WATER MANAGEMENT

Northern Basin flow event environmental review

Review of temporary water restrictions January–April 2020

October 2020

NSW Department of Planning, Industry and Environment | dpie.nsw.gov.au

Published by NSW Department of Planning, Industry and Environment

dpie.nsw.gov.au

Title: Northern Basin flow event environmental review

Subtitle: Review of temporary water restrictions January–April 2020

First published: February 2021

Department reference number: INT20/377487

Acknowledgements

This report has been assembled with the help of the Department of Primary Industries – Fisheries' data, interpretive skills and cooperation.

Summary

In January 2020, the Bureau of Meteorology forecast rainfall over widespread areas of the Northern NSW Murray–Darling Basin. This region had been experiencing severe drought. In some valleys, river inflows were substantially lower than any previous drought on record. Many towns had exhausted, or were close to exhausting, their river water supplies and many rivers had reverted to a series of disconnected pools. River-dependent environments were showing signs of prolonged and severe drought stress.

In order to meet critical human and environmental needs throughout the northern Basin, it was necessary to protect the drought-breaking flows. Temporary restriction orders on river pumping started on 17 January 2020 and applied to most commercial water extraction. The temporary water restriction applied to regulated and unregulated rivers of the Border Rivers, Intersecting Streams, Gwydir, Namoi, Peel, Macquarie–Bogan, and Castlereagh catchments, as well as the Barwon–Darling River.

On 7 February 2020, floodplain harvesting, from the associated floodplains, was also restricted through a further temporary water restriction.

The temporary water restriction orders were in place until 28 February. On 29 February, a new order was made that applied only to the Barwon–Darling River and floodplain, with the goal of ensuring that flows from upstream catchments could move along the Barwon–Darling and reach the Menindee Lakes.

Prior to the rainfall events, the Department of Planning Industry and Environment had been working with the Department of Primary Industries (DPI) – Fisheries to determine the critical environmental needs that should be targeted in the northern valleys under various first-flush scenarios. Together, we developed critical flow targets to alleviate the environmental impacts of drought. We used these flow targets to manage the water restrictions, informing how long restrictions needed to be applied and when they could be relaxed. DPI – Fisheries mapped and identified key drought refugia in each valley, which also provided reach-scale targets for river connectivity. We derived additional flow targets from each valley's long-term water plan to assess whether other beneficial flows were also delivered during the event.

Monitoring of flow gauge data throughout the event showed that the target flows for critical needs criteria were met at all locations. Analyses also suggest that all or most of the critical drought refugia identified by DPI – Fisheries were likely to have received connecting and rejuvenating flows.

The beneficial flow criteria derived from each valley's long-term water plan showed nearly all the baseflow, small fresh, medium and large fresh watering criteria were met. This indicates that we can expect a beneficial ecological response throughout the northern Basin, which will help Basin ecosystems recover from the drought and improve resilience to further disturbance.

Flows to the Macquarie Marshes helped prime the southern marshes and improve transmission of follow-up flows in the northern marshes. Assessment of satellite imagery indicated that by the end of April, around 2,600 hectares of critical northern reed bed was inundated. This is expected to promote vegetation recovery from fires in October 2019.

Assessment of satellite imagery indicated that flows into the Gwydir wetlands began reaching the core reedbeds by late January and continued to increase the area inundated during February and March. Some 1,700 hectares of wetland were inundated in the central Gingham and 1,800 hectares in the lower Gwydir. These flows met some but not all of the critical flow criteria for the wetlands but will still help facilitate vegetation recovery and improve resilience.

Preliminary monitoring confirmed that golden perch larvae and young juveniles were present in the flows along the Barwon–Darling River from Mungindi through to Bourke, suggesting that these fish

continued to drift into the Menindee Lakes. This has substantial Basin-wide benefits as the lakes are thought to be a critical nursery for golden perch and other native fish.

Additional monitoring data regarding fish movement and fish community responses, including potential spawning of other fish species, was delayed because of river conditions and travel restrictions caused by the COVID-19 pandemic. We expect to complete further analyses in 2021.

We focused our management of this northern flow event on regulated waterways and the Barwon–Darling River, largely because these systems presented more management options and had a comprehensive gauging network with which to monitor the progress of flows. Although all of the unregulated rivers in the northern valleys were subject to water take restrictions, they were not as closely monitored.

We recommend that critical environmental needs and critical drought refugia are developed for the Intersecting Streams in preparation for any future event that may require a similar coordinated management approach.

Contents

List of figures

List of plates

List of tables

1 Introduction

Northern inland New South Wales has experienced record drought conditions since 2017. As water became scarce:

- the rivers and creeks became a line of stranded, stagnating pools rather than connected, flowing watercourses
- many regional towns and villages had to rely on emergency groundwater bores or water carting to maintain basic domestic supply
- graziers had to de-stock or cart in water and fodder
- many industries had to reduce production or invest in alternative supplies
- many irrigators had no or very limited access to water for extended periods, in some cases years
- water quality deteriorated as algae bloomed and salinity levels increased
- the remaining refuge pools became deoxygenated, endangering fish and other organisms
- large-scale fish deaths occurred in several areas
- vegetation that requires inundation also suffered.

From late January through to the end of March 2020, widespread rain fell across parts of north-west NSW and southern Queensland. The northern Murray–Darling Basin received more than 200 millimetres of rain. The rainfall created significant inflows in the Border Rivers, Peel, Namoi, Gwydir and Macquarie and along the Barwon–Darling River.

Before these flow events occurred, some major river systems had stopped flowing for extended periods. These river systems included the:

- Macintyre River below Boggabilla
- Mehi and Carole Rivers in the Gwydir valley
- Namoi River below Keepit Dam
- Peel River below Dungowan
- Macquarie River below Warren
- Barwon-Darling system
- Lower Darling River below the Menindee Lakes.

All these river systems received rainfall that recommenced flows and connectivity through to the Barwon–Darling River. By mid-April 2020 the Barwon–Darling was flowing along its full length from Mungindi on the Queensland border into the Menindee Lakes and down to Wentworth. Thousands of kilometres of rivers flowed for the first time in many months.

Most of the inflows in the Border Rivers, Peel, Namoi, Gwydir and Macquarie valleys happened below the major storages and would therefore not be captured. Water users' access to the flows had to be actively managed to maximise the downstream benefits.

Under normal conditions, water sharing plans set the rules for water extraction in NSW. However, during extreme events such as drought, additional restrictions can be applied. Section 324 orders under the *Water Management Act 2000* allow the minister to issue temporary water restrictions. Section 324 orders were used to restrict water access during the January–April 2020 flow event in the northern Basin to meet:

- critical human needs – provide flow locally and downstream, particularly to replenish town water supply weir pools and provide water supply for domestic and stock purposes
- critical environmental needs – provide flow along the length of the river systems to ensure reconnection of rivers and drought refuge pools.

In order to define the critical environmental needs, we developed a series of environmental flow targets. This report is a review of the available evidence to determine whether the targets were met and if the expected environmental outcomes were achieved.

We need to monitor environmental outcomes to determine whether management actions achieved the desired outcomes. Monitoring also provides feedback that can help to improve future actions. As ecological responses to flow events tend to be delayed, and monitoring and reporting on these responses can take a considerable amount of time, this review has used available information while anticipating that more information will be available later. A summary of the ecological impacts of drought in riverine landscapes is provided in Appendix A.

Most of this assessment is based on analyses of hydrological data to assess whether environmental flow targets were met. Hydrological data can be assessed quickly with the assumption that if critical flows were delivered, the critical environmental outcomes would also be expected. We have used river flow gauges and satellite imagery of inundation patterns in this review. Further information about the development of critical flow targets is provided in Appendix B.

1.1 Independent assessment panel

In March 2020, the NSW Government commissioned an independent assessment of the management of the 2020 northern Basin first-flush event. The objective of the assessment was to provide transparency around the decision-making processes and identify ways to improve the management of future first-flush events.

The independent assessment panel made ten recommendations to improve the management of first flush events.

Recommendation 3 noted that first-flush management already uses clear methods and best-available scientific evidence, and this should continue. Decision-making could be further improved by developing clear hydrological triggers for initiating first-flush events. These should be consistent with the relevant legal framework and linked to community and environmental objectives.

Recommendation 3 also identified the need for transparent methods that identify town weir pool requirements, other critical human water needs and basic landholder rights (including native title rights), and cultural flows.

Recommendation 4 identified the need to review incident management systems to address deficiencies highlighted by the 2020 northern Basin first-flush event. Incident management capabilities should include communication arrangements, event escalation/de-escalation frameworks, operational procedures and clarification of the roles and responsibilities of the key government agencies. The panel emphasised the need for an improved communications plan, in addition to the information set out in guidance materials:

This report will help address those recommendations by reviewing the effectiveness of the hydrologic triggers and environmental outcomes, and communicating these findings.

2 Implementation of temporary water restrictions

Temporary water restrictions were introduced under Section 324 of the NSW *Water Management Act 2000* on the 17 January 2020. The order restricted water take for all unregulated access licenses, regulated (high security) and regulated (general security) access licenses (unless the water was ordered and delivered by WaterNSW from a dam in the northern NSW Murray–Darling Basin, including the Barwon–Darling River).

The public interests for these water restrictions were defined at the time as follows:

- ‘To cope with a water shortage’ – Remaining water supplies in the north-western catchments were at very low levels. The north-western regulated river systems, the

Barwon–Darling and the Lower Darling were at Stage 3 (severe) or Stage 4 (critical) water shortage under the NSW Extreme Events Policy. Replenishment flows to many systems had not occurred for some time for domestic and stock purposes and water was being carted to many areas.

- 'Threat to public health and safety' – Town water supplies were reaching low levels across much of the north-west and far-west of NSW. Many towns would potentially have been without access to river water within a few months if there were no low inflows to storages. Similarly, many creek systems in these valleys had not had full replenishment flows to meet domestic and stock needs, and water was being carted for these purposes. It was essential that all inflows be protected for these higher-priority critical needs.
- 'Manage water for environmental purposes' – Low-flow conditions persisted across most of the northern NSW Murray–Darling Basin. As the drought continued and the river system became increasingly disconnected, pools that provided critical refuge for aquatic biota were drying up. The quality in remaining pools was declining, putting native fish (and other aquatic biota) at risk.

The original restriction was set to expire on the 31 January 2020, but modifications or extensions were made in most valleys. The details of relevant restrictions in each valley are documented in section 3 of this report and in Appendix C.

3 Description of the northern flow event

The temporary restriction order on river pumping started on 17 January 2020 and applied to most commercial water extraction within regulated and unregulated rivers of the Border Rivers, Gwydir, Namoi, Peel, Macquarie–Bogan, and Castlereagh catchments, and also in the Barwon–Darling River and Intersecting Streams. On 7 February 2020, a further temporary water restriction prevented floodplain harvesting from the associated floodplains. Information on where and when temporary water restrictions orders were placed up until 28 February 2020 can be found on the expired water restrictions page of the department's website.

The temporary restriction orders were in place until 28 February 2020. On 29 February 2020, a new order was made that applied only to the Barwon–Darling River and floodplain to ensure flows from the upstream catchments could move along the Barwon–Darling and reach Menindee Lakes.

During the period of the temporary water restrictions, some limited pumping was permitted based on a set of flow triggers and principles. You can download a fact sheet detailing where and when some access was permitted from the temporary water restrictions page of the department's website.

