Department of Climate Change, Energy, the Environment and Water

Long-term trends in floodplain pool inundation in the northern Murray–Darling Basin

Reporting for the Environmental Outcome Monitoring and Research Program

October 2025

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the traditional custodians of the land and pays respect to Elders past, present and future.

We recognise Australian Aboriginal and Torres Strait Islander peoples' unique cultural and spiritual relationships to place and their rich contribution to society.

Artist and designer Nikita Ridgeway from Aboriginal design agency – Boss Lady Creative Designs, created the People and Community symbol.

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Contents

Abbreviations and Acronyms

Abbreviation/Acronym	Description
Basin Plan	Murray–Darling Basin Plan 2012
BOM	Bureau of Meteorology
DEA	Digital Earth Australia
EOMRP	Environmental Outcomes Monitoring and Research Program
Floodplain pool	Floodplain pools include lagoons, billabongs, waterholes, cowals, swamps, and some in-channel pools within ephemeral floodplain channels.
FMP	Floodplain Management Plan
mNDWI	Modified Normalized Difference Water Index
NSW	New South Wales
SILO	Scientific Information for Land Owners

Executive summary

This document presents a comprehensive analysis of long-term trends in floodplain pool inundation and their ecological importance for fauna in the northern Murray–Darling Basin. It summarises the work undertaken as part of the Environmental Outcomes Monitoring and Research Program (EOMRP) between July 2022 and June 2024, including key findings related to floodplain pools.

The EOMRP provides critical information to support multiple functions of the Water Group within the NSW Department of Climate Change, Energy, the Environment and Water. This includes fulfilling NSW's reporting obligations under Basin Plan Schedule 12, supporting research into environmental performance indicators, and informing the development and evaluation of water sharing and floodplain management plans.

Figure 1: Department staff sampling environmental DNA at Baroona Waterhole, Gwydir catchment. Photo credit: Daniel Coleman

This project advances our understanding of how water management affects the inundation patterns, water retention, and ecology of floodplain pool environments such as lagoons, waterholes, cowals, billabongs, warrambools, lakes and anabranch pools. These habitats support water-dependent fauna, particularly as refugia between flood events, and serve as productivity hotspots within a mosaic of terrestrial and aquatic systems.

A key outcome of this project is the establishment of a robust baseline dataset on floodplain pool inundation and ecology in the northern Murray–Darling Basin valleys, which comprises the Barwon-Darling, NSW Border Rivers, Namoi, Gwydir and Macquarie. This baseline provides a reference point from which to assess the effectiveness of future floodplain management reforms such as the Healthy Floodplains Project, and ongoing water management interventions aimed at improving floodplain connectivity and ensuring water use remains within legal limits.

An automated remote sensing approach was developed to assess floodplain pool water surface area change between 1987 and 2024 on an identified subset of 212 floodplain pools across the northern Murray–Darling Basin. Long-term trends reveal significant declines in monthly floodplain pool water surface area, mean and maximum monthly river flow, mean monthly rainfall, while water surface areas within on-farm storages, and maximum air temperatures have significantly increased.

Broadly, implementation of the Basin Plan has had a limited impact on floodplain pool water surface area trends outside of the core targeted environmental water sites. However, there is strong evidence that environmental water delivery, supported by the Basin Plan and water sharing plans has led to substantial improvements in surface water extent within key wetlands like the Macquarie Marshes and Gwydir Wetlands. The automated method developed in this project enables ongoing, effective monitoring to support evaluation of the Basin Plan, NSW floodplain harvesting policy, water sharing plans, and floodplain management strategies into the future.

A subset of 35 floodplain pools across the Barwon-Darling, NSW Border Rivers, Gwydir and Namoi valleys were prioritised for a detailed site-based assessment of floodplain pool habitat and occurrence of water-dependent fauna. Environmental DNA (eDNA) sampling revealed the presence of 75 different taxa, with 40 water-dependent fauna including native fish, waterbirds, turtles, frogs and rakali (Figure 1). Most pools support medium-to large-bodied fish, including golden perch, spangled perch and bony bream, and a diversity of waterbirds. The association between key floodplain pool characteristics - such as time since connection, depth, size and persistence - and diversity or presence of individual taxa was not as pronounced as hypothesised. Nevertheless, the diversity of taxa present demonstrates the importance of floodplain pools as habitat for water-dependent species in the northern Murray–Darling Basin.

1 Background

There are a range of aquatic floodplain refuge habitats in the northern Murray–Darling Basin. In this report, they are collectively referred to as floodplain pools, and can be lagoons, waterholes, cowals, billabongs, warrambools, lakes, and some in-channel pools within floodplain channels (Figure 2 and Figure 3). Floodplain pools are an important habitat for fish, waterbirds, rakali (water rat), reptiles, frogs, and other terrestrial fauna species. However, regulation of river flows by dams, floodplain structures, and channelling of water into storages can disrupt connectivity and change the timing, frequency and duration of inundation events in these habitats. This has resulted in floodplain environments being some of the most heavily altered water-dependent ecosystems in NSW (Reid & Brooks, 2000; Bunn & Arthington, 2002; NSW Threatened Species Scientific Committee, 2019).

Figure 2: Gulligal Lagoon in the Namoi catchment. Floodplain lagoons in the northern Murray–Darling Basin provide an important habitat refuge within a highly modified landscape. Photo credit: Tim Haeusler

The majority of monitoring and research within the floodplains of the Murray–Darling Basin has focussed on broad spatial scale inundation changes and ecological responses within the major wetland habitats (Page *et al.*, 2005; Frazier & Page, 2006; Steinfeld & Kingsford, 2013). To date, there has been little focus on the smaller, discrete floodplain pools, which are not part of the core floodplain wetlands but provide important aquatic refuge between floods. The physical (size, shape, depth, etc.) and hydrological characteristics (for example, water persistence, inundation regime) of these floodplain pool habitats varies substantially among pools. Documenting the distribution of floodplain pools, assessing long-term changes to inundation and water retention, and understanding what aquatic animals use these pools are critical to evaluating the influence of current water management actions and identifying future changes that may be required to protect and enhance these habitats within NSW.

Figure 3: Examples of the diversity in form and landscapes of floodplain pools in the northern Murray–Darling Basin. Source: Google Earth imagery

1.1 Water management for floodplains in NSW

1.1.1 The environmental objectives for floodplains

There are a range of environmental objectives listed in state and federal legislation. However, the overall environmental objectives within Part 2 (8.04) of the Basin Plan 2012 and Chapter 1 (3b) of the *Water Management Act 2000* can be summarised as a focus on the protection and restoration of water-dependent ecosystems within water sources of the Murray–Darling Basin (Table 8 in Appendix 7.1 for more detail). The mechanisms to achieve these objectives are summarised below.

1.1.2 The Water Management Act 2000

The NSW Government has two key mechanisms under the *Water Management Act 2000* to manage water on the floodplains of inland NSW:

1. floodplain diversions (water volume) are managed by water sharing plans under the framework of the Floodplain Harvesting Policy
2. flood works, or structures (water passage) on the floodplain are managed by floodplain management plans.

Harvesting of water from floodplains can reduce the volume, frequency and duration of floods and change the timing of these events, impacting on the health of floodplain environments and downstream waterways.

The Floodplain Harvesting Policy was introduced to restrict unconstrained growth of floodplain harvesting and integrate the activity into the water licensing framework, in compliance with the requirements of the *Water Management Act 2000*. Licensing and measuring the take of water from the floodplain is the only way to manage overall extraction within legal limits and prevent overuse. This will improve water resource management in NSW, enabling more effective protection of the environment increasing reliability of water supply for downstream water users.

1.1.3 The Basin Plan 2012

The Basin Plan was introduced to provide a framework to achieve a healthy, working Murray–Darling Basin. It provides several mechanisms to improve floodplain environments. These include:

- setting the Sustainable Diversion Limits (SDLs), which limit the annual extraction of water from valleys within the Basin
- returning some of these annual extractions to the environment through water buy backs
- infrastructure development to help deliver water for the environment more effectively.

1.2 Project aims

This project aims to improve our understanding of the influence of water management on the inundation history, water retention, and ecology of floodplain pools in the northern Murray–Darling Basin.

This is done by assessing the long-term trends of surface water area (that is, inundation or retention of water) in floodplain pools alongside water resource development (for example, on-farm storages) and climate variables (for example, rainfall) using satellite imagery back to 1987. In addition, field surveys of water-dependent fauna using eDNA are used to document the ecosystems supported by floodplain pools, and the influence of pool characteristics on the presence of key species. The results will contribute to the monitoring and evaluation of floodplain environments as required under the *Water Management Act 2000*, the Basin Plan 2012, the Floodplain Harvesting Policy and instruments such as floodplain management plans and water sharing plans.

The specific aims and associated research questions were:

1. **To identify key floodplain pools in the northern Murray–Darling Basin**

Q1. How many notable floodplain pools are there in the northern Murray–Darling Basin and where are they?

2. **To quantify the history of inundation and persistence of these floodplain pools using water surface area within floodplain pools**

Q1. What are the long-term changes in water surface area for floodplain pools across the northern Murray–Darling Basin and are the changes associated with climate and/or water use?

Q2. Has the Basin Plan contributed to improving the water surface area of floodplain pools in the northern Murray–Darling Basin?

3. **To understand what water-dependent fauna use floodplain pools and the importance of connectivity and inundation**

Q1. What fauna do floodplain pools support in the northern Murray–Darling Basin?

Q2. What is the influence of floodplain pool characteristics on the presence of key fauna species in floodplain pools?

1.3 Study area

The NSW component of the northern Murray–Darling Basin encompasses a number of water sharing plan and floodplain management plan areas, which all have various levels of connectivity to the Barwon-Darling valley). The water resources within the region support an array of environmental and cultural assets, social amenities, and economic activities.

Floodplain environments are an important subset of the environmental assets and values within each valley. They support a range of water-dependent fauna, including waterbirds, native fish, turtles, frogs, and other mammals and reptiles. They also support a large variety of vegetation species and terrestrial animals that benefit from the habitat and food resources generated by floodplain inundation. This project focuses on the floodplain pools that remain after floodwaters recede within the NSW Border Rivers, Namoi, Gwydir and Barwon-Darling catchments in the northern Murray–Darling Basin (Figure 4).

