessed for the relevant breakout zones likely to influence outcomes in the greater Macquarie Marshes. This did not include assessments for all Ramsar sites as they were primarily below the lowest breakout zones developed in this report. It is likely that the outcomes for the greater Macquarie Marshes will reflect outcomes for some of the Ramsar sites, however generalising the outcomes from the identified breakout zones was undesirable due to the uncertainties explained in Section D.2 'Assumptions and limitations'. The wetlands and associated breakout zones used in this assessment are:

- greater Macquarie Marshes which occurred in breakout zones Birchells Plains (C), Gradgery (F), Marebone (G), Glencoe (I), and Pillicarwarrin (J), and
- the Wilgara Ramsar site which is located in the Wilgara (H) breakout zone.

4.6.2 Impacts on specific EWRs for wetlands

Greater Macquarie Marshes

The outcomes for the greater Macquarie Marshes are expected to improve at all breakout zones including the Greater Macquarie Marshes and the Ramsar listed Wilgara site with Wilgara breakout zone (Table 10). The **frequency**, and **timing** of flow events is predicted to improve at all six breakout zones. The greatest increase in frequency and timing metrics include Wilgara, Glencoe and Birchells Plains (Table 10). The lowest percentage increase was for timing EWR metric at Pillicarwarrina and Marebone breakout zones (5%). However, frequency metrics for these breakout zones are expected to have greater increases (10%- 78%). It is predicted that wetland ecology will benefit from the policy with greatest improvements at Wilgara breakout zone which incorporates the Wilgara Ramsar site. The Greater Macquarie Marshes will also ecologically benefit from increased timing and frequency of flows due to the implementation of the policy particularly at Glencoe, Birchells Plains and Gradgery breakout zones.

Table 10 Percentage change in frequency of achieving EWRs for the greater Macquarie Marshes and the Wilgara Ramsar site after implementing the policy with the growth in general security scenarioThe outcomes represent the percent change for the breakout zones which support these wetlands, averaged over the 124 year simulation period

Hydro feature	EWR metric	Greater Macquarie Marshes					Wilgara Ramsar site
		Birchells Plains	Gradgery	Marebone	Glencoe	Pillicarwarrin a	Wilgara
Frequency	9 years in 10	96%	50%	78%	230%	78%	500%
	8 years in 10	93%	55%	58%	198%	58%	453%
	7 years in 10	86%	51%	57%	205%	57%	418%
	6 years in 10	86%	47%	41%	179%	41%	277%
	5 years in 10	87%	48%	32%	151%	32%	300%
	2 years in 10	77%	41%	24%	105%	24%	149%
	Inter-event <4yrs	52%	29%	11%	62%	11%	88%
	Inter-event <5yrs	51%	29%	10%	59%	10%	78%
Timing	August – March	57%	30%	5%	79%	5%	83%

4.7 Flow-dependent frogs

The Macquarie floodplain contains important refugia and habitat for frog species including anabranches, lagoons, wetlands, watercourses and billabongs. Changes to the timing, frequency and duration of floods reaching these habitats is likely to have a range of benefits to maintenance and breeding outcomes for flow-dependent frogs. Up to 20 frog species (Appendix A: DPIE Water 2021c) either predicted or recorded in the floodplain breakouts. This assessment only considers the outcomes for 8 of these species due to their strong association with floods (DPI Water 2018). These species were either predicted or recorded in all breakout zones. The species include the Eastern sign-bearing froglet (*Crinia parinsignifera*), salmon striped frog (*Limnodynastes salmini*), green tree frog (*Litoria caerulea*), broad-palmed frog (*Litoria latopalmata*), Peron's tree frog (*Litoria peronei*), Fletchers frog (*Lechriodus fletcheri*), spotted grass frog (*Limnodynastes tasmaniensis*), desert tree frog (*Litoria rubella*). At least one of these species was predicted or recorded in each breakout zone. This report generalises the predicted outcomes for all of these frog species.

4.7.1 Metrics

To identify the impact of changes in hydrological features important to frogs we used specific **duration, frequency and timing** EWRs adapted from the expected frog outcomes in the Macquarie-Castlereagh LTWP (DPIE EES 2019a). These are likely to maintain habitat or provide reproduction opportunities for frogs. The metrics selected were categorised into **maintenance** of habitat and **reproduction**:

Maintenance metrics:

- improved flood frequency (average interevent) and flood duration across all seasons which should maintain refuge for core wetlands and off-channel waterholes,

Reproduction or breeding metrics:

- at least one flow event every two years to support breeding events,
- the timing and duration of floods in October to March for spring to summer breeders, and
- the timing and duration of floods in July to April for flexible breeders

Further details for the EWRs are provided in Appendix C of DPIE Water (2021c). In total, 7 water requirements for flow-dependent frogs were tested.