4 Northern Basin-wide assessment of ecological outcomes

4.1 Approach to assessing environmental outcomes

For this report, we monitored and assessed flow data for the first-flush event. This has the advantage that the data can be obtained relatively quickly after the event. The majority of the analysis in this report is therefore based on hydrology and assesses whether critical flow criteria were met. We can expect additional environmental benefits through the delivery of environmental flow targets. This is discussed in sections 4.2 and 4.3. Preliminary environmental data was available in some instances, and has been included in the discussion.

We have take the approach of using flow data because environmental responses to flow events, such as seed germination or production, spawning, increased growth, improvements in health, and

increased migration, can often take some time to occur. Also, there is typically a delay in scientific assessments because information must be collected in the field, analysed and reported.

Field-based monitoring of responses to this particular flow event was an issue because of travel restrictions due to the COVID-19 health crisis.

4.1.1 Key dates for environmental flow targets

We developed flow targets to meet critical environmental needs collaboratively with DPI – Fisheries. The targets were based on literature and expert knowledge regarding the on-ground drought requirements for native flora and fauna within the northern Basin (see Appendix B).

We considered flow targets as being met if a single cumulative flow requirement or duration component was achieved. A northern Basin-wide summary showing the key dates when we considered flow targets to be met is given in Table 1. Further flow target information and key dates for each valley are provided in Appendix D.

Table 1. Flow targets and dates when target criteria were met

Valley	Details
Intersecting Streams	Critical water needs were not defined for the Intersecting Streams, but the supplementary flow targets were met in the Moonie River water source by 11 February 2020 and all other water sources by 16 March 2020.
Border Rivers	All of the critical water needs criteria in the Border Rivers were met by 19 February 2020.
Gwydir	Most of the critical in-stream water needs criteria were achieved by early February 2020 except for Mallowa Creek which was achieved in mid-March 2020. The critical water needs in the Gwydir valley were a combination of in-stream and wetland targets.
Namoi	Most critical water needs criteria were achieved by 9 February 2020 except for Peel River at Piallamore, which had not been achieved as of 19 April 2020.
Macquarie	Most of the critical in-stream water needs of the Macquarie River upstream of the Marebone Break were met by 28 January 2020. The critical water needs for the Macquarie Marshes wetlands were achieved on 2 April 2020 for the upstream flows at the Marebone Break junction (60 GL), and 14 April 2020 for 30 GL at Pillicawarrina gauge.
Barwon–Darling	All the critical water needs for in-stream environments were achieved by 6 March 2020. The Darling River at Bourke achieved 15,600 ML and 14,700 ML between 6–7 March 2020 and the Darling River at Wilcannia recorded 13,500 ML on three consecutive days between 17–19 March 2020. Two additional criteria, although not included in the critical water needs list, were to fill the dead storage in Lake Wetherell and Lake Pamamaroo to volumes of 118 GL and 31.7 GL respectively. These were achieved between 22–23 March 2020 and have since recorded peak storage volumes of 185 GL and 132.6 GL in the period up to 19 July 2020.

4.2 Vegetation response

Rainfall and flow events improve the health of the environment, including critical wetlands and riparian habitat. When the frequency and duration of flow events are impacted by regulation and natural events, compensating management strategies need to be implemented to maintain and protect wetland and riparian vegetation. This means that during times of drought, flow events may need to be protected to maintain the health of vegetation and other aquatic organisms. Such events also help vegetation and other biota to recover once drought ends.

Management objectives for wetland and riparian vegetation were developed in accordance with the NSW Government's Extreme Events Policy[1]. These objectives informed when temporary restrictions should be imposed to provide benefits to the environment, included avoiding critical loss of species, communities and ecosystems, and irretrievable damage that prevents ecosystems recovering.

The aim of these objectives was to protect refuge pools during extreme events by maintaining water quality, water level, and food resources, and to support the survival of core wetland vegetation and seedbanks. Areas of ecological importance were identified and prioritised for flow protection.

We are monitoring vegetation and wetland responses to the northern flow event, but limited information is currently available. We expect detailed assessments, including for the Narran Lakes, Toorale wetlands, Gwydir wetlands and Macquarie Marshes, will be available in 2021, but preliminary outcomes are discussed below.

4.2.1 Macquarie Marshes

One area of ecological importance is the Macquarie Marshes. Situated 100 kilometres north of Warren in central-west NSW, the Ramsar-listed marshes cover 19,850 hectares. The area serves as an important nesting site for waterbirds and supports river red gum forests, coolibah woodlands and extensive reed beds.

After analysis of historical events, we estimated that a minimum volume of 30 gigalitres over 3 to 5 months was needed to meet the critical water demand of the northern reed bed and associated river red gum woodland following the prolonged dry period. The target volume was measured at the nearby Pillicawarrina Gauge (421147). We expect that the wetting of core wetland areas and closely fringing river red gums will assist in the marshes' recovery once the drought has broken.

Delivery of flows during this time was particularly important as a fire in the northern Macquarie Marshes in October 2019 caused extensive damage, with around 3,000 hectares of the reedbed and some adjacent river red gum woodland burnt. While the reedbed had re-sprouted from subsequent rainfall in early 2020, it urgently needed water to replenish root zones and ensure continued growth of the reeds (Plate 1).

Most of the criteria for instream critical water needs were met by the end of January 2020, with the longer duration and more beneficial baseflow to large fresh criteria met by mid to late February 2020. The criteria to address the Macquarie Marshes in particular – the target of 30 gigalitres at Pillicawarrina – was not met until the 14 April 2020 after a series of flow peaks travelled down the catchment. To assess how these flows may have benefited the marshes, we undertook inundation mapping to determine if protected flows reached core wetland areas.

[1] The policy can be downloaded from the extreme events information page on the department's website

Plate 1. Bora Well as of March 2020
Inserts are taken at same location before reedbed fire with typical growth.

The Water and Wetland team from the department's Environment, Energy and Science division used Sentinel 2 satellite imagery to track wetland inundation progress. The team found that flows in February 2020 helped 'prime' the streams in the wetlands of the southern Macquarie Marshes, allowing more efficient transmission of follow-up flows through to the northern Macquarie Marshes. Figure 1 shows the extent of inundation compared to extent of burnt area in early March 2020. By the end of April 2020, over 30 gigalitres had been delivered and around 2,600 hectares of the critical northern reed bed inundated. Mapping shows the progress of flows over the 3 months between February and April 2020 (Figure 2).

Immediate benefits from the inundation included priming of channels to improve the efficiency of future deliveries, supporting the reed recovery following fire in the northern reed beds, and supporting river red gums fringing core wetland areas. We will continue routine monitoring of vegetation responses to inform the appropriateness of the interim criteria and triggers for future management actions.

Figure 1. Satamap image of wetland inundation taken 1 March 2020.
Red area shows inundation at that time and the blue line the extent of the burnt area.

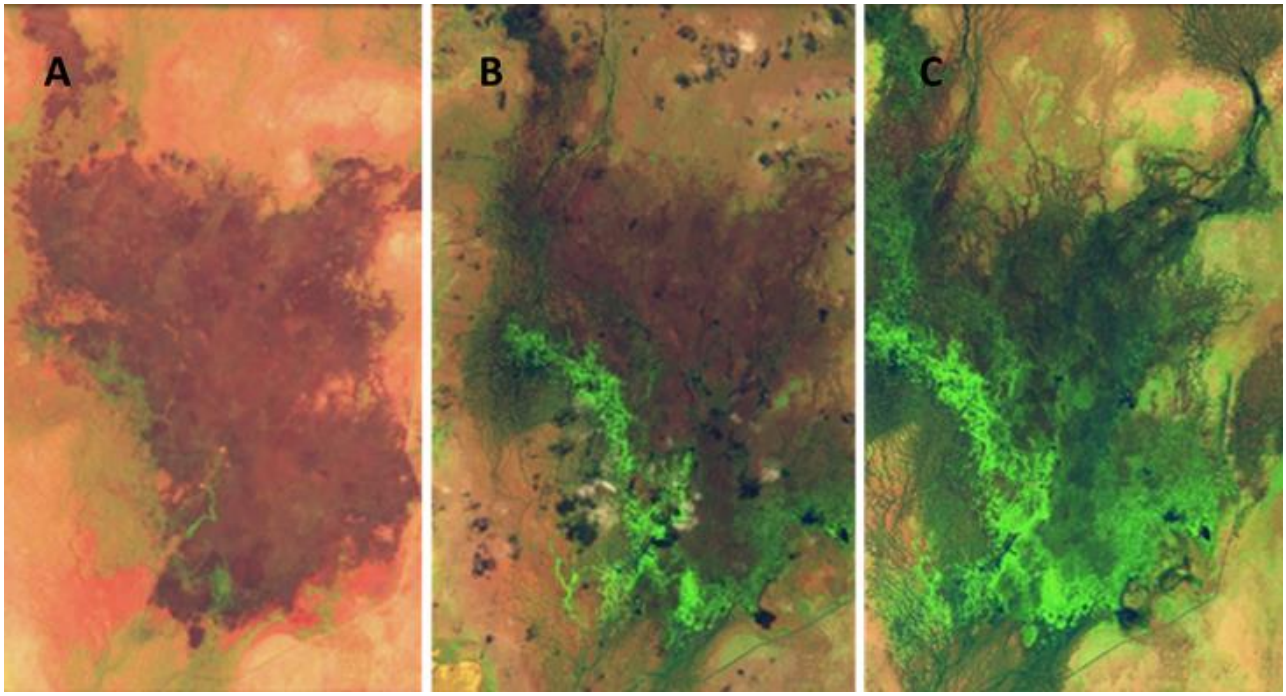

Figure 2. Sentinel imagery demonstrating the progression of flows to the Macquarie Marshes.
A. 2/02/2020 – 0 GL at Pillicawarrina gauge; B. 31/03/2020 – 17.8 GL at Pillicawarrina gauge;
C. 15/04/2020 – 30.7 GL at Pillicawarrina gauge

4.2.2 Gwydir wetlands

Another important ecological asset located in the northern Basin are the Ramsar-listed Gwydir wetlands (Plate 2). They are an example of terminal delta wetlands found when a river delta occurs in an inland valley. They are among the few inland wetlands of this kind remaining in the Murray–Darling Basin. The Ramsar site covers 823 hectares and consists of four separate subsites around the Gingham watercourse and Lower Gwydir (also known as the Big Leather Watercourse).

Analysis of whether criteria were met in the Gwydir Valley shows that, although most of the in-stream critical water flows were achieved, not all the wetland flows were achieved. As shown in Table D 1**Error! Reference source not found.** in Appendix D, the two-yearly wetland flow of 36 gigalitres at the Allambie gauge (418078) was not achieved, nor were the annual or two-yearly wetland flows in the Gingham Watercourse at the Tillaloo gauge (418076) (15 and 30 gigalitres) or the Gingham Bridge gauge (418079) (3 and 15 gigalitres). The 18-month and two-yearly wetland flows to the Mehi and Mallowa wetlands (3 and 8 gigalitres) measured at the Mallowa Creek regulator gauge (418049) were not achieved.

Despite some criteria not being met at some gauges, the department has measured inundation extent to assess how the Gwydir wetlands responded to the flow event. Preliminary results indicate that flows began to reach the core reedbeds by end of January 2020 and continued to increase the area inundated during February and early March 2020.