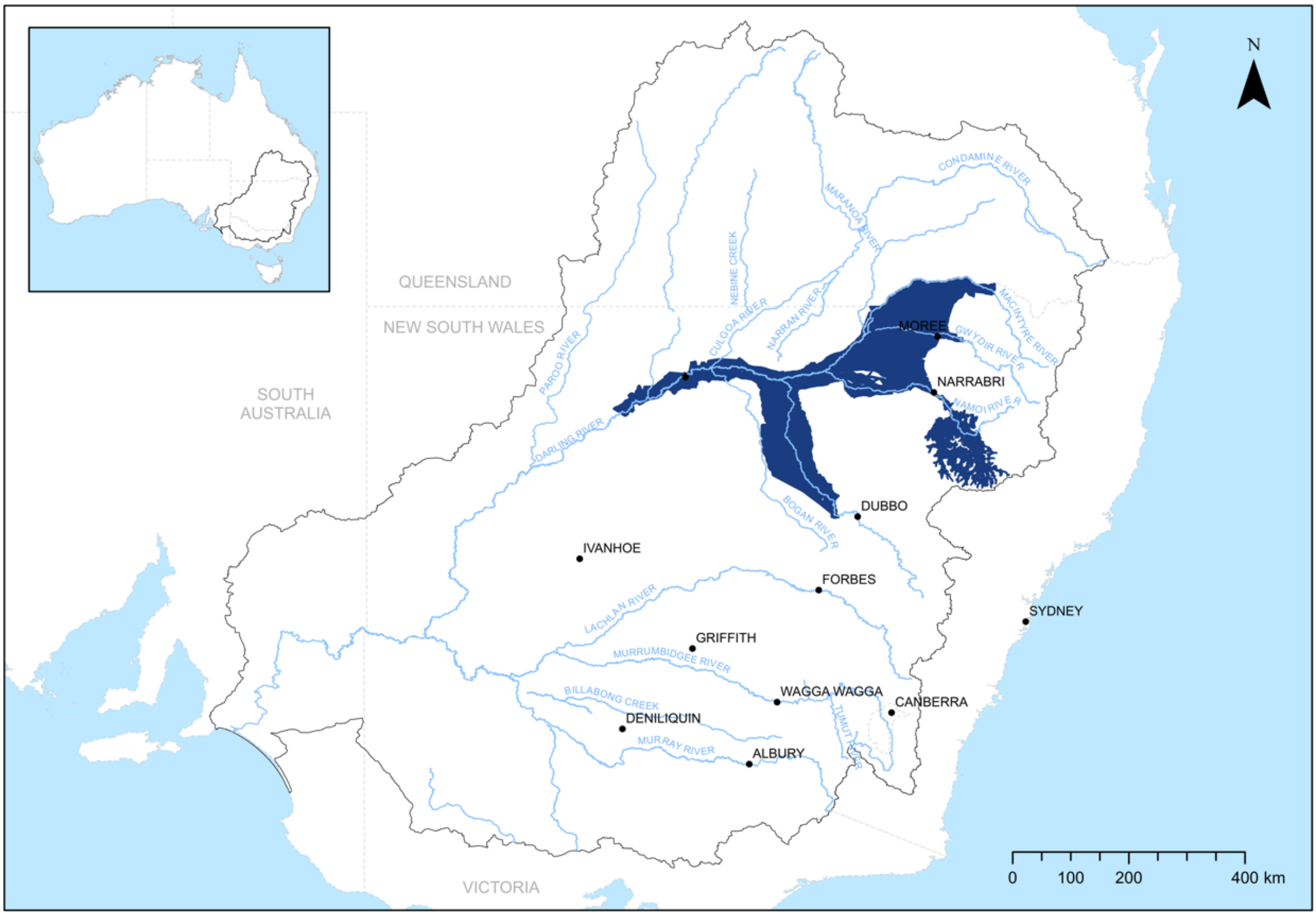

Figure 4: Map of the Murray–Darling Basin. Study area, consisting of the NSW Border Rivers, Namoi, Gwydir, Barwon-Darling and Macquarie floodplain environments

1.4 Rainfall

The northern Murray–Darling Basin spans semi-arid, temperate and subtropical climatic zones with variable rainfall patterns. Drought and floods are a normal component of the region's climate, and can drive broad scale patterns in river flow, particularly in relation to the large overbank events that are important to floodplain environments within the region. The study period for the field component of this study (2021–23) covers a La Niña period, which resulted in above average rainfall across a large spatial extent. In contrast, rainfall was well below average before the study period, with the lowest rainfall on record driving widespread drought that peaked in 2019. The remote sensing study period covers a much larger period, from 1 May 1987 to the end of April 2024. Average monthly rainfall varied substantially across this period (Figure 5).

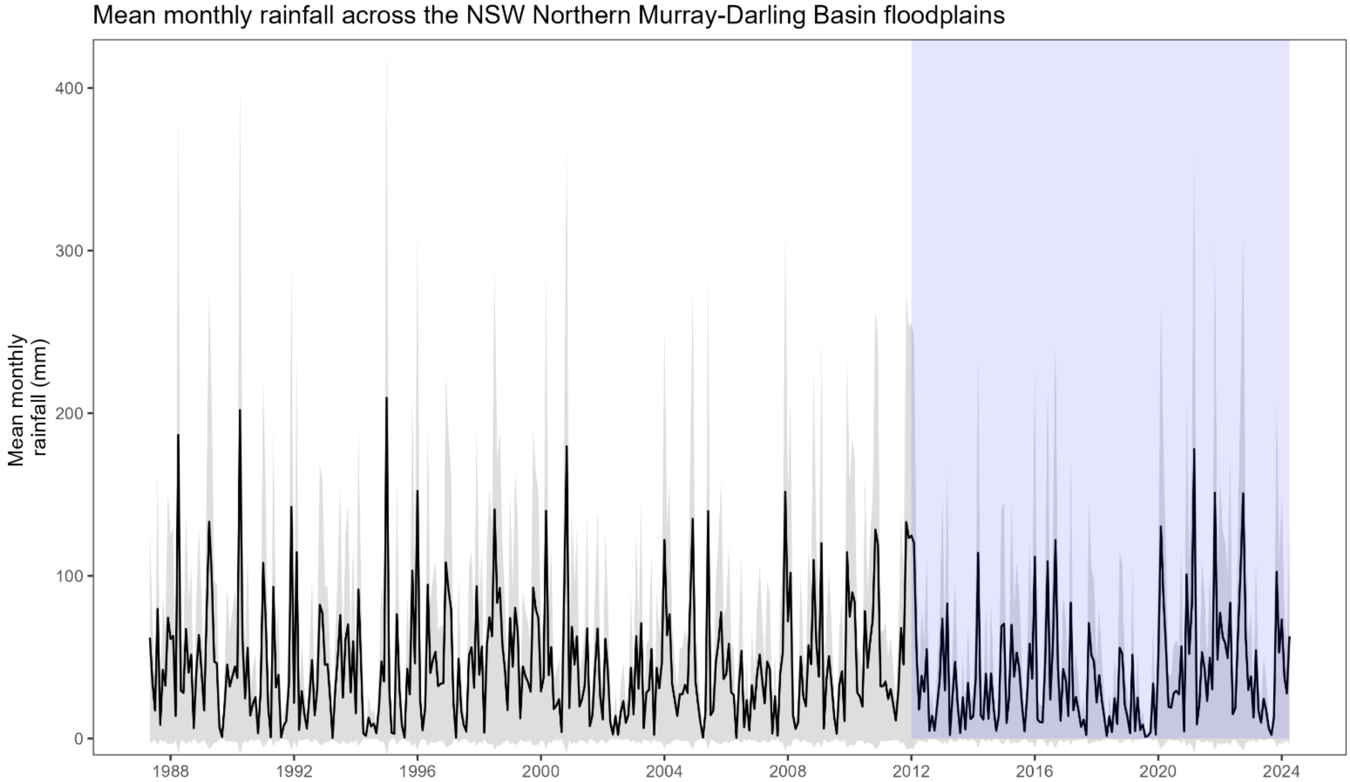

Figure 5: Mean monthly rainfall across the NSW Border Rivers, Gwydir, Namoi, Macquarie and Barwon-Darling floodplain (restricted to floodplain management plan boundaries) for the remote sensing study period. Shaded area shows the Basin Plan period

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1.5 Hydrology

The flow thresholds required to inundate and connect floodplain pools vary within and between the northern Murray–Darling Basin valleys. Most pools are connected during overbank flows (Figure 6) when river flows are high or from overland flows within the catchment. In some cases, low-lying floodplain pools may connect during smaller events, particularly if they are pools within ephemeral channels.

As part of the Basin Plan implementation, long-term water plans were written that identified the environmental water requirements important for the different ecosystems that rely on flows at various heights, including floodplain pools. The environmental water requirements also identified important river flow gauges to estimate overbank events and associated flow rates. These have been used to identify appropriate flow gauges in each valley for this report (e.g. Figure 7, Figure 8, and Figure 9).

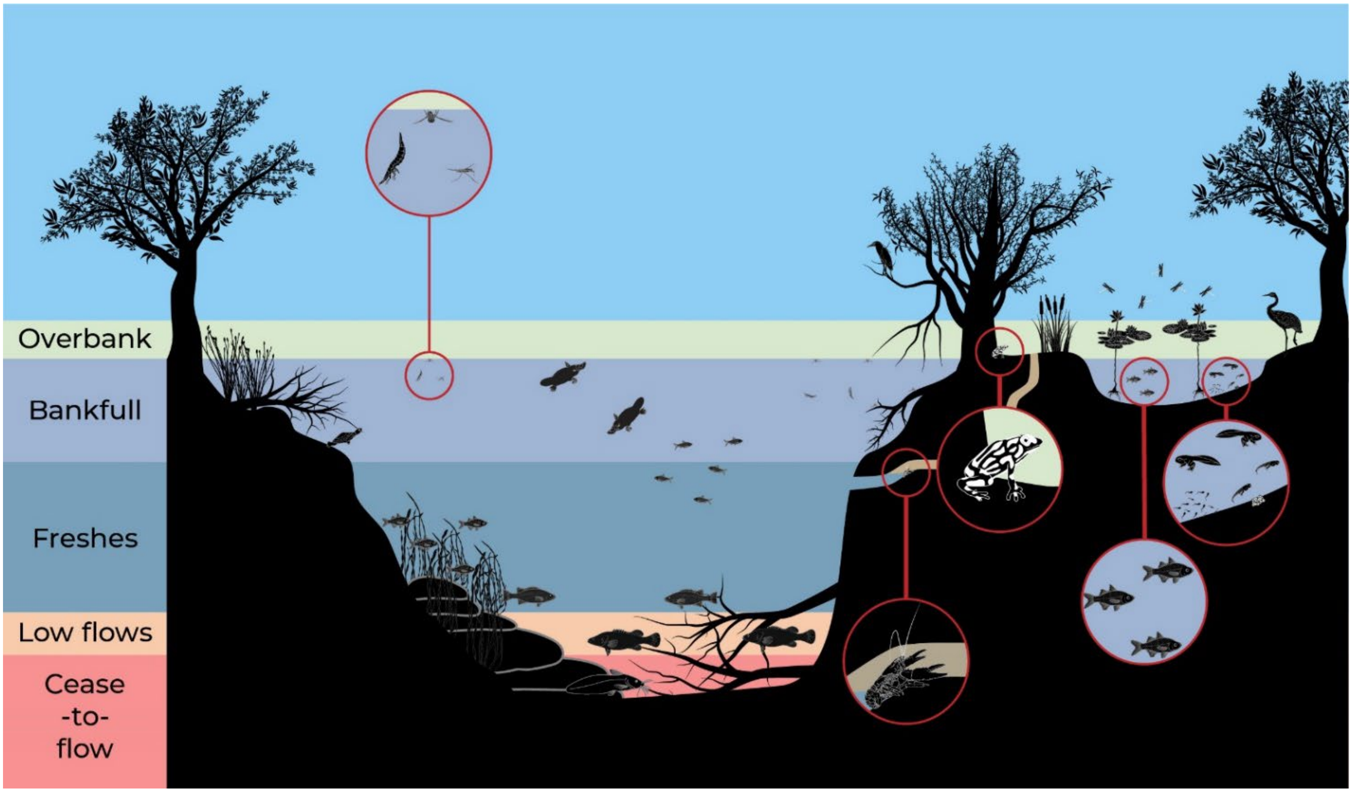


Figure 6: Conceptual model of the main flow categories and what areas of a river they influence

Mean monthly river flow across the northern Murray–Darling Basin since 1987 has been highly variable, spanning multiple drought and flood years (Figure 7). Hydrographs for two key gauges in each valley since the commencement of the Basin Plan (water year 2012–13) to water year 2022–23 highlight the highly variable nature of river flows and, therefore, floodplain inundation within the study area (Figure 8 and Figure 9). The highest and lowest mean monthly flows across the study area have occurred within the last 5 years, with both the 2019 drought marking a key dry period and the extreme wet period after 2020 triggering some of the largest floods on record (Figure 7, Figure 8, and Figure 9).