4.7.2 Impacts on specific EWRs for flow-dependent frogs

There was predicted beneficial change in frequency and timing metrics for all four EWRs (Table 11). There was a -15% reduction between events for maintenance and increase in frequency breeding metric (28%). Timing metrics are also predicted to increase for spring to summer breeders (46%) and flexible breeders (24%) (Table 11).

The changes to achievement of EWR metrics varied across the flood plain. No changes are predicted for Marthaguy, Gunningbar and Wyndabyne breakouts zones and only small percentage change for Trangie breakout zone. Similar to the previous environmental values assessed, Wilgara, Glencoe and Birchells Plains are predicted to have the greatest increase in EWR metrics. These breakout zones will have the greatest outcomes for flow dependent frogs Eastern sign-bearing froglet (*Crinia parinsignifera*), salmon striped frog (*Limnodynastes salmini*), green tree frog (*Litoria caerulea*), broad-palmed frog (*Litoria latopalmata*), Peron's tree frog (*Litoria peronei*), Fletchers frog (*Lechriodus fletcheri*), spotted grass frog (*Limnodynastes tasmaniensis*), desert tree frog (*Litoria rubella*). These species are also predicted benefit from hydrological changes at Marebone, Gradgery and Pillicarwarinna breakout zones.

Table 11 Percentage change in the frequency of achieving asset-specific EWRs for flow dependant frogs in the Macquarie Valley floodplain after implementing the policy. Values represent average (minimum and maximum) predicted outcomes, averaged over the simulation period across the 10 breakout zones.

Hydro feature	EWR metric	% change
Frequency	Maintenance (mean interevent)	-15% (0, -42)
	Breeding	28% (0, +93)
Timing	Breeding: spring to summer breeders (Oct-Mar)	46% (-4, + 186)
	Breeding: flexible breeders: Jul-Apr	24% (-2, +87)

5 References

Legislation

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

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

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

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

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

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

Macquarie specific

(Draft) *Floodplain Management Plan for the Macquarie Valley Floodplain 2018*. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0006/166524/draft-FMP-for-the-Macquarie-Valley-Floodplain-2018.pdf

(Draft) Water Sharing Plan for the Macquarie and Cudgegong Regulated Rivers Water Source Order 2020. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0007/315619/final-wsp-macquarie-cudgegong-regulated-rivers-water-source-2020.pdf

(Amended) Water Sharing Plan for the Macquarie Bogan Unregulated Rivers Water Source 2012. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0006/315618/final-wsp-macquarie-bogan-unregulated-rivers-water-sources-2012.pdf

(Amended) Water Sharing Plan for the Castlereagh Unregulated Rivers Water Source 2011. https://www.industry.nsw.gov.au/__data/assets/pdf_file/0005/315617/final-wsp-castlereagh-river-unregulated-water-sources-2011.pdf

Reports and journal articles

Arthur, A. D., J. R. W. Reid, R. T. Kingsford, H. M. McGinness, K. A. Ward, and M. J. Harper. 2012. Breeding Flow Thresholds of Colonial Breeding Waterbirds in the Murray-Darling Basin, Australia. Wetlands 32:257–265.

Bino, G., C. Steinfeld, and R. T. Kingsford. 2014. Maximizing colonial waterbirds' breeding events using identified ecological thresholds and environmental flow management. Ecological Applications 24:142–157.

Brandis, K., and G. Bino. 2016. A review of the relationships between flow and waterbird ecology in the Condamine-Balonne and Barwon-Darling River Systems. Page 111. Final report to the Murray-Darling Basin Authority.

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

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

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

DPI Water. 2018. Rural floodplain management plans: Background document to the Floodplain Management Plan for the Macquarie Valley Floodplain 2018 – Appendices. NSW Department of Industry – Water.

DPIE EES. 2019a. Macquarie-Castlereagh Long Term Water Plan—Part A. Page 121. Department of Planning, Industry and Environment - Environment, Energy and Science, Sydney NSW 2000.

DPIE EES. 2019b. Macquarie-Castlereagh Long Term Water Plan—Part B. Department of Planning, Industry and Environment - Environment, Energy and Science, Sydney NSW 2000.

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

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

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

DPIE Water. 2021c. Environmental outcomes of implementing the Floodplain Harvesting policy in the Macquarie Valley. Department of Planning, Industry and Environment - Water, Sydney NSW, Australia.

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

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

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

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

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

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

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

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

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

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

Appendix A 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[6].

Table 12 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

[6] 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 13 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
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