Within the Central Gingham Water Management Area, more than 1,700 hectares of semi-permanent wetlands, which supports common reed, Cumbungi and water couch, were inundated and responded well (Plate 3).

In the Lower Gwydir, more than 1,800 hectares of semi-permanent wetland was inundated a result of flow protections. This outcome is likely to help the recovery of aquatic vegetation in these areas when drought breaks, including the critically endangered marsh club-rush sedgeland in the Darling Riverine Plains bioregion.

Plate 2. Gwydir Wetlands State Conservation Area, Bunnor Lagoon (Photo: Commonwealth Environmental Water Office)

Plate 3. Vegetation response in the Gwydir wetlands.
This follows flow delivery to core wetland areas of the central Gingham wetland, 13 March 2020.

As in the Macquarie Marshes, we will continue routine monitoring of vegetation responses within the Gwydir. Outcomes from monitoring activities will inform the appropriateness of the interim criteria and triggers for future management actions.

4.2.3 In-channel and riparian vegetation

It is very likely that riparian and in-channel vegetation also benefited from the protection of flows, though assessing any immediate responses is difficult. Relevant long-term water plans indicate that base flows and small to large freshes are important flow requirements for protection and maintenance of in-channel and riparian vegetation. Fresh events vary in size, duration, timing and frequency, and can lead to different environmental responses.

Rivers and wetlands need a combination of flows over time, so the long-term water plans identify these as distinct 'environmental water requirements' (EWRs). For example, 'large fresh 1' and 'large fresh 2' EWRs are recommended for the Macquarie River and Macquarie Marshes, each providing different benefits and outcomes (see the Macquarie-Castlereagh Long Term Water Plan - Part B). These large fresh flows were delivered throughout February to April 2020 and were expected to support riparian and in-channel vegetation (Plate 4).

Plate 4. Flows in the Barwon River at Collarenebri (Photo: Commonwealth Environmental Water Office)

Large fresh 2 EWR events – defined as 1,000 megalitres per day for at least five days at the Oxley gauge (421022) in the Macquarie Marshes (see Macquarie-Castlereagh Long Term Water Plan - Part B) – have been identified as an important flow component in maintaining riparian and in-channel vegetation. Flows meeting the large fresh 2 requirements were delivered between 25 and 29 February 2020 and 12 and 16 March 2020, and again from the 8 to 23 April 2020 (Figure 3).

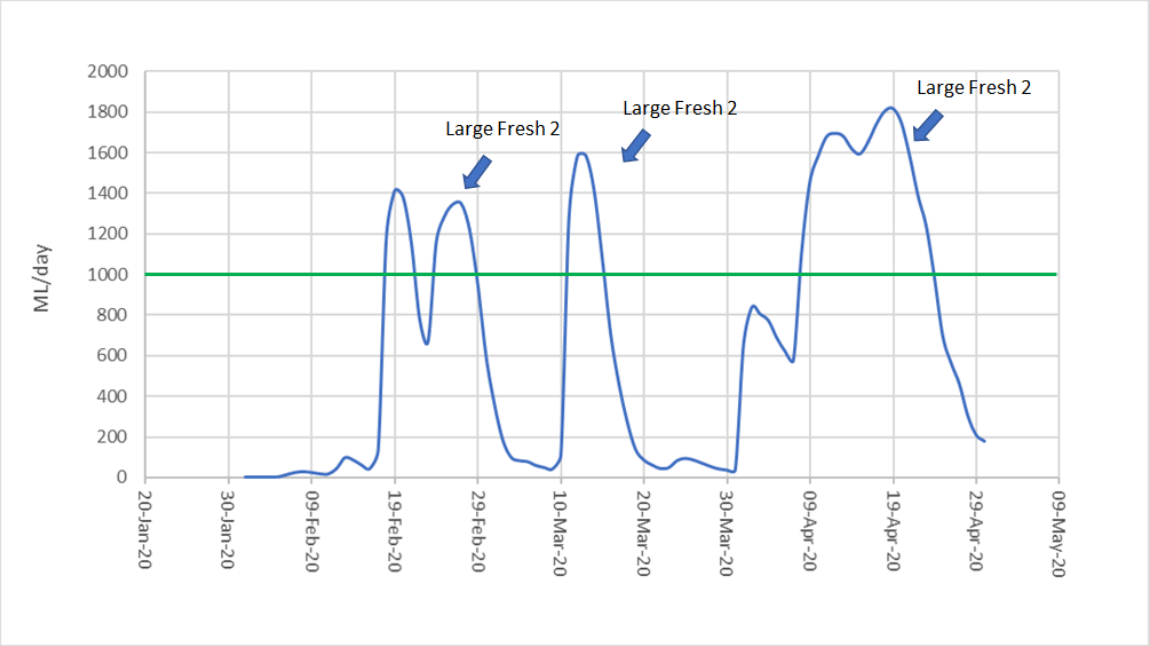

Figure 3. Flows to Macquarie Marshes based on discharge at Oxley (gauge no: 421022) (Source: www.waternsw.com.au/waterinsights/real-time-data).

Similarly, the Gwydir Long-Term Water Plan identifies small freshes as an important flow component in maintaining riparian and in-channel vegetation. The plan identifies a small fresh 1 as greater than 250 megalitres per day for at least 10 days at the Tyrell offtake gauge (gauge no: 418063). This was achieved between 13 and 25 February 2020 (Figure 4).

We will monitor the condition of riparian vegetation retrospectively as the development of remote-sensing assessment tools are further improved and implemented.

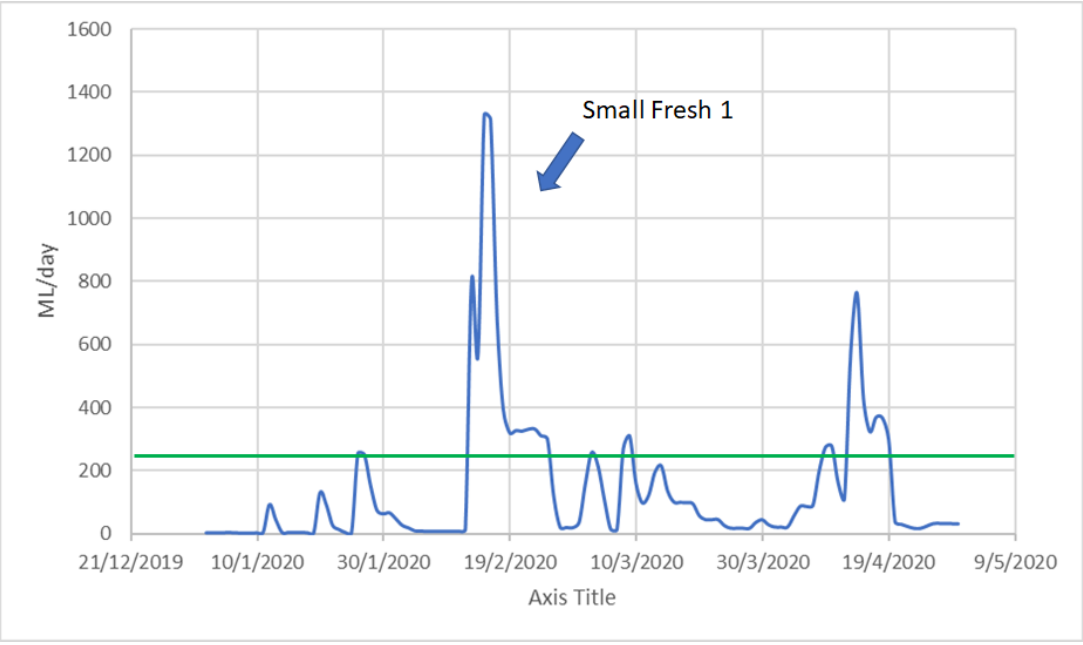

Figure 4. Flows to the lower Gwydir based on discharge at Tyreel Offtake (gauge no: 418063). (Source: www.waternsw.com.au/waterinsights/real-time-data)

Preliminary results indicate that protected flows reached the intended ecological assets, with core wetland areas being inundated and floodplain vegetation responding. Hydrologic evidence indicates that important flow components, identified to support and maintain riparian and in-

channel vegetation, were met on numerous occasions across water sources, with examples from the Gwydir and Macquarie provided. We will continue to monitor vegetation responses to these flows to inform future management water management decisions.

A summary of vegetation responses to the first flush event can be found on the north-west flows update page of the department website.

4.3 Fish responses

4.3.1 Delivering flows to priority drought refugia

A key environmental priority of the northern Basin flow event was to provide flows to the critical drought refugia identified by DPI – Fisheries as part of the Native Fish Drought Response 2019–20. It was not possible to confidently identify every refugia pool within each river, so critical river zones were identified and the total number of refugia within each zone was estimated.

Long-term water plans define 'small fresh' flow events as having sufficient volume and duration to be able to provide connectivity through a reach and replenish pools. In order to assess whether refugia were likely to have received sufficient flows, the small fresh EWR flow conditions within each refuge zone were derived from the relevant long-term water plan. Reference flow gauges used within each zone were assessed to determine whether these EWR conditions had been met. Flow events were considered likely to have provided connectivity if:

- small fresh EWR conditions, as defined in the relevant long-term water plan, were met at least once between 1 January and 19 April 2020
  or
- mean daily flows exceeded the 50th percentile flow on at least 10 days between 1 January and 19 April 2020.

For the purposes of this report, we have assumed that a small fresh or 50th percentile flow event through a refugia zone would provide water and connectivity to all or most of the listed refugia pools. More detailed analyses are required, both in terms of detailed hydrological analyses and refugia mapping, to confirm the exact number of refuges that received water.

4.3.2 Results

The assessment indicated that connecting flows were likely to have moved through all the identified refugia zones in the Border Rivers, Namoi and Barwon–Darling valleys.

Connecting flows were likely in all refugia zones in the Gwydir valley, apart from the Gwydir River between Tyreel and Brageen Crossing (418066) (Table E 2 in Appendix E). Although there were multiple flow events that exceeded baseflow EWR conditions, small fresh EWRs have not been defined by the long-term water plan at that gauge. The zone was assessed as 'possible' because some refugia may have received water, but more detailed analyses are needed to determine if all or most refugia were reached.

Connecting flows were likely in all refugia zones in the Macquarie valley, except for the Macquarie River from Oxley to the Barwon River (421012) (Table E 4 in Appendix E). Although there were two flow events greater than ten days at the reference gauge, flows were typically less than 100 megalitres per day, which met the baseflow EWR conditions but not the small fresh conditions. This zone was assessed as 'possible' because some refugia may have received water, but more detailed analyses are needed to determine if all or most refugia were reached.

As mentioned earlier, drought refugia were not identified for the Intersecting Streams, however small fresh flows and large fresh flows were achieved in most of the water sources. It is therefore likely that many of the drought refugia in these areas were wetted and connected by the flow events.

Table 2 provides a summary of refugia zones in each valley, including the number of estimated refugia and the likelihood that flows were able to achieve connectivity and rejuvenate pool conditions. Full details of refugia zones are available in Appendix E.

Table 2. High-priority drought refugia and likelihood of connecting flows in the northern Basin.