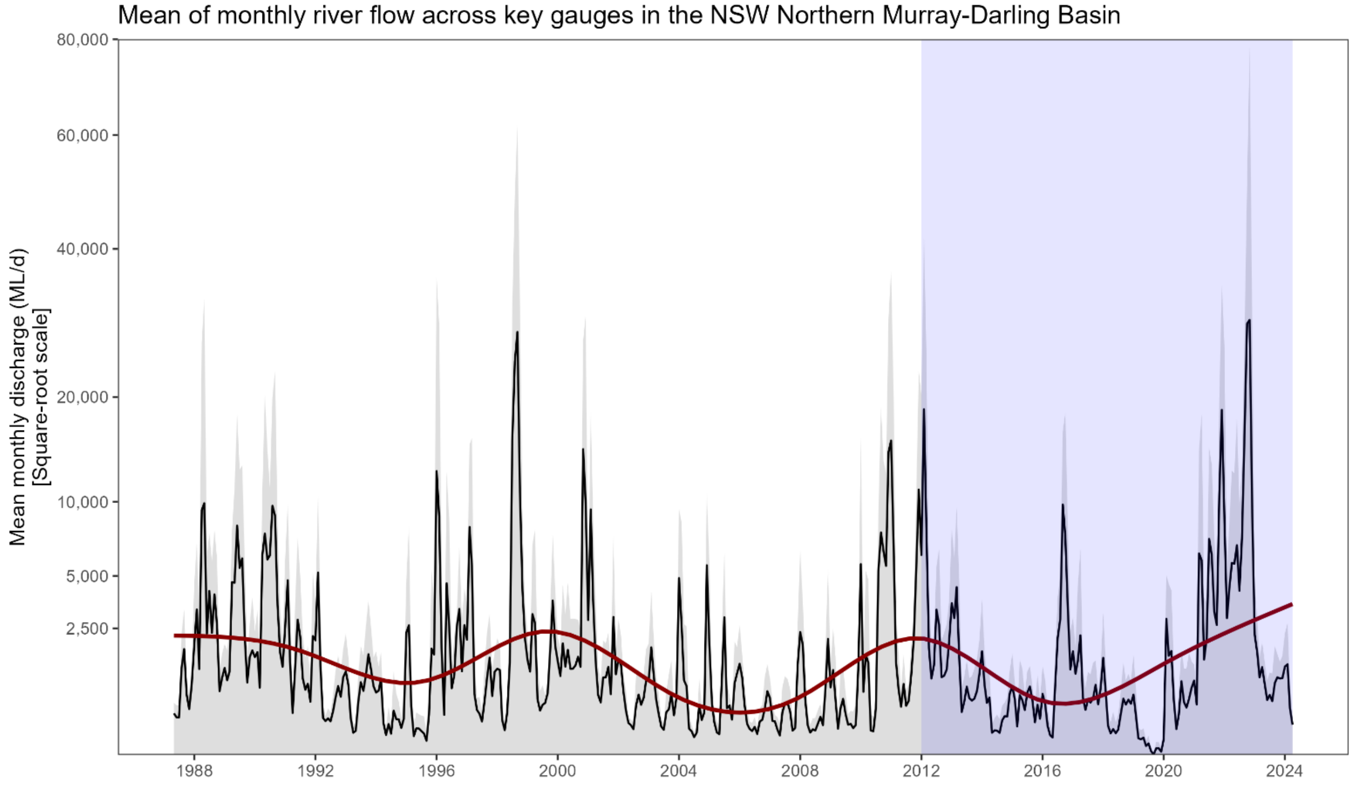


Figure 7: Mean monthly river flow (ML/d) across the NSW Border Rivers, Gwydir, Namoi, Macquarie and Barwon-Darling floodplain (restricted to one gauge per valley) for the remote sensing study period. Gauges include: 422002, 416201A, 418004, 419039 and 421090+421

Overbank events in the Gwydir valley, have occurred only twice since 2012–13, once in March 2021 and again in October 2022, during the study period – represented by Gwydir at Yarraman (418004, Figure 8) and Mehi at Moree (418002, Figure 8). There have been a number of key events within the Namoi valley since 2012–13, as shown by the Namoi River at Mollee (419039, Figure 8). However, there were two significant events that impacted the valley more broadly, in December 2021 and in October 2022, as demonstrated by Pian Creek at Waminda (419049, Figure 8). A similar pattern occurred in the NSW Border Rivers with multiple overbank events shown by Macintyre River at Goondiwindi (416201A, Figure 9), with six events having a more significant impact across the valley, as demonstrated by Whalan at Euraba (416072, Figure 9). Within the Barwon-Darling, upstream and downstream gauges on the Barwon River, Barwon at Collarenebri (422003, Figure 9) and Barwon at Bourke Town (425003, Figure 9) show five key events and highlight the significance of the latest event, which occurred during the study period in October 2022.

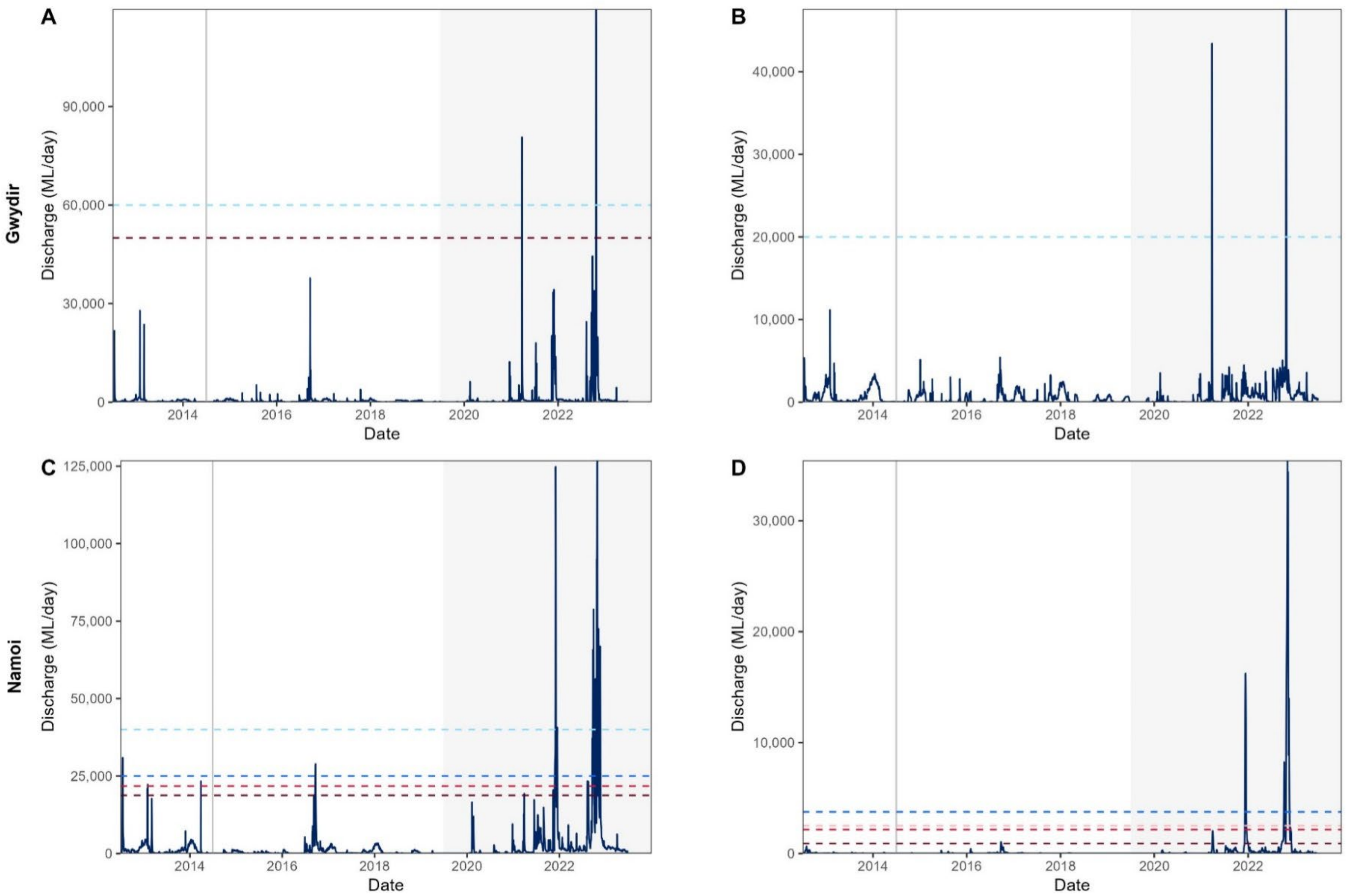


Figure 8: Mean daily discharge (ML/day) since the commencement of the Basin Plan (01/07/2012 – 30/06/2023) at A) Gwydir at Yarraman (418004), B) Mehi at Moree (418002), C) Namoi River at Mollee (419039), D) Pian Creek at Waminda (419049). The grey line represents the commencement of the Basin Plan water trading rules (01/07/2014), and the shaded grey area represents the current evaluation period, commencing 01/07/2019. Dashed lines represent the discharge component of Bankfull (BK, brown) and Overbank (OB, reds and blues) Environmental water requirements set out in the long-term water plans