Valley	Likelihood of refuge pools being connected
Border Rivers	Eight zones assessed; all considered likely to have experienced a connecting event.
Gwydir	Ten zones assessed; eight considered likely to have experienced a connecting event; two considered to have possibly experienced a connecting event.
Namoi	Seven zones assessed; all considered likely to have experienced a connecting event.
Macquarie	Five zones assessed; four considered likely to have experienced a connecting event; one considered to have possibly experienced a connecting event. .
Barwon–Darling	Seven zones assessed; all considered likely to have experienced a connecting event.

4.3.3 Monitoring of fish communities

4.3.3.1 Larval drift samples

Researchers from DPI – Fisheries collected opportunistic drift samples on the Barwon–Darling, Warrego, Culgoa and Moonie rivers during March 2020 to monitor for fish spawning and larval drift (Plate 5). Preliminary results identified larvae and juveniles of golden perch, a large-bodied native fish known to migrate and breed during flow events. Larvae and juveniles were collected at several locations on the Barwon–Darling River between Mungindi and Bourke.

Sampling in the upper and lower reaches of the Barwon-Darling was done approximately two weeks apart (Table 3). This indicates that golden perch may have spawned on multiple occasions, and that larvae may have drifted and matured into juveniles within the body of water as it progressed south. These results are consistent with previous monitoring of flow events on the Barwon–Darling River, where larvae were collected from southern Queensland and through into the Menindee Lakes (Stuart and Sharpe 2020).

At the time of publishing this report, the larval drift samples had not been analysed to determine whether other fish species had also spawned during the event. Nor had results been analyses for the Warrego, Culgoa and Moonie rivers. Based on previous northern flow events, we anticipate that larvae and juveniles may have travelled from the Queensland reaches of these rivers as flows moved south (Stuart and Sharpe 2020).

Plate 5. Larval drift sample containing golden perch larvae and juveniles.
Collected from the Barwon–Darling River at Walgett, 4 March 2020. **(Photo: NSW Department of Primary Industries – Fisheries)**

Table 3. Opportunistic larval drift sampling.

Waterway	Site name	Date	Golden perch larvae	Golden perch early stage juvenile
Barwon River	Walgett	4/03/2020	yes	yes
Barwon River	Brewarrina	5/03/2020	yes	yes
Barwon River	Mungindi	5/03/2020	yes	yes
Darling River	Bourke	4/03/2020	yes	yes
Moonie River	Moonie River Bridge	5/03/2020	yes	yes
Warrego River	Fords Bridge	26/03/2020	not processed	not processed
Culgoa River	lower Culgoa	26/03/2020	not processed	not processed
Darling River	3 Mile Creek bridge	20/03/2020	yes	yes
Darling River	Viewmont	20/03/2020	not processed	yes
Darling River	Bourke	26/03/2020	not processed	yes

4.3.3.2 Fish movement tracking

DPI – Fisheries maintains a network of acoustic tracking stations to track the movement of golden perch on the Barwon–Darling River between Bourke and Goondiwindi and sections of the Gwydir and Mehi Rivers. These stations log the movements of thousands of fish that have been tagged with tracking devices. We expect that golden perch adults would have moved extensively during the northern flow event, thereby helping to expand the range and improve the long-term resilience of the species.

Data from the acoustic tracking stations must be manually downloaded on-site. Unfortunately, download of this data has been delayed due to the combination of large flows in February and March 2020, and field work travel restrictions due to the COVID-19 pandemic response. We anticipate that data will be collected, analysed and reported in 2021.

4.3.3.3 Routine native fish monitoring

DPI – Fisheries undertakes annual monitoring of fish communities. Samples were collected between January and March 2020 from sites on the Barwon–Darling River including Bourke, Goondiwindi, the Gwydir River and the upper reaches of the Border Rivers, Gwydir, Namoi and Macquarie valleys. Sampling was interrupted by large flows and travel restrictions due to the COVID-19 pandemic, but we anticipate that results will be available in 2021.

Fish monitoring data will provide information about the diversity and population structure of fish communities within the drought refugia zones that were a priority during the northern flow event. Comparison with long-term data will help to establish whether populations have continued to persist through the drought and the connecting flow events.

A summary of fish responses to the protection of first flush flows can be found on the north-west flows update page of the department website.

5 Conclusions and recommendation

The northern Murray–Darling Basin has experienced record drought conditions since 2017. Following significant rainfall across southern Queensland and northern NSW of more than 200 millimetres, significant inflows occurred in the rivers of the northern Basin.

The NSW Government chose to protect the first flush of flows across all the northern Basin by implementing restrictions to water extraction. The primary purpose of these restrictions was to

protect water for critical human needs and to provide water to critical refuge habitats for aquatic biota.

The ongoing management of the water restrictions and any relaxation of the rules are guided by a set of hydrological criteria at suitable flow gauging stations within each of the major valleys and river systems. These criteria were set to ensure that the critical water needs of the town water supplies and stock and domestic users were met, as well as the critical water needs of the environment

In addition to these critical water needs, a set of criteria was also identified from each of the long-term water plans for each valley to assess whether additional environmental benefits could be achieved by the flow event, often after water restrictions were eased.

It is evident from the flow records that the implementation of water restrictions enabled the majority of the critical water needs to be met, particularly for in-stream environments. If judged by hydrological criteria alone, the critical water needs of wetland communities were not always met, as evident in the Gwydir valley. However, inundation mapping in both the Macquarie Marshes and the Gwydir wetlands showed that the wetlands received some water to core areas that may facilitate a fuller and faster recovery should further wet conditions prevail in the coming months.

In addition to the critical water needs criteria, the flow event was sufficient to provide longer duration baseflows and a range of small to large fresh flows in many of the valleys to satisfy the annual and, in some cases, two- yearly EWRs of certain ecosystems.

The coordinated management of water restrictions also meant that the majority of critical drought refugia received flows that were likely to create connectivity and alleviate water conditions. This is critical to the long term resilience of fish populations in the northern Basin.

There is limited environmental monitoring data at present. However, more information will be available in 2021. Preliminary results indicate successful outcomes for golden perch in the Barwon–Darling River and successful water delivery to stressed wetlands in the Gwydir and Macquarie valleys. We anticipate that environmental outcomes will be favourable because of the high proportion of drought refugia and long-term water plan environmental water requirements that received adequate water.

Monitoring of active management during this event was largely focused on regulated waterways and the Barwon–Darling River because these systems presented more management options and had a comprehensive gauging network with which to monitor the progress of flows. Unregulated rivers in all the northern valleys were also subject to restrictions but were not closely monitored, nor were critical environmental needs flow targets developed. Similarly, critical drought refugia were not identified in the Intersecting Streams valleys.

We recommend that critical environmental needs and critical drought refugia are developed for the Intersecting Streams in preparation for any future event that may require a similar coordinated management approach.

6 References

Arthington A.H., Olden J.D., Balcombe S.R. & Thoms M.C. (2010). Multi-scale environmental factors explain fish losses and refuge quality in drying waterholes of Cooper Creek, an Australian arid-zone river. *Marine and Freshwater Research* **61**, 842–856. https://doi.org/10.1071/MF09096

Fairfull S. & Witheridge G. (2003). *Why do fish need to cross the road: fish passage requirements for waterway crossings*. NSW Fisheries, Cronulla, NSW.

Lake P.S. (2011). *Drought and aquatic ecosystems: effects and responses*. John Wiley & Sons.

Magoulick D.D. & Kobza R.M. (2003). The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology* **48**, 1186–1198. https://doi.org/10.1046/j.1365-2427.2003.01089.x

McNeil D.G., Gehrig S.L. & Sharpe C.P. (2013). *Resistance and resilience of Murray–Darling Basin fishes to drought disturbance. Final Report to the Murray–Darling Basin Authority – Native Fish Strategy Project MD/1086 – Ecosystem Resilience and the Role of Refugia for Native Fish Communities & Populations.*

MDBA 2019, *Independent assessment of the 2018–19 fish deaths in the lower Darling: Final Report 29 March 2019.* Murray–Darling Basin Authority

Mitrovic S.M., Oliver R.L., Rees C., Bowling L.C. & Buckney R.T. (2003). Critical flow velocities for the growth and dominance of Anabaena circinalis in some turbid freshwater rivers. *Freshwater Biology* **48**, 164–174. https://doi.org/10.1046/j.1365-2427.2003.00957.x

O'Conner J., Mallen-Cooper M. & Stuart I. (2015). *Performance, Operation and Maintenance Guidelines for Fishways and Fish Passage Works*. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning.

Stuart, I.G, Sharpe, C.P. 2020, Riverine spawning, long distance larval drift, and floodplain recruitment of a pelagophilic fish: A case study of golden perch (Macquaria ambigua) in the arid Darling River, Australia. *Aquatic Conservation, Marine and Freshwater Ecosystems, 2020.* 1–16.

Vertessy R., Barma D., Baumgartner L., Mitrovic S., Sheldon F. & Bond N. (2019). *Independent assessment of the 2018–19 fish deaths in the lower Darling, Final Report.* Murray–Darling Basin Authority.

Watts R.J., Kopf R.K., McCasker N., Howitt J.A., Conallin J., Wooden I., *et al.* (2018). Adaptive Management of Environmental Flows: Using Irrigation Infrastructure to Deliver Environmental Benefits During a Large Hypoxic Blackwater Event in the Southern Murray–Darling Basin, Australia. *Environmental Management* **61**, 469–480. https://doi.org/10.1007/s00267-017-0941-1

Appendix A. Ecological impacts of drought in riverine landscapes

Drought is a disturbance that impacts ecological processes in a variety of complex ways (Lake, 2011). Drought can vary in intensity, magnitude, duration and extent and impact longitudinal, lateral and vertical connectivity (Magoulick and Kobza, 2003). Impacts from droughts include:

- decreased waterbody depth and surface area
- decreased complexity and availability of hydraulic and physical habitat
- physicochemical changes in water quality including, water temperatures, hypoxia (deoxygenation), salinity, organic loading and toxicity.

Drought refugia are highly important features for the structure and function of the riverine landscape during these very low and cease-to-flow periods (Lake, 2011). As droughts intensify, waterbodies dry and contract, impacting a range of abiotic and biotic processes. Normally complex habitats containing logs, tree roots and branches will simplify as water levels drop and the woody habitats are left exposed (McNeil, 2013). Drought refugia become over-crowded, increasing predation and competition (Arthington *et al.*, 2010). Additionally, water quality will be impacted in a variety of ways, including increasing salinity and algae concentrations, while levels of dissolved oxygen decrease (Magoulick and Kobza, 2003).

Drought refuge pools can become stratified, separating into layers of cold, low-oxygen water on the bottom and warmer, more oxygenated water near the surface. Thermal stratification of pools develops faster in months with higher temperature and low flows, also during periods of high algal biomass, which increases the absorption of solar energy. When algal blooms decompose, the demand and use of dissolved oxygen by biological matter increases significantly, reducing the oxygen available to fish and other aquatic organisms.

Stratified pools can also be very unstable. Sudden drops in air temperature can cause pools to destratify, mixing the layers and rapidly depleting oxygen. When flows do resume, if volumes entering the pools are low, layers may mix without replenishing oxygen levels. Dissolved oxygen concentrations below 4 milligrams per litre can have sub-lethal effects for aquatic organisms, and below 2 milligrams per litre can be lethal (Watts *et al.*, 2018). Several of the recent fish kill events on the Barwon-Darling have been attributed to destratification of isolated refuge pools (MDBA 2019).

Biota are impacted by and respond differently to drought conditions because they each have a unique range of traits such as longevity, predator susceptibility, water quality tolerances and dispersal ability (McNeil, 2013). Some animals and plants, such as golden perch and river red gum, respond opportunistically once a drought breaks, using the initial flows to stimulate reproduction and rapidly dispersing through the river system. Drought-breaking flow events can therefore be critical to maintaining the long-term health and distribution of these populations.

Wetlands provide important feeding and breeding habitat for waterbirds, fish, frogs and other biota. Many native forest and wetland species rely on seasonal wet and dry periods to trigger seed production, germination and other processes. However, extended periods of drought can exceed the resilience of plant communities, severely damaging plants and root zones and depleting viable seed banks.

Drought-affected wetland communities can be less resilient to other disturbances such as disease or fire. For example, a fire in the northern Macquarie Marshes in October 2019 caused extensive damage to around 3,000 hectares of reedbed and river red gum woodland, already under severe drought stress. If core wetlands are not maintained it may lead to significant loss in fish populations supported in wetland areas of the Basin.

Extended drought can lead to the loss of important seedbanks, preventing wetland vegetation from recovering once conditions improve, reducing valuable habitat for other species (including fish) and reducing the overall ecological resilience. This can lead to invasion by terrestrial and other weed species, which further undermines the diversity and resilience of Basin ecosystems.

Appendix B. Flow targets for meeting critical ecological outcomes

The environmental flow targets identified for each valley include a set considered to be the absolute minimum to satisfy the critical water needs for the environment. These environmental flow targets sought to keep parts of the ecosystem alive long enough so that the river environment can recover when wetter conditions prevail. Flow targets were based on an absolute minimum base flow and included a single cumulative flow requirement. The second set introduced an additional duration component, and covered not only baseflows but a small and large fresh component, any of which can be achieved to consider the criteria to be met.

As mentioned in section 4.1.1, flow targets for meeting critical environmental needs were developed collaboratively with DPI – Fisheries. They were based on expert knowledge and known environmental water needs for native flora and fauna within the northern Basin.

The critical needs environmental flow targets were selected to:

- improve water quality in refugia pools
- provide connectivity and fish passage between isolated pools
- promote movement and spawning opportunities for native fish that rely on flow events as natural cues for reproduction (e.g. golden perch, silver perch and Murray cod)
- provide low-level lake fill for fish and other aquatic biota to support and maintain lake processes
- inundate inner-core wetland areas to maintain critical flow-dependent vegetation and wetland processes.

Critical pools, wetlands and other key habitat were identified for each valley, along with recommended critical flow targets (Appendix D). Flow gauging stations were selected to represent the needs of the river in each major valley, including the middle reaches and lower end of the system. Providing a range of gauges throughout each valley enabled decision-makers to track a flow event through a system and determine whether the event had met the relevant requirements at each gauge (see Valley maps in Appendix C). When predicting whether a flow will reach a downstream location, consideration had to be made for large river conveyance volumes that are experienced in extended dry periods. Following an extended drought, flow targets are calculated to allow for refilling pools, wetting riverbed and bank substrates, recharging connected alluvial aquifers, compensating for evaporation and extraction due to basic landholder rights.

Flow targets for critical environmental needs were only prioritised for regulated rivers and the Barwon–Darling River. This decision was based on two criteria:

- There are more management options available in these systems, allowing for more flexibility in managing the flows.
- The array of flow gauges on regulated rivers and the Barwon–Darling River is more comprehensive, providing more accurate and timely information for monitoring and controlling the progress of the flow event.

Flow targets to meet critical environmental needs were not developed for the Intersecting Streams because the above criteria could not be met. However, supplementary flow targets were used in this report in order to evaluate outcomes (Appendix D). The development of critical flow targets for these unregulated water sources will be considered during future events.

Information on critical drought refugia was collected by DPI – Fisheries as part of the Native Fish Drought Response 2019–20. Priority reaches were identified in each valley, and a combination of detailed habitat mapping and rapid assessment was used to estimate the number of refuge pools within each reach. This approach provides a good indication of the extent of critical habitat within

each valley and helped with setting flow targets. Critical drought refugia were identified in all the northern NSW Basin valleys except for the Intersecting Streams. Information on the Intersecting Streams will be prepared for future events. Information about the priority refugia in each valley is provided in Appendix D.

Appendix C. Chronology of restrictions, exemptions and supplementary flow events

This appendix provides information about the restrictions imposed and when these expired or were cancelled. Table C 1 contains a summary of the restrictions imposed across the valleys. Each valley map identifies the flow gauges that were used to monitor and assess whether flow targets had been met and whether restrictions could be relaxed. Flow targets for each valley are detailed in Appendix D. A map of the Intersecting Streams has not been included because flow gauges were not used to help manage the flow events.

Table C 1. Gazetted water restrictions and restriction exemptions

Valley	Restrictions	Exemptions
Intersecting Streams	**Temporary restriction placed from the 31st of January 2020**, on unregulated, regulated (high security) and regulated (general security) access licences.	None
Border Rivers	**Temporary restriction placed from the 17th of January 2020**, on unregulated, regulated (high security) and regulated (general security) access licences.	Regulated (high security) take exempt. Take from the unregulated water sources exempt from the 21st of February 2020. Regulated (general security) take exempt from the 23rd of February 2020.
	Temporary restriction of floodplain harvesting from the 12th of February 2020, in Lower Macintyre River, Whalan Creek, and Boomi River floodplains.	Floodplain harvesting in Lower Macintyre River, Whalan Creek, and Boomi River floodplains exempt from the 23rd of February 2020.
Gwydir	**Temporary restriction placed from the 17th of January 2020**, on unregulated, regulated (high security) and regulated (general security) access licences.	Take from Thalaba Creek and Millie Creek water sources exempt from the 8th February 2020. Take from Mehi River unregulated water source exempt from the 9th to the 12th of February 2020. Take from unregulated water sources exempt from the 21st of February 2020.
	Temporary restriction placed on floodplain harvesting from the 7th of February 2020, in the Gwydir Valley floodplain.	Floodplain harvesting from Mehi River, Barwon, and Thalaba Creek water source exempt from the 10th to the 13th of February 2020. Floodplain harvesting from Gwydir Valley floodplain exempt from the 21st of February 2020.
Namoi	**Temporary restriction placed from the 17th of February 2020**, on unregulated, regulated (high security) and regulated (general security) access licences.	Take in several water sources exempt for various periods between the 26th of January to the 28th of February 2020. Regulated (high security) take in the Namoi, Upper Namoi and Peel regulated water sources exempt from the 9th of February 2020. Regulated (general security) take from upper and lower Namoi water sources exempt from the 25th to the 28th of February 2020.
	Temporary restriction placed on floodplain harvesting from the 7th of February 2020, in the Lower Namoi Valley, Wee Waa, Upper Namoi Valley floodplains.	Floodplain harvesting from the Lower Namoi floodplain exempt 10th to the 13th of February 2020. Floodplain harvesting from the Lower Namoi and Wee Waa floodplains exempt from the 23rd of February 2020.
Macquarie	**Temporary restriction placed from the 17th of January 2020**, on unregulated, regulated (high security) and regulated (general security) access licences.	Take from unregulated water sources exempt from the 21st of February 2020.

Valley	Restrictions	Exemptions
	Temporary restriction placed from the 7th of February 2020, on floodplain harvesting from the Narromine to Oxley Station floodplain.	Floodplain harvesting from the Narromine to Oxley Station, Lower Macquarie floodplains exempt from the 21st of February 2020.
	Temporary restriction placed from the 12th of February 2020, on floodplain harvesting from the lower Macquarie floodplain.	None
Barwon-Darling	**Temporary restriction placed from the 17th of January 2020,** on unregulated, regulated (high security) and regulated (general security) access licences.	Unregulated access licences upstream of Culgoa Junction (management zones 1-9) exempt from 5pm 27 February 2020.
	Temporary restriction placed from the 7th of February 2020, on floodplain harvesting from the Barwon-Darling Valley floodplain.	Floodplain harvesting from the Pian Creek, Baradine Creek water sources exempt from the 10th to the 13th of February 2020.
	Temporary restriction placed on unregulated access licences and floodplain harvesting from the 29th of February to the 17th of April 2020, in the Culgoa River Junction to Bourke, Bourke to Louth, Louth to Tilpa, Tilpa to Wilcannia and Wilcannia to Upstream Lake Wetherell management zones.	None

Note: Temporary restrictions ended on the 28th of February 2020 unless otherwise stated.

Figure C 1 through to Figure C 5 show hydrographs for major flow gauges provided to help visualising the movement of flows through the system between 1 January and 19 April 2020 (before, during and after restrictions). The flow records for most gauges were obtained from the public website of WaterNSW (realtimedata.waternsw.com.au) between the 29 April and 1 May 2020. Storage records for the Menindee Lakes were obtained from the Bureau of Meteorology website (www.bom.gov.au/waterdata) on the 4 May 2020.

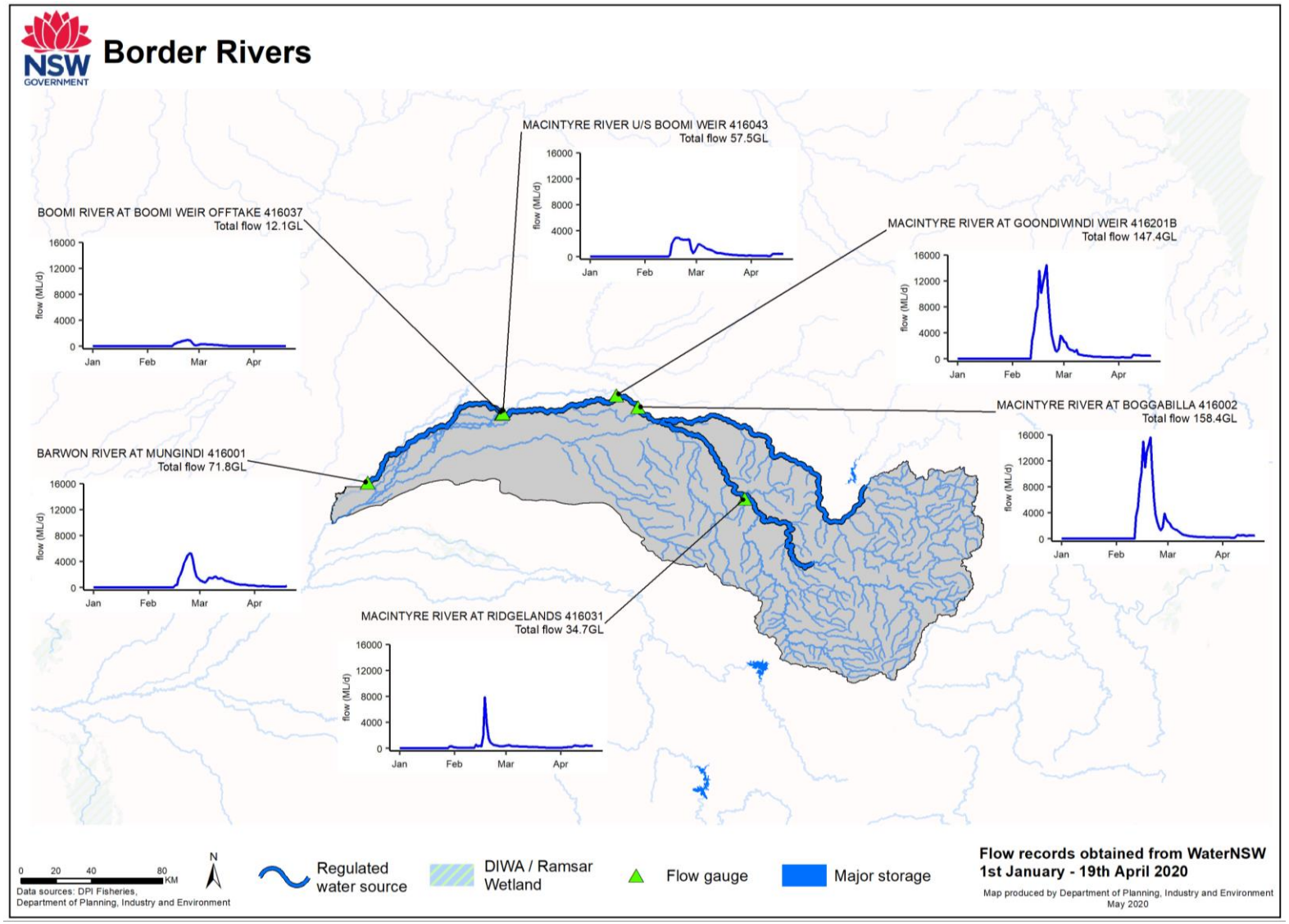

Figure C 1. Location of gauges and flow hydrographs used to set criteria in the Border Rivers.