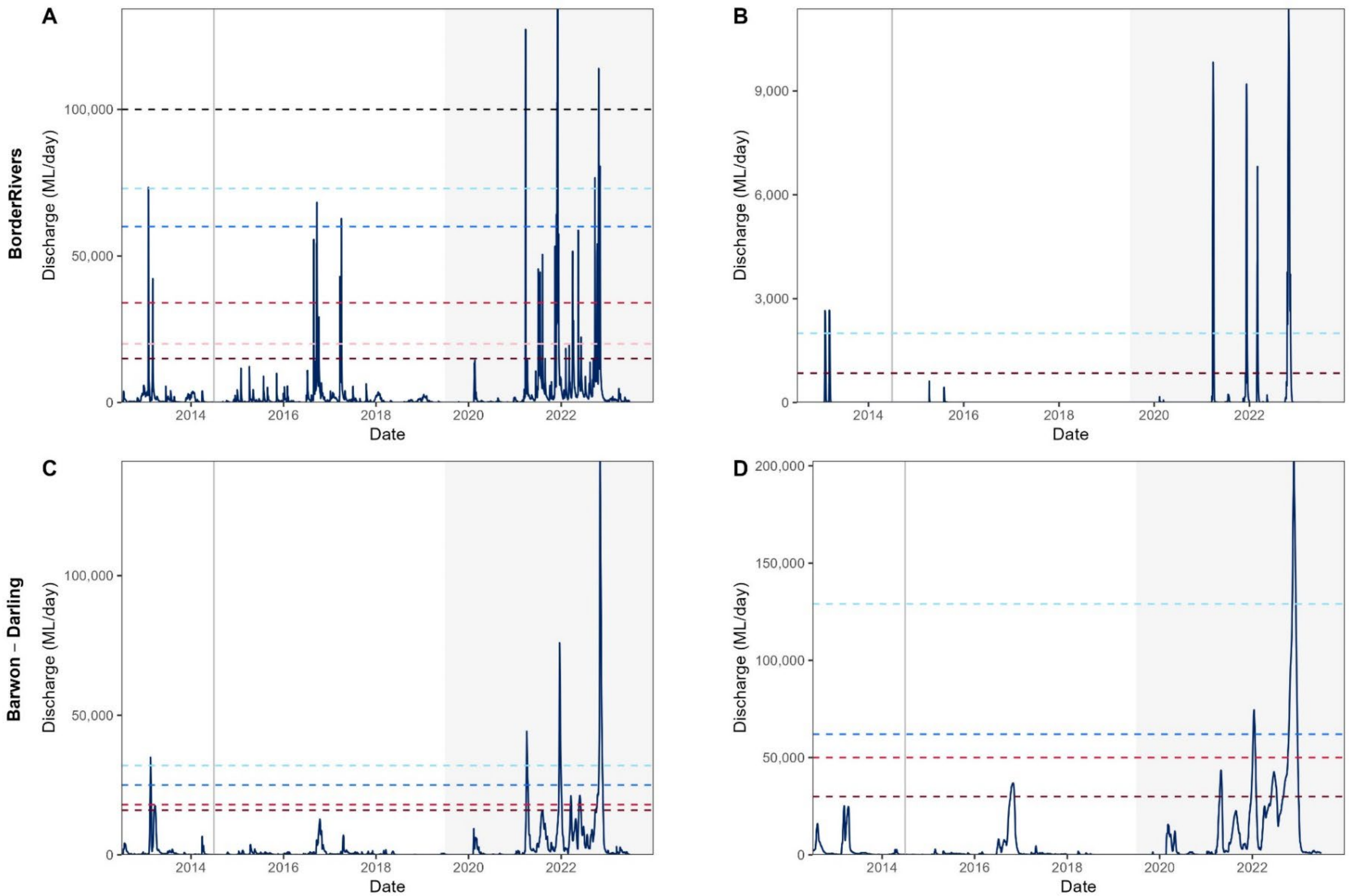


Figure 9: Mean daily discharge (ML/day) since the commencement of the Basin Plan (01/07/2012 – 30/06/2023) at A) Macintyre River at Goondiwindi (416201A), B) Whalan at Euraba (416072), C) Barwon at Collarenebri (422003), and D) Barwon at Bourke Town (425003). The grey line represents the commencement of the Basin Plan water trading rules (01/07/2014), and the shaded grey area represents the current evaluation period, commencing 01/07/2019. Dashed lines represent the discharge component of Bankfull (BK, brown) and Overbank (OB, reds and blues) environmental water requirements set out in the long-term water plans

1.6 Water use and floodplains

Take of overland flow is a large component of the water diversions within the northern Murray–Darling Basin. In total, 1,217 on-farm storages with a cumulative storage capacity of 1300GL (approximately 2.6 Sydney Harbours), were identified by the department in collaboration with the Natural Resources Access Regulator. These jointly-identified storages have been used in a variety of products and represent water storage for a range of licence types, including regulated and unregulated river diversions, groundwater storage, and overland flow diversions (NGIS Australia, 2024). Independent authors (Brown *et al.*, 2022) have suggested there are closer to 1,833 storages, with at least 1,145 operating as floodplain harvesting dams (Ridoutt-Wolfenden, 2022).

The total monthly area of water within on-farm storages has grown since 1987, peaking around the early 2000s (Figure 10). While growth slowed between 2002 and 2024, there appears to be an additional area of on-farm storage growth around 2021-22, coinciding with some of the largest flood events on record (Figure 11and Figure 8).

In addition to on-farm storages, the storage of water in large headwater dams (for example, Keepit Dam), can have substantial impacts on the inundation of floodplain pools in the northern Murray–Darling Basin. These dams capture major flows and reduce flood peaks resulting in a reduction in the number of times water reaches floodplain pools and the volume of water captured in the pools. Headwater storage volumes have remained variable through time but have been at maximum capacity multiple times within the last decade (Figure 11).

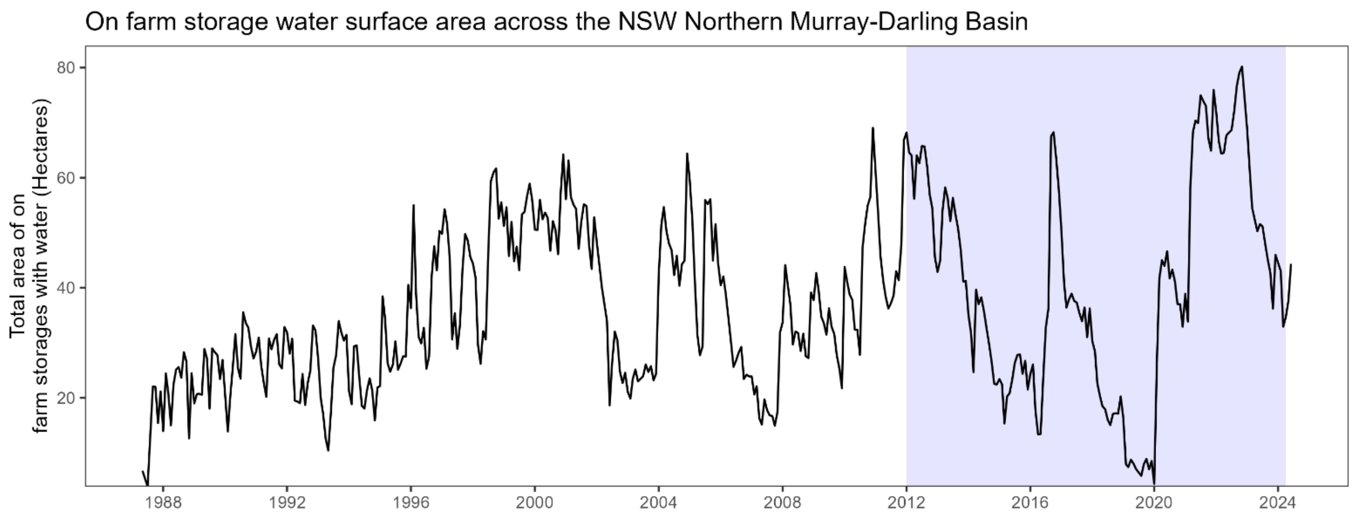


Figure 10: Changes in total monthly water surface area of on-farm storage (water in storages) since 1 May 1987

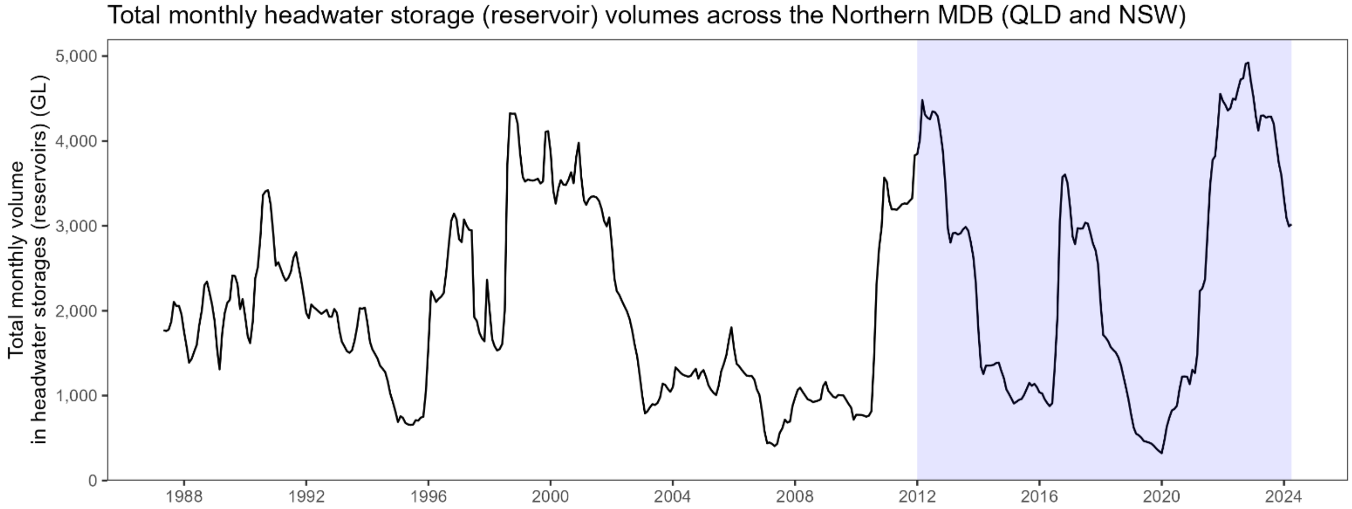


Figure 11: Changes in total monthly headwater storage across the northern Murray–Darling Basin since May 1987. This includes the total of the following storages: Pindari, Glenlyon, Copeton, Keepit, Chaffey, Split Rock, Burrendong, Windamere, Beardmore, Leslie, and Cunnamulla dams

To curtail growth, reduce and regulate floodplain water diversions, the NSW Government implemented the Floodplain Harvesting Policy. The department has granted floodplain harvesting access licences to eligible applicants in the NSW Border Rivers, Gwydir, Macquarie, and Barwon-Darling valleys. The Namoi valley is still to be determined. The shares available for floodplain harvesting vary by valley and are associated with accounting rules that accumulate up to 500% (Table 1).

Table 1: Summary of licenced floodplain harvesting entitlements across the NSW northern Murray–Darling Basin

Floodplain management area	Number of licences	Floodplain harvesting entitlement (100%)	Floodplain harvesting entitlement (500%)
NSW Border Rivers	36	Reg: 51.7 GL	Reg: 258.71 GL
Gwydir	Reg: 86 Unreg: 12	Reg: 104.6 GL Unreg: 13.1 GL	Reg: 523 GL Unreg: 66 GL
Namoi	Not determined at the time of writing this report	Not determined at the time of writing this report	Not determined at the time of writing this report
Macquarie	Reg: 67	Reg: 48.9 GL	Reg: 245 GL
Barwon-Darling	Unreg: 27	Unreg: 51.3 GL	Unreg: 257 GL

The floodplain harvesting measurement rules became law in July 2022. Under these rules, floodplain harvesting is not permitted unless compliant measurement equipment is in place. The department also uses remote sensing methods, including changes to storage surface area and associated storage volume curves, to estimate floodplain diversions during flood events. This is also being undertaken by the Natural Resources Access Regulator as part of their required compliance measures.

2 Methods

2.1 Identifying floodplain pools in the northern Murray–Darling Basin

2.1.1 Water persistence and floodplain pool identification

We identified floodplain pools using Digital Earth Australia (DEA) Water Observations from Space data, which shows the frequency of water observations since 1987 using 30 m Landsat 5/7/8/9 imagery. Data spanning the area of interest was downloaded into ArcMap 10.6.1. Null values, representing dry land, were removed. Pixels with a value greater than 0.2 (that is, had water >20% of the time), which represent semi-permanent or permanent waterbodies, were converted from raster to vector format. All waterbodies that intersected with known on-farm storages (such as farm dams) or river channels were deleted.