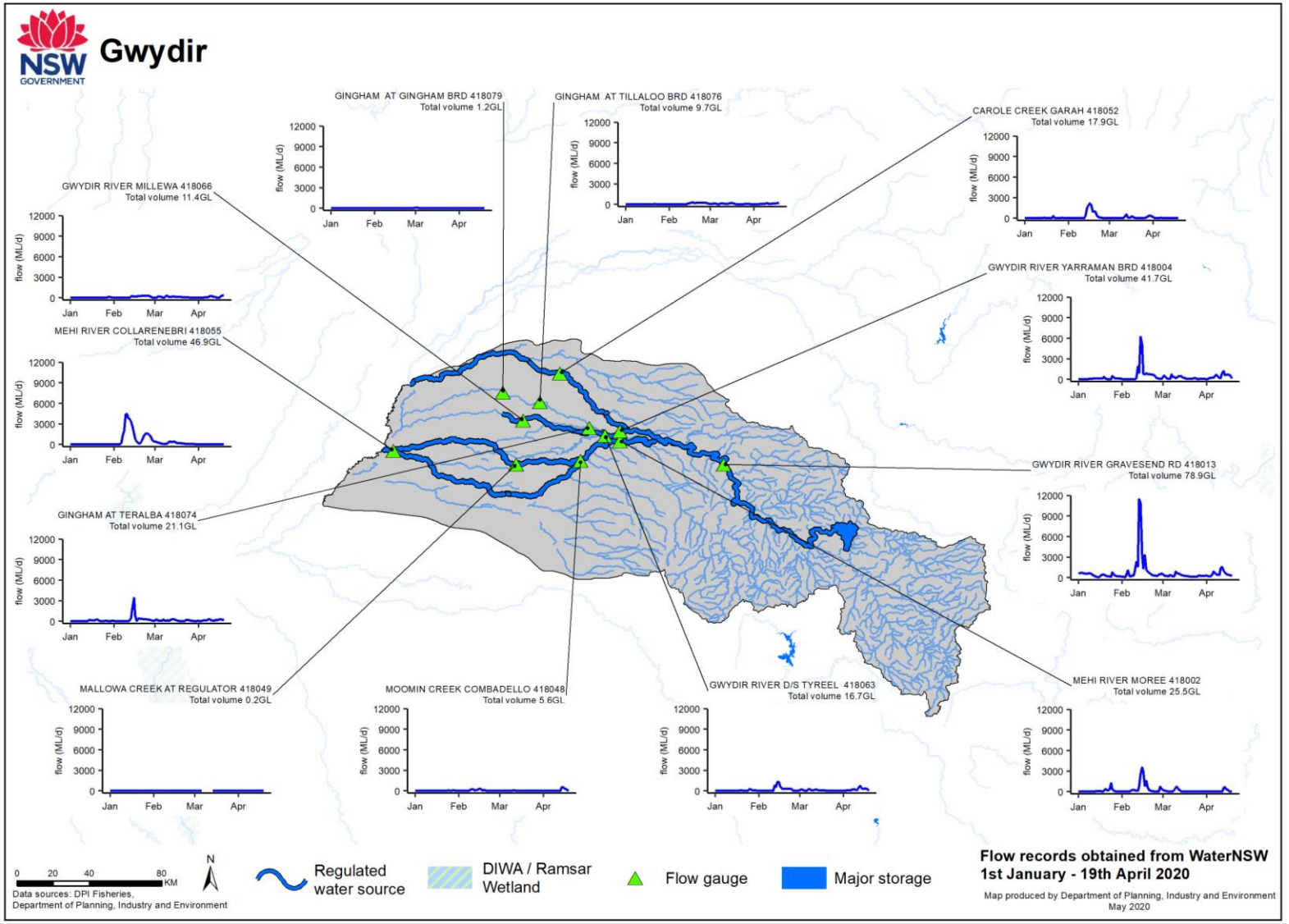

Figure C 2. Location of gauges and hydrographs used to set criteria in the Gwydir valley.
Note that recorded volumes at 418055 Mehi River at Collarenebri may be overestimated because of backwater effects on the Barwon River.

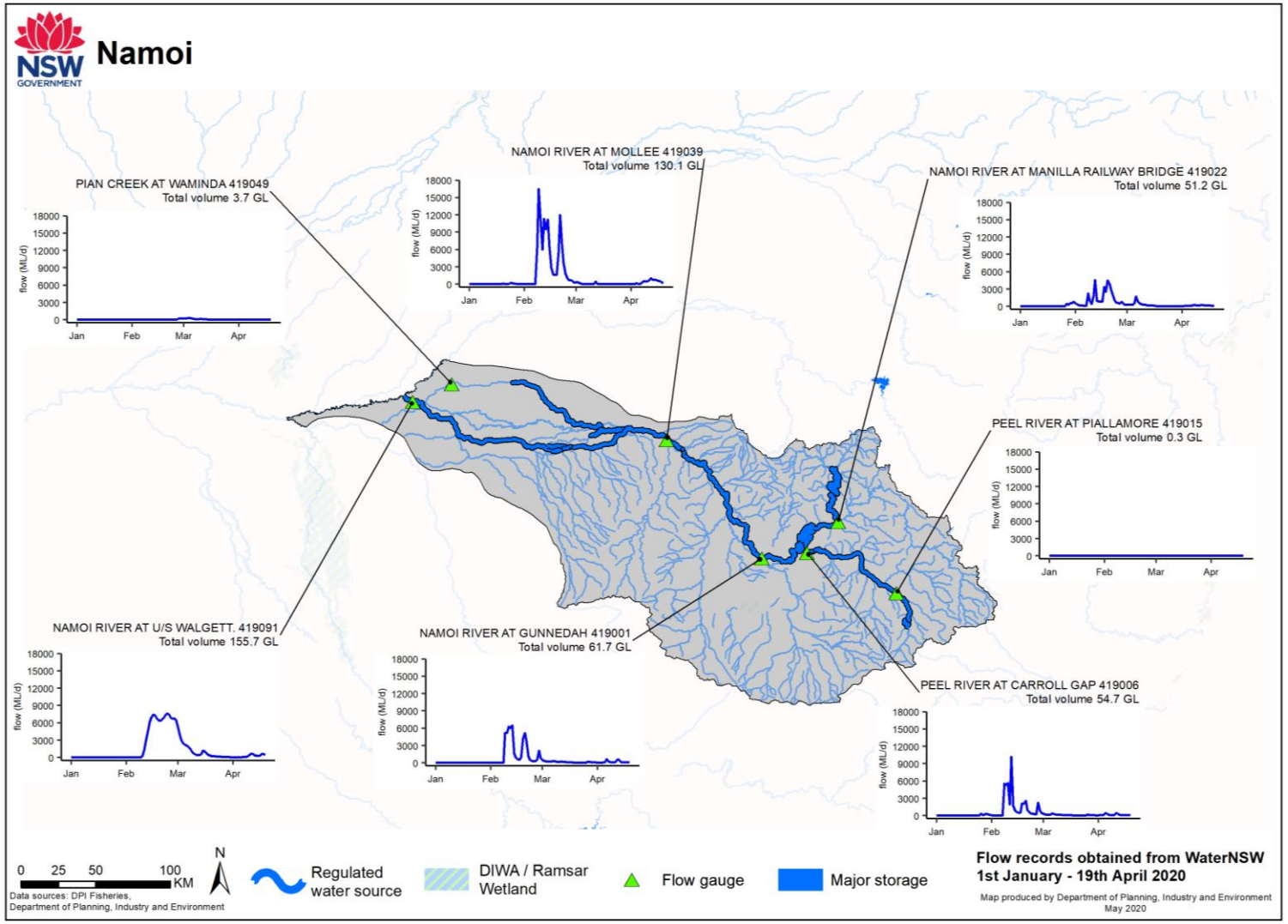

Figure C 3. Location of gauges and flow hydrographs used to set criteria in the Namoi valley.
Note that recorded volumes at 419091 Namoi River at Walgett may be overestimated because of backwater effects on the Barwon River