Vegetation cover or small, non-persistent areas within larger pools often resulted in gaps between polygons representing the same floodplain pool. To rectify this, a spatial buffer of 100 m was used to automatically merge polygons likely to belong to the same floodplain pool. All polygons with a total size of less than 2,700 m2 (equivalent to 3 Landsat pixels) were then deleted as they were too small for further analysis. The remaining polygons were manually checked against high resolution satellite imagery (Sentinel-2) to ensure suitability. Any unsuitable polygons that did not overlap a clear lagoon, waterhole or other floodplain pool type were manually deleted. The resulting final polygon was converted into a shapefile of larger, more persistent floodplain pools in the northern Murray–Darling Basin.

2.2 Inundated surface area changes in floodplain pools

2.2.1 Water detection and surface area calculations

Remote sensing analysis was undertaken to detect water within on-farm storages, and a subset of floodplain pools was identified using the DEA Water Observations from Space data in Section 2.1.1. This was done using Landsat data from May 1987 to April 2024. Landsat 5/7/8/9 was used for the entire period (Table 2) to keep the pixel resolution (30 m) consistent through time, even though higher resolution Sentinel data was available for part of the period.

To identify water surfaces, we utilised the binary Modified Normalized Difference Water Index (mNDWI) computed from Landsat 5/7/8/9 data. The threshold used to distinguish between water and non-water pixels is set at 0.1. Water detection processing was done using binary mNDWI images. This was used to calculate the number of wet pixels within each labelled on-farm storage and floodplain pool polygon (using a 10 m buffer to account for half pixel georeferencing errors). This produced a data frame for each label with the date and number of pixels/area (in hectares). The area in hectares was then converted into a monthly average and maximum for each polygon. The number of satellite images varied over time, with the number of Landsat images increasing with the year.

Table 2: Temporal coverage for each satellite used in the surface area calculations

Satellite	Start year	End year
L9 TOA	November 2021	Continuous
L8 TOA	April 2013	Continuous
L7 TOA	April 1999	Dec 2023
L5 TOA	August 1986	July 2013

In total, 1,217 on-farm storages were identified by the department in collaboration with the Natural Resources Access Regulator and have been used in a variety of programs to date (NGIS Australia, 2024). Volumes were also calculated for each storage using storage curves generated by the NSW Government with Light Detection and Ranging (LiDAR) surveys. These curves were developed for all priority storages in the northern Murray–Darling Basin region as part of implementing the Floodplain Harvesting Policy (NSW DCCEEW, 2024). The final on-farm storage data set includes area and volume values for each unique storage and available satellite image from May 1897 to April 2024. These values were summarised into monthly maximum and mean values for each storage and used in subsequent analysis.

A total of 1,075 potential floodplain pools were identified from the DEA Water Observations from Space data. In addition, the named waterbodies spatial layer (NSW Department of Customer Service, 2022) was used to identify 156 mapped and formally named floodplain lagoons, billabongs, and other floodplain pool waterbodies. We prioritised 376 floodplain pool waterbody polygons to apply the water detection approach. These included the 156 named waterbodies, and 220 of the largest (based on area) floodplain pools identified using the DEA Water Observations from Space data. Each polygon had a 25 m buffer applied to capture margins of pools, which were often highly variable in shape (for example, Figure 3) compared to the rectangular and triangle shape of most on-farm storages. Approximately 80% of the floodplain pool polygons had a surface area greater than 5 hectares, which was deemed an appropriate area for Landsat imagery (Figure 12).

A post-processing review of each dataset for the 376 polygons was conducted. This approach looked for inconsistent, and highly variable fluctuations in surface area between images to filter out floodplain pools that behaved erratically, suggesting the Landsat detection was not effective. This resulted in 212 floodplain pools used for the final analysis. No floodplain pool volumes were calculated as storage curves are not available for each waterbody due to the unique shape and variable depths of floodplain pools across the northern Murray–Darling Basin.

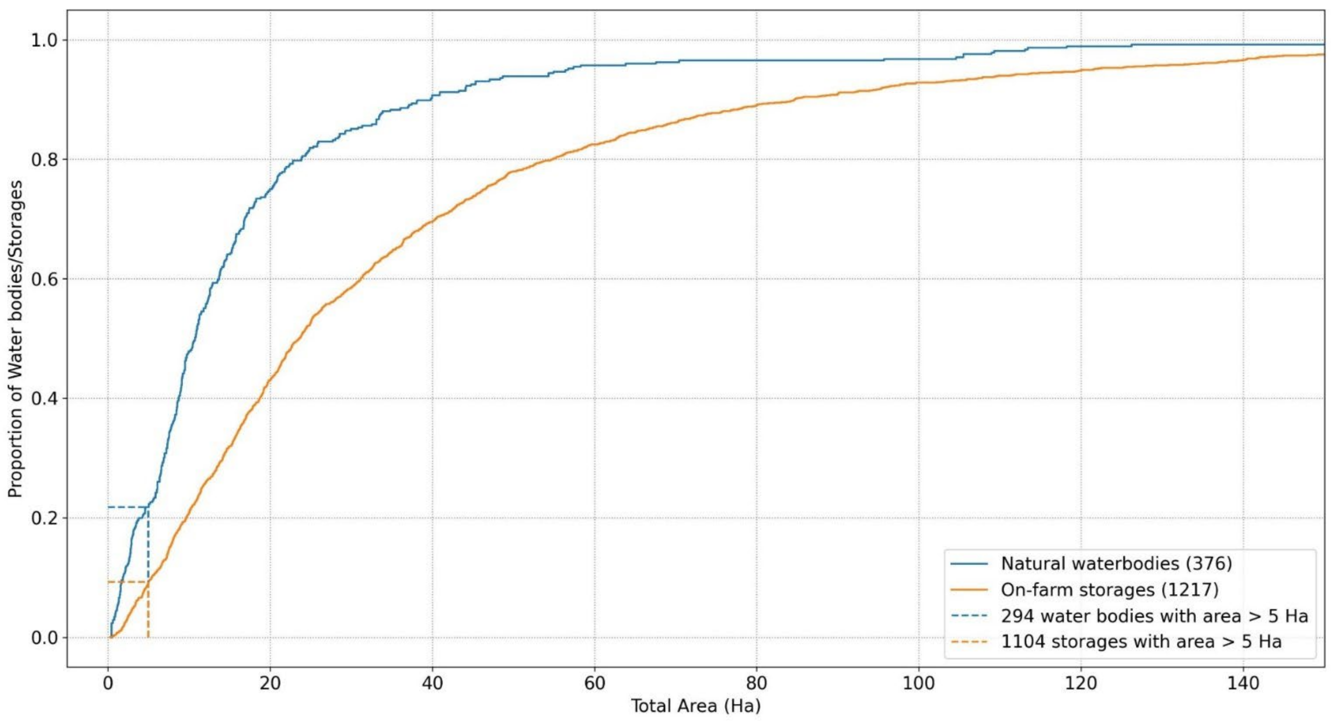


Figure 12: Empirical cumulative distribution function (ECDF) for natural waterbodies (that is, floodplain pools) and on-farm storages. This shows the proportion of polygons with different areas, with the >5 hectares considered the minimum area to undertake further analysis

2.2.2 Climate and other externalities

Data for a range of climate variables considered important for floodplain pool inundation and water retention on the floodplain were also collected. These variables included rainfall, river flows, air temperature, pan evaporation, headwater storage levels (for example, large headwater dams like Copeton Dam), and on-farm storage area and volume.

Monthly gridded rainfall (mm) (mean, total and maximum), maximum daily air temperature (degree Celcius), and maximum daily pan evaporation (mm) were extracted from the SILO climate dataset (Queensland Government, 2024) using the floodplain management plan boundary for each valley. Gridded rainfall was also extracted for each valley boundary to capture rainfall across the entire catchment, including Queensland catchments to account for changes in the Barwon-Darling. Temperature and pan evaporation were transformed into mean monthly summaries to match the monthly time step of the floodplain pool and on-farm storage dataset.

Daily headwater storage volume in all relevant major reservoirs was downloaded from the Bureau of Meteorology (BOM) Water (BOM, 2023). The mean monthly storage volume was calculated for each storage. Each mean monthly storage volume was then totalled per month to calculate the total monthly storage volume in both NSW and Queensland storages. Queensland was included to account for impacts to flows into the Barwon-Darling. The storages used were: 416030, 416315A, 418035, 419041, 419069, 419080, 421078, 421148, 422212B, 422315B, 423202C

River flow data was sourced from the BOM Water data online (BOM, 2023). Mean and maximum monthly river flow was calculated for each valley using one key representative gauge, often used to measure overbank environmental water requirement events for each valley. A high-level summary of long-term changes across the entire northern Murray–Darling Basin was also generated using each valley as a replicate to calculate the mean and confidence intervals. The gauges were: 422002, 416201A, 418004, 419039 and 421090+421088 for the Barwon-Darling, NSW Border Rivers, Gwydir, Namoi and Macquarie valleys respectively.

2.2.3 Data analysis

All analyses were performed in R studio with ggplot2 and dplyr, the primary packages for plots and data manipulation (Wickham, 2016; Wickham *et al.*, 2022; Posit team, 2025).

2.2.3.1 Surface area analysis for floodplain pools and on-farm storages

The final water surface area Landsat dataset was summarised into a monthly mean and maximum area (and volume for storages only). We calculated a relative area for each floodplain pool and on-farm storage in addition to the total area value (including buffer). The relative area was calculated by converting all area measurements for each image and individual pool and on-farm storage into a % value based on the maximum area that had been recorded in the entire time series. This was then averaged across all valleys combined using each individual floodplain pool as a valley replicate to calculate means and confidence intervals.

Each floodplain pool and on-farm storage was spatially linked to the relevant valley using the NSW floodplain management plan boundaries within ArcMap 10.6.1. This enabled summary statistics to be generated at a variety of scales:

1. individual floodplain pool and on-farm storage scale (by unique ID)
2. at a valley scale
3. at the entire northern Murray–Darling Basin scale.

We also generated average surface area values for each floodplain pool prior to and post implementation of the Basin Plan (set as the start of December 2012). These statistics were used to summarise changes to water retention within floodplain pools using percent change calculations from pre and post Basin Plan. Percent changes (- and +) were grouped into 10% increments and plotted using frequency histograms. The 20 pools with the greatest reduction and 20 pools with the largest increase in average surface areas post Basin Plan were investigated in detail using time-series plots.

2.2.3.2 Trend analysis

The long-term trends in each variable were conducted for raw data (that is, rainfall in mm) and data standardised between 0 and 100 for each variable. The standardised data was calculated by using the maximum value for each variable to scale all measurements within that variable. This allowed a comparison of slopes across variables to identify if one variable was increasing or decreasing at a greater rate than another.

The trends were assessed using time-series plots and the non-parametric Mann-Kendall (Mann, 1945; Kendall, 1975) and Sen's Slope (Sen, 1968) models. Both models are commonly used approaches for estimating trends in flow (Guo *et al.*, 2024) and other environmental variables (da Silva *et al.*, 2015; Sa'adi *et al.*, 2019). These tests are primarily for identifying unidirectional trends (that is, increasing or decreasing in one direction). However, these tests were considered appropriate for assessing trends in floodplain pool surface areas and the other climate and storage variables.

The Mann-Kendall and Sen's Slope trend analyses are non-parametric and do not require the data distribution to satisfy normality assumptions. However, they do require the data to have no serial correlation or be temporally independent. As most climate data is serially correlated, we used a trend-free pre-whitening process for each variable. This is a pre-processing step that removes the impact of serial correlation without inflating the existing trend (Yue & Wang, 2002). This was performed using the modified Mann-Kendall variance correction approach developed by Yue & Wang (2004) within the package: modifiedmk (Patakamuri & O'Brien, 2021).

2.3 Water-dependent fauna and floodplain pools

2.3.1 Study sites

We used the DEA Water Observations data to categorise pools based on their historical persistence on the floodplain. Sites with greater than 40% persistence within the dataset were selected and then intersected with named floodplain pools (for example, lagoons, waterholes, billabongs and cowals). The final sites were selected based on a range of persistence categories >40%, ease of access and the degree of modification. We avoided lagoons with irrigation channels or active extraction wherever possible. However, in some valleys there were limited floodplain pools with no modifications. The final list of sites included 35 floodplain pools across the NSW Border Rivers, Gwydir, upper and lower Namoi, and Barwon-Darling floodplains (Figure 13).

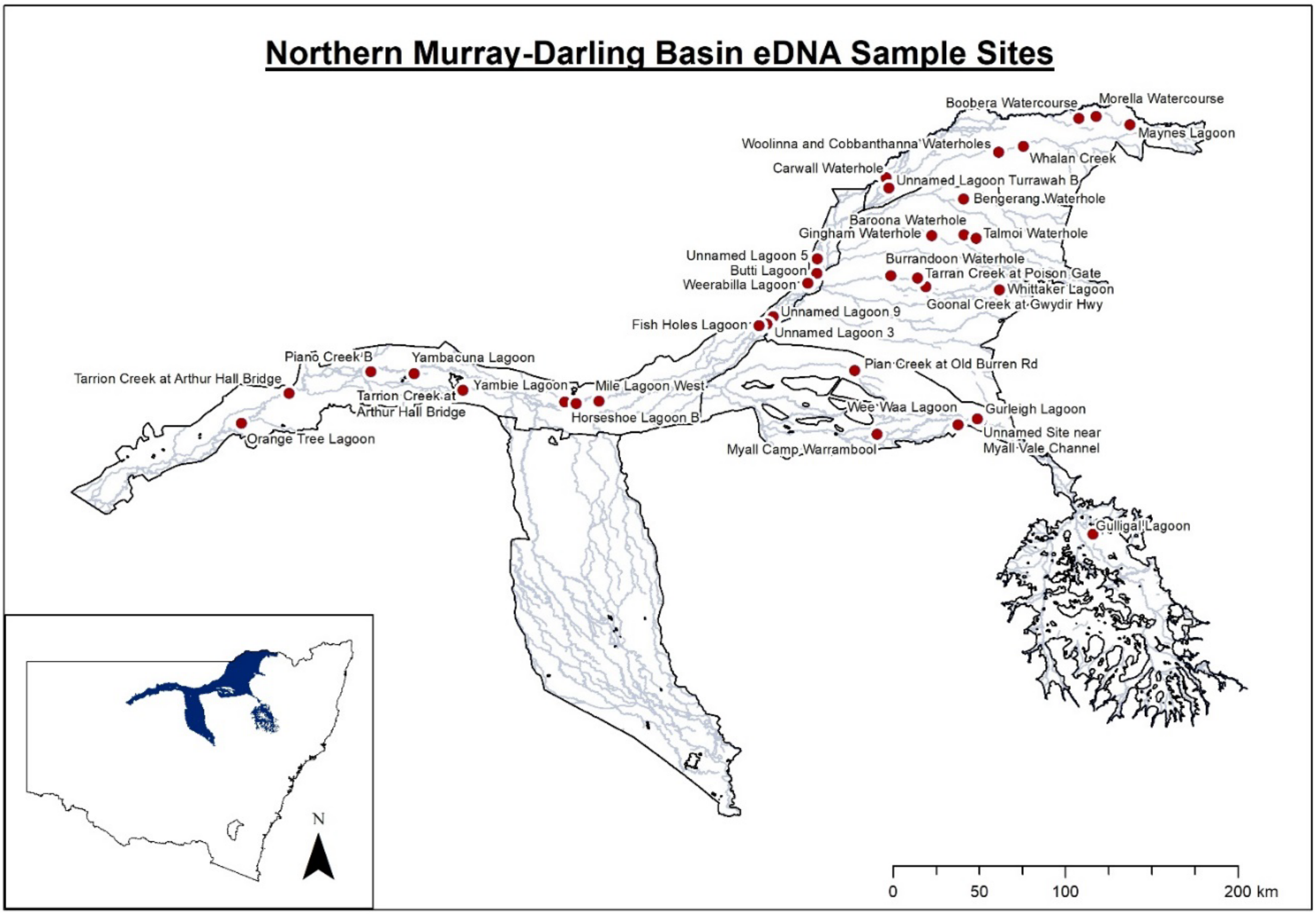


Figure 13: Map of the final floodplain pool sample sites for fauna surveys in the northern Murray–Darling Basin

2.3.2 Data collection

2.3.2.1 Fauna data

Environmental DNA sampling was conducted using a Smith-Root eDNA backpack sampler. Between 6 to 12 eDNA sub-samples were collected at each floodplain pool site, targeting the range of aquatic microhabitats present at a site, including snags, flooded forest, submerged, floating or emergent macrophytes. A maximum target volume of 1 litre was set for each sub-sample (microhabitat type), with a maximum of 2 filters used per sub-sample. If this volume was not met, the filtered volume was recorded to the nearest millilitre. Laboratory analyses of fish and vertebrate metabarcoding were conducted by EnviroDNA.

2.3.2.2 Site characteristics

2.3.2.2.1 Water quality

Water quality variables, including water depth, dissolved oxygen, electrical conductivity, turbidity, pH and water temperature, were measured using a multiprobe. Six water quality readings were taken at each site: 3 samples at zero to 50 cm depth and 3 samples at 50 to 100 cm depth.

2.3.2.2.2 Vegetation

Vegetation surveys were conducted once or twice per site based on the homogeneity of riparian vegetation immediately surrounding the floodplain pool. Percentage cover of each vegetation class (bare ground, litter, non-aquatic grass, grass, shrubs, trees, tall emergent, short emergent, flooded forest, submerged macrophytes, floating macrophytes, and bare water) was estimated within a 40 x 10 m quadrat, with 2 m (20%) of aquatic area and 8 m (80%) of riparian area along a 40 m length of the pool edge. This data was used to calculate a vegetation condition score, structural diversity score (Table 9 in Appendix 7.1 for details) and percent tree cover for each site.

2.3.2.2.3 Pool depth and size

Maximum pool depth (m) was estimated using a Deeper Pro + sonar cast from a fishing line. Pool area (ha) and perimeter (km) were calculated in ArcGIS 10.6.1 using the latest satellite imagery and the inundation extent map (described in Section 2.2 and Section 3.2) from the date closest to the sampling date. A polygon was traced around each floodplain pool to map the size of the pool at full capacity. Drone imagery and video were collected when conditions allowed to confirm pool inundation extent with satellite imagery.

2.3.2.2.4 Pool connectivity

Using the inundation imagery described in Section 2.1 and 2.2, and presented in Section 3.1, we quantified the following:

- minimum flow path distance to the main channel: The minimum distance (km) from the main channel to the floodplain pool based on the most recent inundation event
- maximum flow path distance to the main channel: The maximum distance (km) from the main channel to the floodplain pool is based on the most recent inundation event.

When a floodplain pool was located within an ephemeral channel and not adjacent to the channel, the main river channel was considered the most upstream river section with a permanent river pool.

2.3.2.2.5 Pool persistence and inundation

The persistence of floodplain pools was calculated using the DEA Water Observations data set and the methods described in Section 2.2 and presented in Section 3.2. The maximum persistence (%) was measured as the single most persistent 30 m2 pixel between 1987 — 2024 within the floodplain pool boundary. The mean persistence (%) was an average of all 30 m2 persistence pixels that fell within the floodplain pool perimeter across the data period. We also used inundation mapping to calculate the time since the last connection or flood that connected the pool to a main channel prior to the eDNA sample being collected.

2.3.3 Data analysis

2.3.3.1 Fauna within the floodplain pools of the northern Murray–Darling Basin

In this report, we often refer to the different types of water-dependent fauna as taxa (unless otherwise specified), not species, because not all eDNA detections could be identified at the species level, for example, some waterbirds could only be identified at the genus level. The data was transformed into a taxa richness measure to account for the different levels of identification. The total number of taxa detected was pooled across filter replicates to represent one estimate of taxa richness per site. The data was filtered to only include all native water dependent animals (native fish, waterbirds, turtles and rakali) for analysis. Non-native fish were excluded from the analysis as they were not target species. Only 4 amphibians were present at a small number of sites and were excluded due to the timing of sampling (winter) and reduced likelihood of amphibian DNA being present.

The variation in fauna richness and assemblages among valleys and sites was investigated using visual and statistical approaches. The difference in fauna richness among valleys was analysed using boxplots and an ANOVA. A Levenes test was used to test the assumption of homogeneity. Site-based differences in fauna richness and the presence of specific taxa were assessed using bar plots and summary statistics. The comparison of fauna assemblages amongst valleys was performed using a Distance-based Linear Model (DistLM) in PRIMER 7 (Clarke *et al.*, 2015) with the valley as a factor. We also visualised the differences among valleys using a Principal Coordinate Analysis (PCoA) generated from the vegan package (Oksanen *et al.*, 2020). The DISTLM and PCoA were performed in PRIMER 7 (Clarke *et al.*, 2015). All other analyses were undertaken using R Studio (Posit team, 2025) and ggplot2 (Wickham, 2016).

2.3.3.2 Influence of floodplain pool characteristics on the presence of key species

We used a variety of multivariate techniques to investigate whether any of the documented floodplain pool characteristics were important determinants on what key species were detected at a site. The eDNA concentrations were converted to presence/absence data before analysis.

The pool characteristics for each analysis were selected from the following: surface area, maximum water depth, minimum connectivity distance to a channel during flood events, vegetation condition score, vegetation structural diversity score, percent tree cover, maximum water persistence, and native fish eDNA concentration. Each pool characteristic was standardised as they were measured in different units and scales, for example percent tree cover was represented as a percentage (%) whilst minimum connectivity distance was measured in kilometres (km). In addition, some characteristics were heavily skewed. To address this, we standardised the characteristics by the maximum value of each so that each characteristic was on a scale between 0 and 100.

The taxa and floodplain pool characteristics (predictors) included in each model and the justification are detailed below:

Native fish presence model: The likelihood of occurrence or presence (presence/absence) of key native fish taxa was analysed using generalised linear models. However, not all native fish taxa were included in the analysis for a variety of reasons. This model included the presence/absence of native fish that occurred at less than 80% of sites, but more than 5% of the sites. This threshold was chosen as taxa that occur at most sites, that is, >80% of sites are unlikely to be influenced by pool characteristics as they occur almost everywhere. In contrast, species that occur at less than 5% of sites (one of 35 sites) would not be able to be modelled due to a lack of data. For example, bony herring and spangled perch occurred at 97% and 100% of sites, whilst Murray cod only occurred at one site, making these species unsuitable for this modelling approach. The final species assessed were golden perch, carp gudgeon, Murray–Darling rainbowfish, and Australian smelt.

The association of 6 floodplain pool characteristics (Table 3) on the presence of these 4 native fish taxa was analysed using a Generalised Linear Model with the base package in R-Studio (Posit team, 2025). No interactions were investigated within these models. The slope estimate and p-value were used to compare predictors. We also visually assessed any predictors with significant associations by creating partial dependency plots with the visreg package (Breheny & Burchett, 2017) in RStudio.