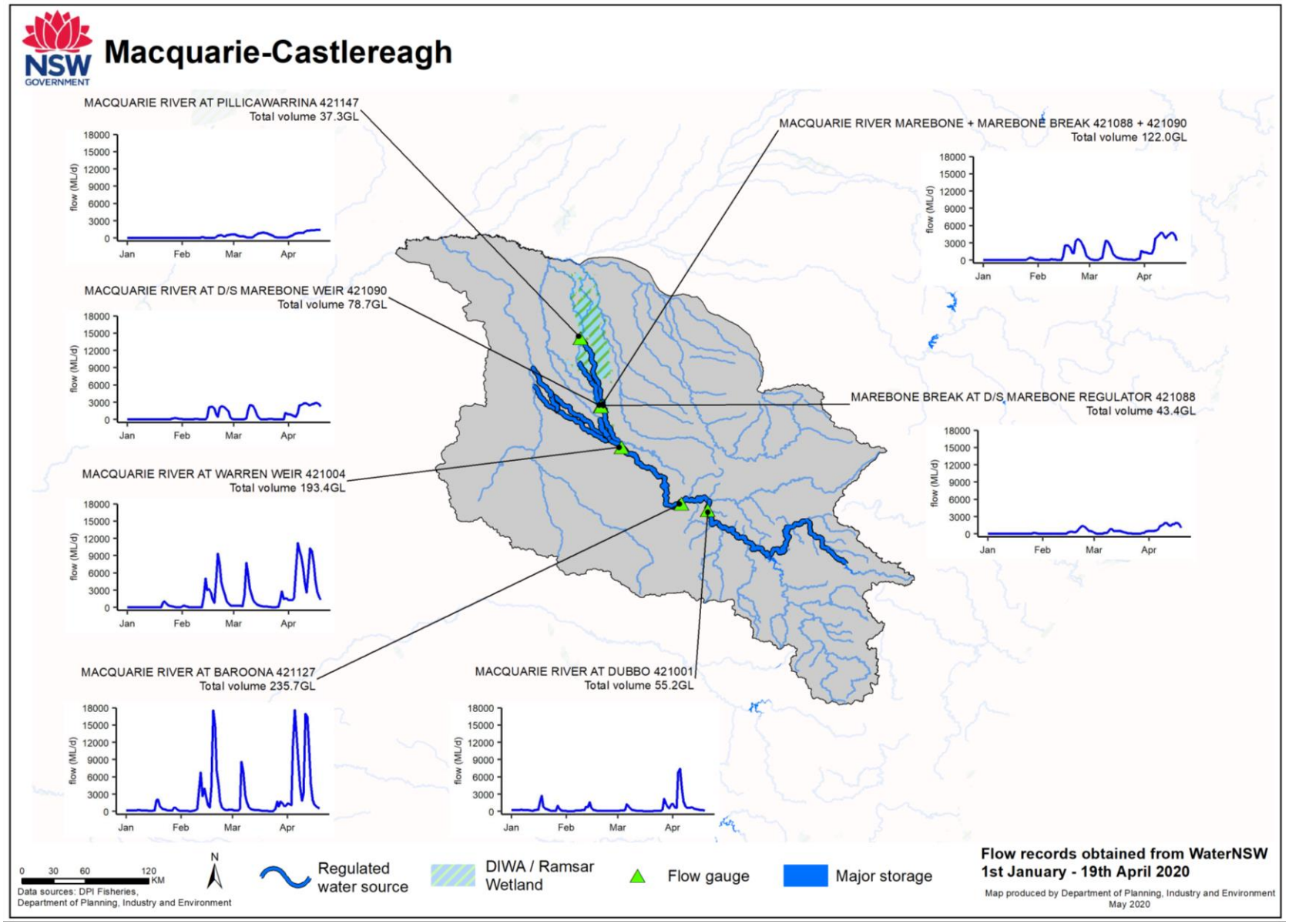

Figure C 4. Location of gauges and flow hydrographs used to set criteria in the Macquarie valley.

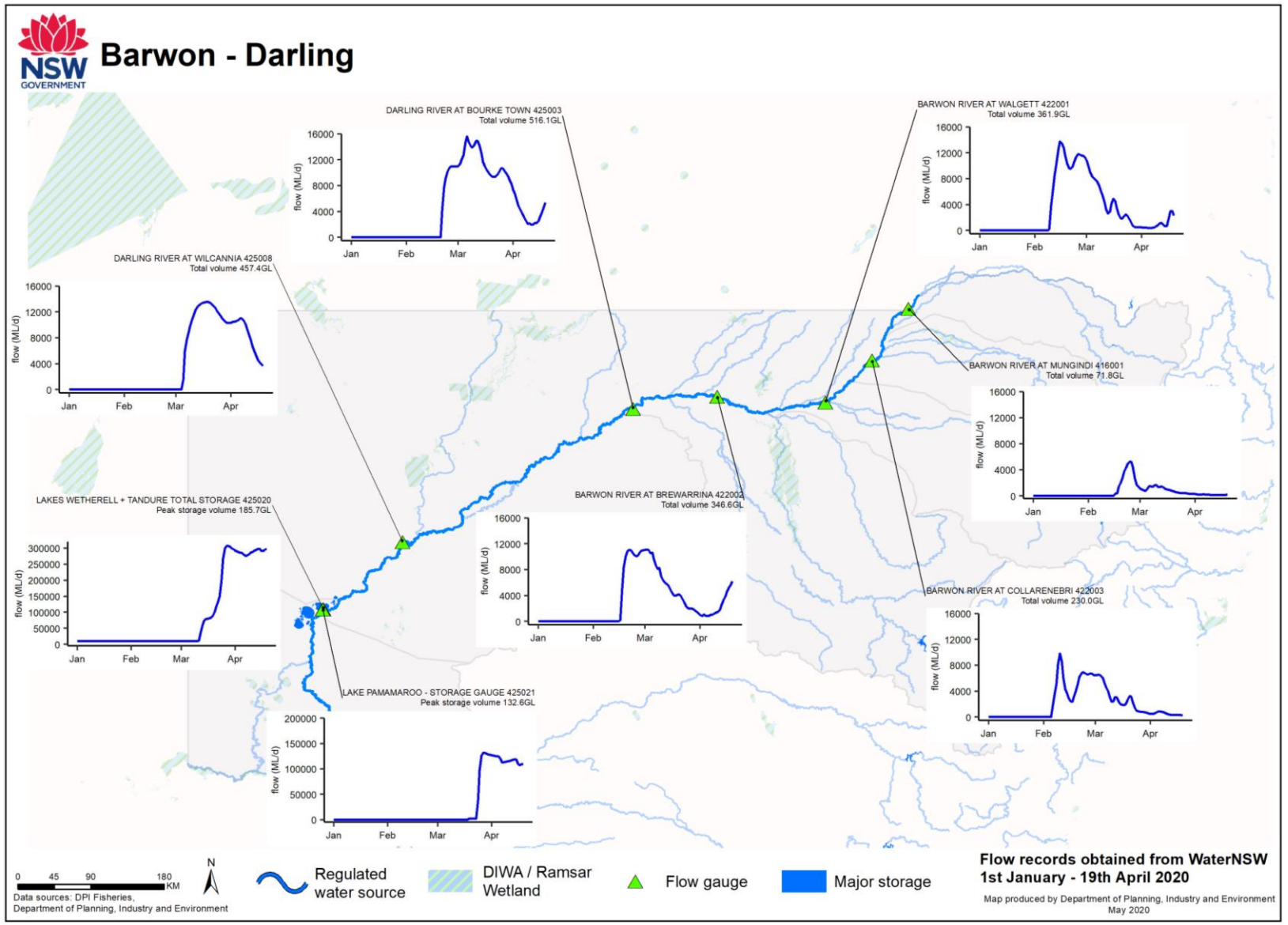

Figure C 5. Location of gauges and flow hydrographs used to set criteria in the Barwon–Darling valley.

Appendix D. Critical water needs and additional environmental water criteria

The criteria used to manage the water restrictions were based on estimates of the critical EWRs to maintain ecosystems so that they may recover when wetter conditions prevail. Additional criteria were also derived to assess whether longer duration flows, which can have multiple environmental benefits, were also provided as the event progressed and water restrictions were eased.

The criteria for longer duration flows were derived from the EWRs listed in each valley's Long Term Water Plan. Environmental Water Requirements are evidence-based recommendations about the flow requirements of flora and fauna within a management area. Aquatic organisms rely on a wide range of flows to trigger and support various stages in their life history, hence *Long Term Water Plans* contain a range of EWRs. Each EWR will provide beneficial outcomes to multiple species and ecosystems.

It is important to note that management decisions were not based on whether these additional criteria had been met. They are included in this analysis because they are an important component for assessing the environmental outcomes

Table D 1 through to Table D 7 indicate if and when criteria were met at target locations.

Table D 1. Critical water needs criteria – Gwydir valley.

Target location	Critical water needs	Date criteria met
Gwydir at Gravesend 418013	4,400 ML	7/01/2020
Gwydir at Yarraman 418004	2,400 ML	25/01/2020
Gwydir DS Tyreel 418063	1,000 ML	27/01/2020
Gwydir at Millewa 418066 Wetland Flow 1 (annual)	6,000 ML	8/03/2020
Gwydir at Allambie 418078 Wetland flow 2 (2 yearly)	36,000 GL	Criteria not achieved
Gingham at Teralba 418074	1,000 ML	19/01/2020
Central Gingham at Tillaloo 418076 (annual)	15 GL	Criteria not achieved
Central Gingham at Tillaloo 418076 (2 yearly)	30 GL	Criteria not achieved
Lower Gingham at Gingham Brd 418079 (annual)	3GL	Criteria not achieved
Lower Gingham at Gingham Brd 418079 (2 yearly)	15GL	Criteria not achieved
Mehi at Moree 418002	1,300 ML	21/01/2020
Mehi near Collarenebri 418055	400 ML	7/02/2020
Moomin Creek at Combadello 418048	300 ML	25/01/2020
Mehi and Mallowa wetlands (418049)	3 GL	Criteria not achieved
Mehi and Mallowa wetlands (418049)	8 GL	Criteria not achieved
Mallowa creek at regulator 418049	100 ML	15/03/2020
Carole near Garah 418052	700 ML	22/01/2020

Table D 2. Critical water needs criteria – Namoi valley.

Target location	Critical water needs	Date criteria met
Namoi River at Manilla (gauge 419022)	700 ML	28/01/2020
Namoi River at Gunnedah (gauge 419001)	2,000 ML	9/02/2020
Namoi River at Mollee (gauge 419039)	2,000 ML	8/02/2020
Namoi River upstream of Walgett (gauge 419091)	300 ML	10/02/2020
Pian Creek at Waminda (gauge 419049)	500 ML	20/01/2020
Peel River at Piallamore (gauge 419015)	1,000 ML	Criteria not achieved
Peel River at Carroll (gauge 419006)	1,000 ML	29/01/2020

Table D 3. Critical water needs criteria – Macquarie valley.

Target location	Critical water needs	Date criteria met
Macquarie at Baroona (421127)	2,000 ML	18/01/2020
Macquarie at Dubbo (421001)	2,000 ML	18/01/2020
Baroona to Warren Macquarie at Warren Weir (421004)	2,000 ML	23/01/2020
Warren to Macquarie Marshes (@combined Marebone Break & Macquarie River below Marebone gauges) 421088 + 421090	1,000 ML	28/01/2020
Whole of Macquarie Marshes wetland flows – Northern, Southern & Eastern Marshes (@combined Macquarie River & Marebone Break below Marebone gauges) 421088 + 421090	650 ML	28/01/2020
Whole of Macquarie Marshes wetland flows – Northern, Southern & Eastern Marshes (@combined Macquarie River & Marebone Break below Marebone gauges) 421088 + 421090	For core wetlands (small overbank/ wetland 1): 60,000 ML 18mths - 2 years	No - as of 31/03/2020 (57,937 ML)

Table D 4. Critical water needs criteria – Barwon–Darling valley.

Target location	Critical water needs	Date criteria met
Barwon River at Collarenebri 422003	2,800 ML	7/02/2020
Barwon River at Dangar Bridge 422001	3,200 ML	10/02/2020
Barwon River at Brewarrina 422002	5,000 ML	17/02/2020
Darling River at Bourke 425003	5,000 ML	22/02/2020
Darling River at Wilcannia 425008	3,500 ML	6/03/2020

Table D 5. Critical water needs criteria – Border Rivers valley.

Target location	Critical water needs	Date criteria met
Severn River at Ashford 416006	400 ML	26/01/2020
Macintyre River at Ridgelands 416031	2,100 ML	14/02/2020
Macintyre at Boggabilla 416002	2,300 ML	12/02/2020
Macintyre at Goondiwindi 416201A	1,200 ML	12/02/2020
Macintyre u/s Boomi 416043	600 ML	16/02/2020
Boomi River at Boomi Weir Offtake 416037	50 ML	15/02/2020
Barwon River at Mungindi 416001	3,000 ML	19/02/2020

Table D 6. Additional environmental water outcomes (in-stream) – Intersecting Streams valley.

Target location	Baseflow	Date criteria met
Moonie River at Gundablouie 417001	>30 ML/d (9 days) = 270 ML	11/02/2020
Narran River at Wilby Wilby 422016	>126 ML/d (6 days) = 756 ML	03/03/2020
Culgoa River at Brenda 422015	>50 ML/d (93 days) = 4650 ML	Criteria not achieved
Birrie River at Googooga 422013	>50 ML/day (6 days) = 300 ML	19/02/2020
Bokhara River at Bokhara (Goodwins) 422005	>30 ML/d (1 day) = 30 ML	08/03/2020
Yantabulla Swamp/Wetland on the Cuttaburra Creek at Turra 423005	not defined	NA
Warrego River at Barringun 423004	not defined	NA

Table D 7. Additional environmental water outcomes (wetland inundation) – Intersecting Streams valley.

Target location	Small wetland inundation WL1	Date criteria met
Narran Lakes at Wilby Wilby 422016	Cumulative volume of 25 GL within 60 days	08/03/2020
Yantabulla Swamp/Wetland on the Cuttaburra Creek at Turra 423005	Cumulative volume of 82,548 ML within 260 days	07/03/2020
Western floodplain at Toorale at the combined Fords Bridge 423001 and Fords Bridge Bywash 423002	Cumulative volume of 7,000 ML within 30 days	16/03/2020

Appendix E. High priority drought refugia and connecting flow events

Table E 1 through to Table E 5 provide details of refugia zones in each valley, including the number of estimated refugia and the likelihood that flows were able to achieve connectivity and rejuvenate pool conditions. For all tables, Italics represents preliminary data from rapid refugia assessment undertaken by NSW DPI as part of the Native Fish Drought Response 2019–20. It should not be considered comprehensive for the zone. All other data is detailed habitat mapping undertaken by NSW DPI (2012). Flow records obtained from WaterNSW, May 2020.

Table E 1. High priority drought refugia and likelihood of connecting flow events – Border Rivers valley

Zone and flow reference gauge	Zone length (km)	Total number of pools	Total surface area (ha)	Mean depth (m)	Likelihood of small fresh EWR/20th percentile flow events (LTPW = Long-term water plan)
Dumaresq River (Pike Ck to -28.835567S, 151.089217) 416011 Dumaresq River at Roseneath	97.7	47	14.7	3.45	**Likely** – Continuous flows from 11 Feb to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Dumaresq River (-28.835567S, 151.089217 to Macintyre River confluence) 416007 Dumaresq River at Bonshaw	95.1	42	18.74	4.02	**Likely** – Continuous flows from 11 Feb to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Dumaresq/Macintyre River confluence to Mungindi 416002 Macintyre River at Bogabilla	*275*	*21*	-	-	**Likely** – Continuous flows from 9 Feb to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Pindari Dam to -29.16804S, 151.06416 416006 Severn River at Ashford	*57*	*54*	*2.48*	*3.16*	**Likely** – Continuous flows from 18 Jan to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Severn River at -29.16804S, 151.06416 to Macintyre River confluence 416006 Severn River at Ashford	*18*	*2*	-	-	**Likely** – Continuous flows from 18 Jan to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Severn River at -29.46754, 151.48118 to Pindari Dam 416039 Severn River at Strathbogie	*32*	*4*	-	-	**Likely** – Continuous flows from 27 Jan to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Tenterfield Creek at -29.03058S, 151.773451 to Dumaresq River confluence 416003 Tenterfield Creek at Clifton	*43*	*4*	-	-	**Likely** – Continuous flows from 19 Jan to 1 Feb, then from 9 Feb to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Mole River from -29.10086S, 151.74622 to Dumaresq River confluence 416032 Mole River at Donaldson	*35*	*3*	-	-	**Likely** – Continuous flows from 25 Jan to 19 Apr 2020. LTWP small fresh EWRs were met at least once.

Table E 2. High priority drought refugia and likelihood of connecting flow events – Gwydir valley

Zone and flow reference gauge	Zone length (km)	Total number of pools	Total surface area (ha)	Mean depth (m)	Likelihood of small fresh EWR/20th percentile flow events (LTPW = Long-term water plan)
Gwydir River from -30.67075S, 151.45117 to Copeton Dam 418008 Gwydir River at Bundarra	*86*	*10*	-	-	**Likely** – Flows commenced on 11 Jan, flow events in Jan, Feb and Apr 2020. Flows exceeded 20th percentile >10 days.
Gwydir (Tyreel to Brageen Crossing) 418066 Gwydir River at Millewa	62	12	0.71	2.21	**Possible** – Flows commenced on 28 Jan and continued past 19 Apr 2020. LTWP baseflow EWRs were met at least once, but small fresh EWRs not defined in LTWP.
Gwydir (Copeton to Gwydir Raft pool) 418013 Gwydir River at Gravesend Road Bridge	*185*	*14*	-	-	**Likely** – Continuous flows from on 1 Jan to 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Mehi (Tareelaroi to Gundare) 418037 Mehi River D/S Combadello	84	18	0.78	2.15	**Likely** – Flows commenced on 16 Jan with flow events in Jan, Feb and Mar 2020. LTWP small fresh EWRs were met at least once.
Mehi (Tareelaroi to Mehi Weir) 418002 Mehi River at Moree	*141*	*7*	-	-	**Likely** – Flows commenced on 9 Jan with flow events in Jan, Feb, Mar and Apr 2020. LTWP small fresh EWRs were met at least once.
Moomin Creek (Combadello to Telleraga Rd) 418048 Moomin Creek at Combadello	*35*	*4*	-	-	**Likely** – Flows commenced on 17 Jan with flow events in Jan, Feb, Mar and Apr 2020. LTWP small fresh EWRs were met at least once.
Carole (Carole Ck Reg. to Garah) 418052 Carole Creek at Garah	70	*15*	0.12	1.64	**Possible** – Flows commenced on 15 Jan with one large event in Feb 2020. LTWP small fresh EWRs were met at least once.
Horton River from - 30.288659S, 150.392296 to confluence with Gwydir River 418015 Horton River at Rider	100	71	5.73	1.7	**Likely** – Flows commenced on 25 Jan, small events in Jan, Feb and Apr 2020. Flows exceeded 20th percentile >10 days.
Halls Creek from -29.99014S, 150.59424 to Gwydir River confluence 418025 Halls Creek at Bingara	*14*	*2*	-	-	**Likely** – Flows commenced on 18 Jan, small events in Jan, Feb and Apr 2020. Flows exceeded 20th percentile >10 days.
Myall Creek from -29.77277S, 150.79834 to Gwydir River confluence 418017 Myall Creek at Molroy	*41*	*3*	-	-	**Possible** – Flows commenced on Jan 17 but were intermittent. One event in Jan and one in Feb 2020. Flows exceeded 20th percentile >10 days.

Table E 3. High priority drought refugia and likelihood of connecting flow events – Namoi valley.

Zone and flow reference gauge	Zone length (km)	Total number of pools	Total surface area (ha)	Mean depth (m)	Likelihood of small fresh EWR/20th percentile flow events (LTPW = Long-term water plan)
Upper Namoi 419022 Namoi River at Manilla	*55*	*4*	-	*3.28*	**Likely** – Flows commenced on 21 Jan, several flow events in Feb 2020. LTWP small fresh EWRs were met at least once.
Lower Namoi (downstream of Wee Waa to Goangra) 419026 Namoi River at Goangra	*130*	*22*	-	*0.85*	**Likely** – Flows commenced on 10 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Peel River (downstream Chaffey Dam to Carrol Gap) 419006 Peel River at Carrol Gap	*130*	*24*	-	*2.04*	**Likely** – Flows commenced on 27 Jan and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Namoi River (Carrol to Gunnedah) 419001 Namoi River at Gunnedah	40	22	-	3.76	**Likely** – Flows commenced on 9 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Namoi River (Gunnedah to Boggabri) 419012 Namoi River at Boggabri	60	92	-	3.58	**Likely** – Small flows from 19 Jan to 3 Feb, large flow event commenced 9 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Namoi River (Boggabri to Narrabri) 419039 Namoi River at Mollee	90	80	-	3.24	**Likely** – First flow event commenced 20 Jan to 1 Feb, next event 9 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Namoi River (Narrabri to Mollee Weir) 419039 Namoi River at Mollee	15	11	-	3.58	**Likely** – First flow event commenced 20 Jan to 1 Feb, next event 9 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.

Table E 4. High priority drought refugia and likelihood of connecting flow events – Macquarie valley.

Zone and flow reference gauge	Zone length (km)	Total number of pools	Total surface area (ha)	Mean depth (m)	Likelihood of small fresh EWR/20th percentile flow events (LTPW = Long-term water plan)
Burrendong to Baroona 421001 Macquarie River at Dubbo	162.3	65	16.26	3.69	**Likely** – Continuous flows between 1 Jan and 19 Apr, flow events in Jan, Feb, Mar and Apr 2020. LTWP small fresh EWRs were met at least once.
Baroona to Warren 421004 Macquarie River at Warren Weir	156.3	88	5.95	4.42	**Likely** – Flows commenced on 22 Jan to 6 Feb, then 12 Feb past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Warren to Marebone 421090 Macquarie River at D/S Marebone Weir	72.3	81	3.19	3.01	**Likely** – Flows commenced on 27 Jan and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Marebone to Oxley 421022 Macquarie River at Oxley	82.6	71	1.71	2.1	**Likely** – Flows commenced on 6 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Oxley to Barwon River 421012 Macquarie River at Carinda	186.7	0	0	0	**Possible** – Continuous flow between Feb 29 and Mar 23, then Apr 4 to 19 Apr 2020. LTWP baseflow EWR conditions were met at least once, but small fresh EWR was not met.

Table E 5. High priority drought refugia and likelihood of connecting flow events – Barwon-Darling valley.

Zone and flow reference gauge	Zone length (km)	Total number of pools	Total surface area (ha)	Mean depth (m)	Likelihood of small fresh EWR/20th percentile flow events (LTPW = Long-term water plan)
Mungindi to Boomi confluence 422004 Barwon River at Mogil Mogil	60.5	26	1.79	2.57	**Likely** – Flows commenced on 27 Jan and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Boomi confluence to Collarenebri Weir 422003 Barwon River at Collarenebri	99.8	121	25.16	3.35	**Likely** – Flows commenced on 7 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Collarenebri Weir to Walgett 422001 Barwon River at Dangar Bridge (Walgett)	128.3	80	16.33	3.13	**Likely** – Flows commenced on 11 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Walgett to Brewarrina 422002 Barwon River at Brewarrina	279	297	51.5	5.1	**Likely** – Flows commenced on 17 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Brewarrina to Bourke 425003 Darling River at Bourke Town	207	216	55.9	4.5	**Likely** – Flows commenced on 23 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Bourke to Tilpa 425900 Darling River at Tilpa	355	374	157	4.7	**Likely** – Flows commenced on 29 Feb and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.
Tilpa to Wilcannia 425008 Darling River at Wilcannia	275	182	65.1	4.5	**Likely** – Flows commenced on 7 Mar and continued past 19 Apr 2020. LTWP small fresh EWRs were met at least once.