Waterbird presence model: The likelihood of occurrence or presence (presence/absence) of key waterbird species was analysed using generalised linear models. However, not all waterbird taxa were included in the analysis. Unlike native fish, no waterbird taxa occurred across all sites; the most common species was the Australian wood duck, which was found at 68% of sites. We therefore selected the 4 most common waterbirds (Figure 32), which occurred at 28-68% of the floodplain pool sites. The final species assessed were: Australian wood duck, little pied cormorant, little black cormorant, and Nankeen night heron.

The association of 6 floodplain pool characteristics (Table 3) with the presence of these 4 waterbird species was analysed using a Generalised Linear Model with the base package in R-Studio (Posit team, 2025). No interactions were investigated within these models. The slope estimate and p-value were used to compare predictors. We also visually assessed any predictors with significant associations by creating partial dependency plots with the visreg package (Breheny & Burchett, 2017) in RStudio.

Table 3: List of the floodplain pool characteristics used as predictors in the distance based linear model (DistLM) for fauna assemblage composition and the generalised linear models (GLMs) for native fish presence, and waterbird presence. All predictors were standardised between 0 and 100 within PRIMER 7

Floodplain pool characteristics (predictors)	Fauna assemblage	Native fish presence	Waterbird presence
Surface area	Yes	Yes	Yes
Depth	Yes	Yes	No[6]
Maximum persistence	Yes	Yes	Yes
Time since last connection	Yes	Yes	Yes
Minimum flow path distance to main channel	Yes	Yes	No[7]
Vegetation condition score	Yes	No[3]	Yes
Vegetation structural diversity score	No[1]	Yes	No[8]
Percent tree cover	Yes	No[4]	Yes
Native fish eDNA concentration	No[2]	No[5]	Yes

[1] Not used as it is correlated with condition score which may be more relevant to the entire assemblage.

[2] Not used as native fish are included within the fauna assemblage data.

[3] Not used as it is correlated with structural diversity which may be more relevant to native fish.

[4] For native fish, one vegetation category was deemed appropriate.

[5] Native fish biomass was not considered a useful predictor for native fish presence.

[6] There is no logical reason for depth to influence waterbird presence.

[7] Distance to channel was excluded for waterbirds due to their high dispersal capacity.

[8] Not used as it is correlated with condition score which may be more relevant to waterbirds.

3 Results

3.1 Identifying floodplain pools in the northern Murray–Darling Basin

There is one key question we aim to answer to understand the distribution of floodplain pools across the NSW part of the northern Murray–Darling Basin:

> Section 3.1: Q1 How many notable floodplain pools are there in the northern Murray–Darling Basin and where are they?

A total of 1,075 floodplain pools larger than 3 Landsat satellite image pixels (>0.27 hectares per pool) and persistent for more than 20% of the time from 1987 to 2023 were identified in the northern Murray–Darling Basin (Figure 14).

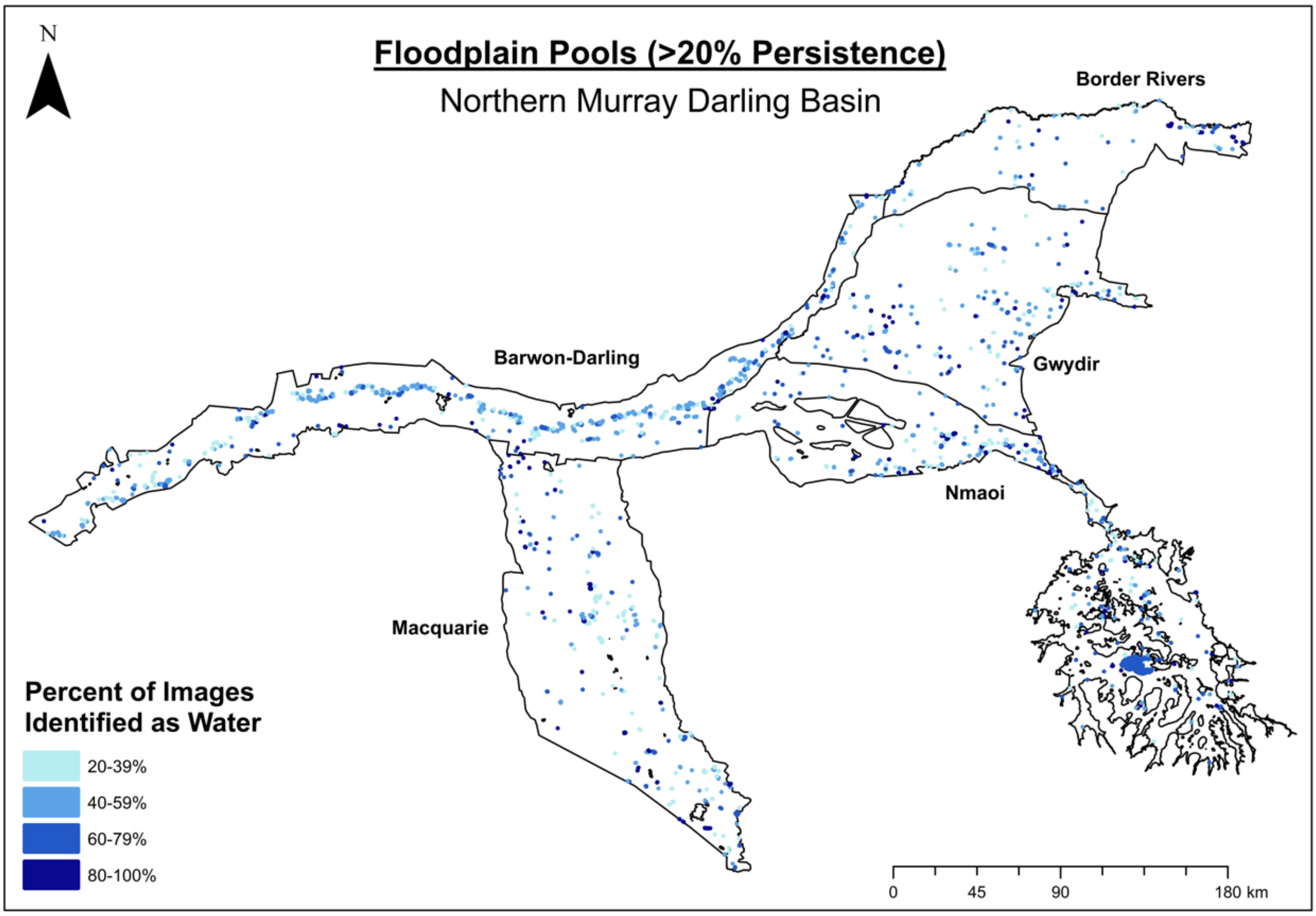


Figure 14: Distribution and persistence of floodplain pools identified using the Water Observations from Space tool, which displays the detected surface water for the period 1987 to 2024. All pools shown are those inundated more than 20% of the time and are larger than 2,700 m2 (0.27 Hectares). Note that the size of floodplain pools is not to scale and have been enlarged for visual representation

The detection of pools via satellite imagery is limited by vegetation cover and hence may exclude floodplain pools with a high amount of canopy cover. Additionally, the 20% persistence category would exclude many ephemeral pools that fill and dry rapidly but are still an integral component of the floodplain ecosystem.

The combined area of all floodplain pools was 8,205 ha. Pools were identified across all catchment areas, with 38% being in the Barwon-Darling floodplain management zone (Table 4). Lake Goran on the Upper Namoi floodplain was the largest floodplain pool, representing 93% of the floodplain pool area for the Upper Namoi. Most of the detected pools were unnamed and not represented in NSW Spatial Services datasets. However, some are well known waterholes like the Gingham waterhole on the Gwydir floodplain and Boobera Lagoon in the NSW Border Rivers.

Table 4: Distribution of floodplain pools detected in the northern Murray–Darling Basin. FMP = Floodplain management plan boundary

Floodplain Area	Number of floodplain pools detected	Total Area of floodplain pools (ha)
Barwon-Darling valley FMP	405	1,149.93
NSW Border Rivers valley FMP	70	138.52
Gwydir valley FMP	161	262.65
Lower Namoi valley FMP	126	314.71
Upper Namoi valley FMP	127	5,745.82[1]
Macquarie valley FMP	186	593.40
TOTAL	**1,075**	**8,205.03**

[1] Lake Goran is the largest floodplain waterbody included and is responsible for most of the total area in the Upper Namoi.

Based on the most persistent pixel from each waterbody, most floodplain pools (380) were persistent for 40-60% of the time, and 128 were persistent for 80-100% of the time (Table 5). The average maximum persistence value across all floodplain pools was 53%.

Table 5: Number of pools within persistence categories across the northern Murray–Darling Basin. Persistence categories represent the percentage of satellite images identified as having water from 1987 to present

Persistence	Number of Floodplain pools with maximum pixel value in group
20-40%	339
40-60%	380
60-80%	228
80-100%	128

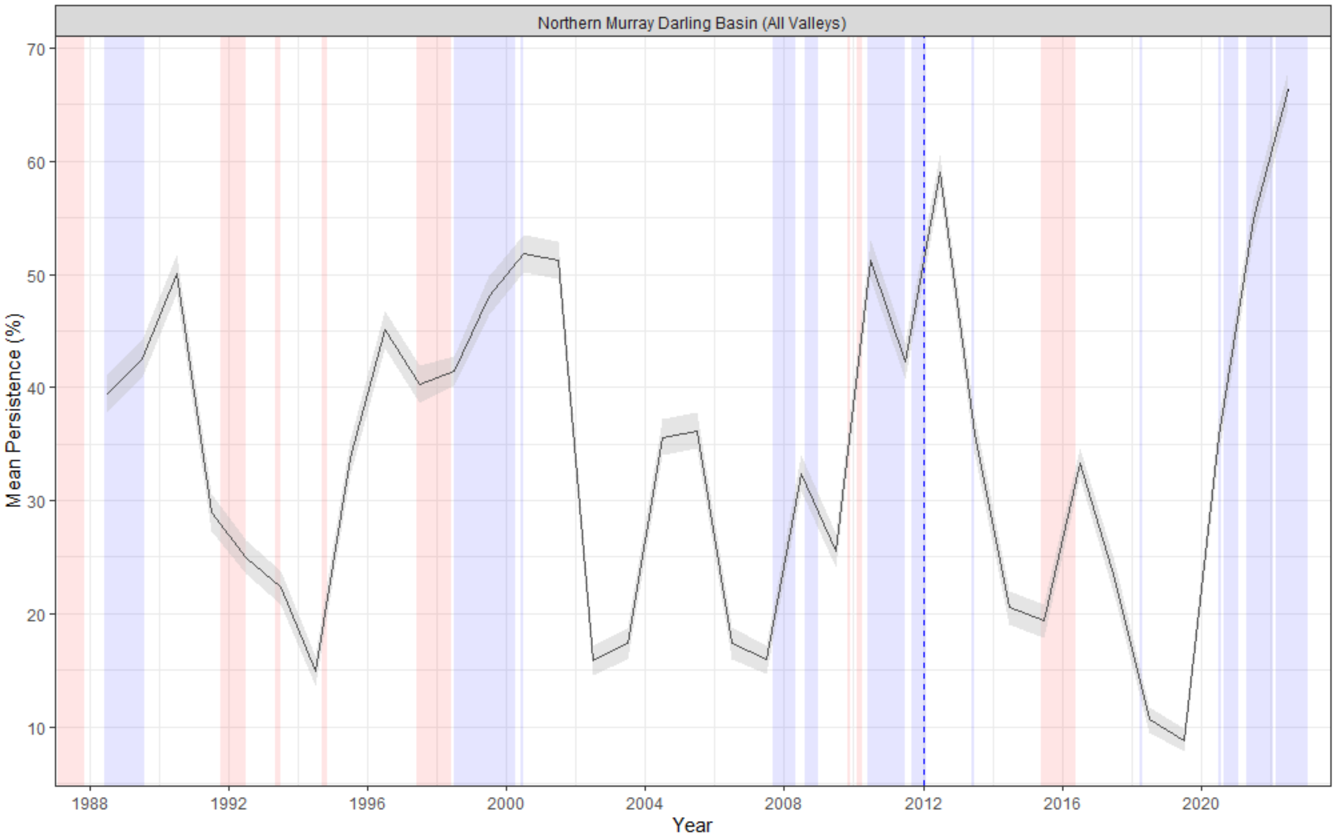


Figure 15: Mean monthly floodplain pool persistence (% of pixels with water each month) across the entire northern Murray-Darlin: Basin from 1987 to 2024. The blue and red vertical bars represent the Multivariate El Niño – Southern Oscillation (ENSO) Index, where the shading represents a stronger El Niño (red)/La Niña phase (blue) (+/- 1 MEI)

3.2 Inundated surface area changes in floodplain pools

There are 2 key questions we aim to answer to understand how surface water inundation and retention has changed in floodplain pools across the NSW part of the northern Murray–Darling Basin, and whether the Basin Plan has had any influence on these outcomes. At this stage, the NSW government led Healthy Floodplains Project is in early stages of implementation and any benefits from this program are yet to be fully realised.

Section 3.2.1: Q1 What are the long-term changes in water surface area for floodplain pools across the northern Murray–Darling Basin, and are the changes associated with climate and/or water use?

Section 3.2.2: Q2 Has the Basin Plan contributed to improving the water surface areas of floodplain pools in the northern Murray–Darling Basin?

3.2.1 Long-term history of floodplain pool surface area

Time series data for each individual floodplain pool was analysed to assess whether the results of this automated approach were sensible (Figure 16). The detection of water in some floodplain pools was impacted by vegetation cover or pool size/shape relative to Landsat pixel size, skewing results. These pools were excluded from further analysis (Figure 16, Table 6).

Table 6: The number of floodplain pools analysed in the northern Murray–Darling Basin. FMP = Floodplain management plan boundary

Floodplain area	Number of pools subject to Landsat method	Number of pools selected for further analysis
Barwon-Darling valley FMP	126	98
NSW Border Rivers valley FMP	91	39
Gwydir valley FMP	34	17
Lower Namoi valley FMP	54	33
Upper Namoi valley FMP	68	25
Total	**373**	**212**

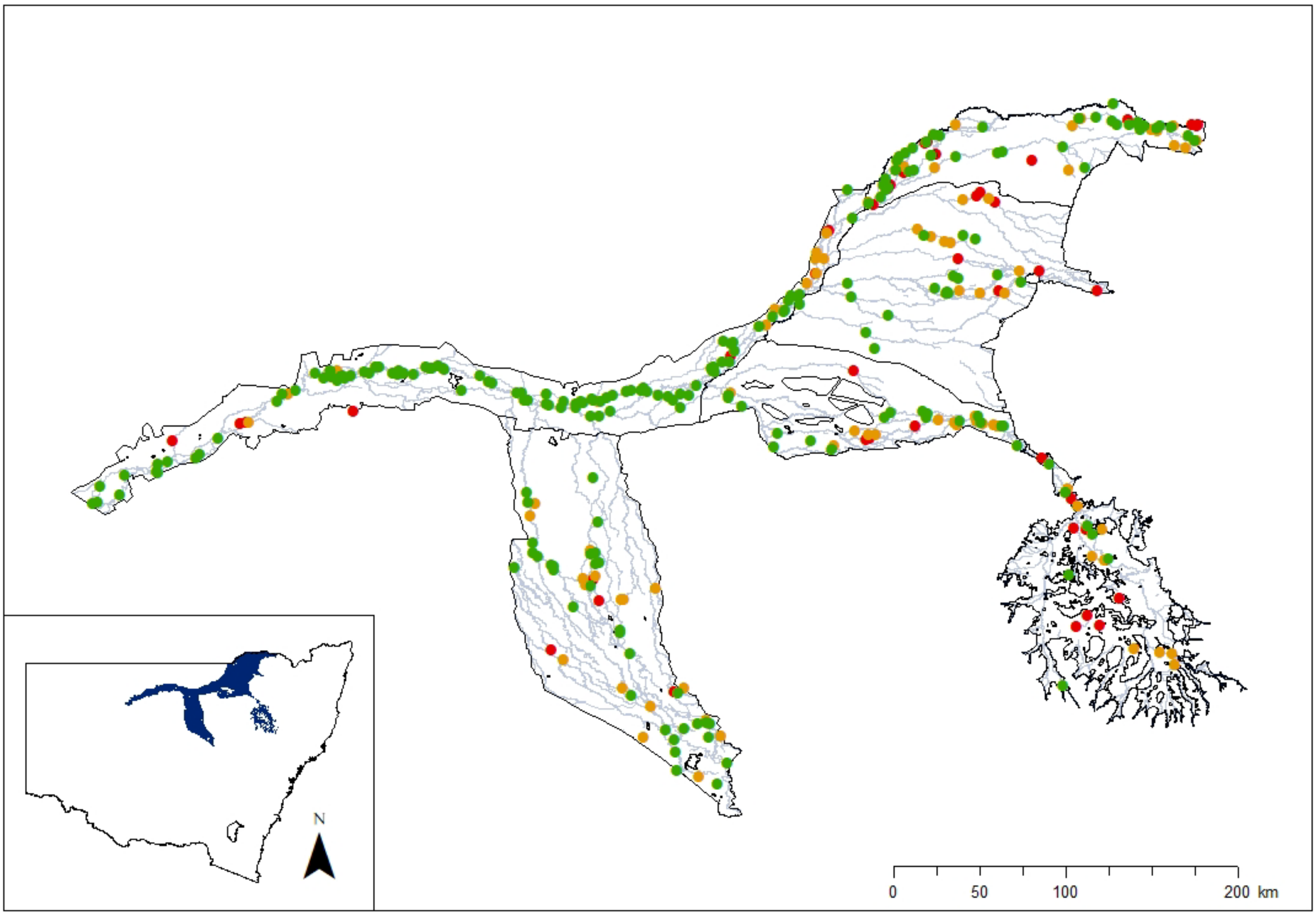


Figure 16: Map of the floodplain pools identified for water surface area tracking. If the surface area was well resolved through this method, the pools were selected for further analysis (green), while those that didn't resolve as well (orange) or at all (red) were excluded from further analysis

The total surface water area in the 212 prioritised floodplain pools somewhat aligns with broadscale climatic variability due to the El Niño – Southern Oscillation (ENSO) Index (Figure 17). Floodplain pools typically had smaller cumulative surface area during strong or extended El Niño events, which in Australia are associated with drier conditions. Conversely, strong La Niña events, which are associated with higher rainfall, typically result in higher surface areas of floodplain pools.

3.2.1.1 Long-term changes across the entire northern Murray–Darling Basin

The analysis of the mean monthly floodplain pool water surface area using Landsat imagery since 1987 shows a long-term trend of significant decline (Figure 18). There has been a similar trend in mean monthly river flow (Figure 18) and maximum monthly river flow (Figure 19), even though trends in mean monthly rainfall averaged across all the floodplains combined are not declining (Figure 18).

Mean monthly rainfall has significantly reduced within some valleys (see next section) (Figure 21). Although the declining long-term trend for floodplain pool inundation is significant, the slope is small, suggesting a gradual decline over the study period. The slope of decline was most likely reduced due to the extremely wet conditions experienced between 2020 and 2024, which also resulted in the largest areas of inundation since 1987 (Figure 17).

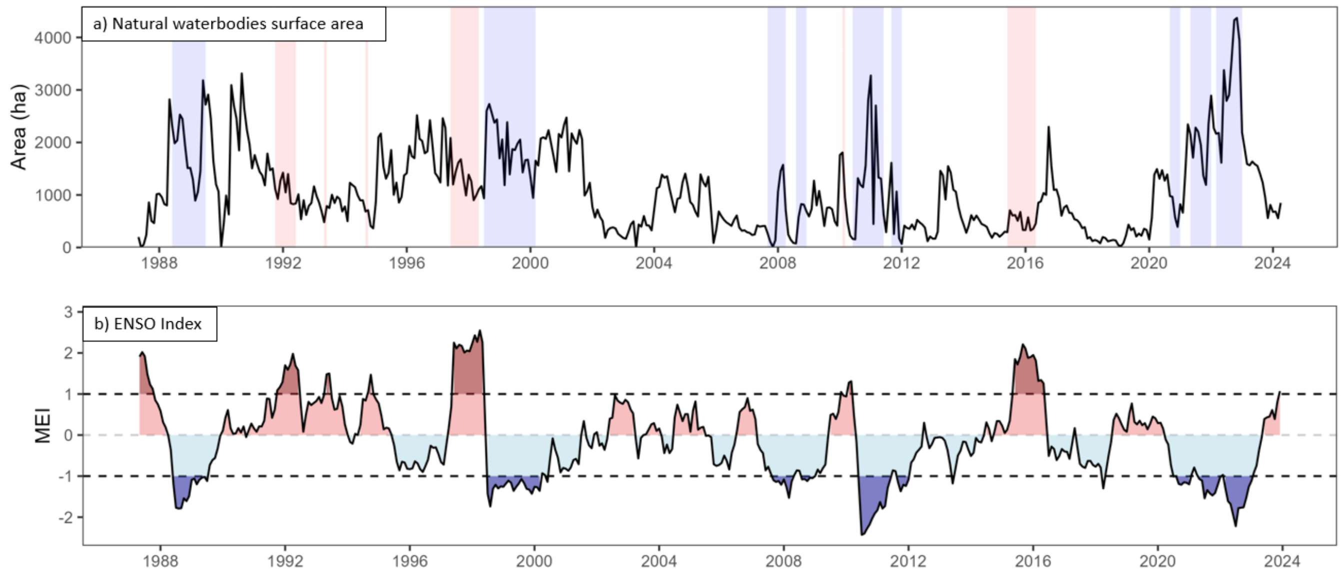


Figure 17: a) Total water surface area (ha) in all studied floodplain pools across the northern Murray–Darling Basin from 1987 to 2024. b) Multivariate El Niño – Southern Oscillation (ENSO) Index (MEI), where values greater than 0 indicate an El Niño phase, and values less than 0 indicate a La Niña phase. The shading in panel a) represents a stronger El Niño/La Niña phase (+/- 1 MEI), corresponding to the darker shade in panel b) above/below the dashed line

In contrast, the trend for water surface area within on-farm storages is increasing significantly (Figure 18), with the positive trend almost twice as strong as the declining trend in floodplain pool water surface area. Floodplain pool water surface areas were frequently higher and stable before 2002, after which the surface area within floodplain pools was depressed for long periods, with higher inundation around 2012 and after 2020 (Figure 18). This coincided with a rapid growth in on-farm storage water surface area up until the early 2000’s (Figure 10), followed by a period of stable on-farm storage area development with some small amounts of growth (Figure 18).

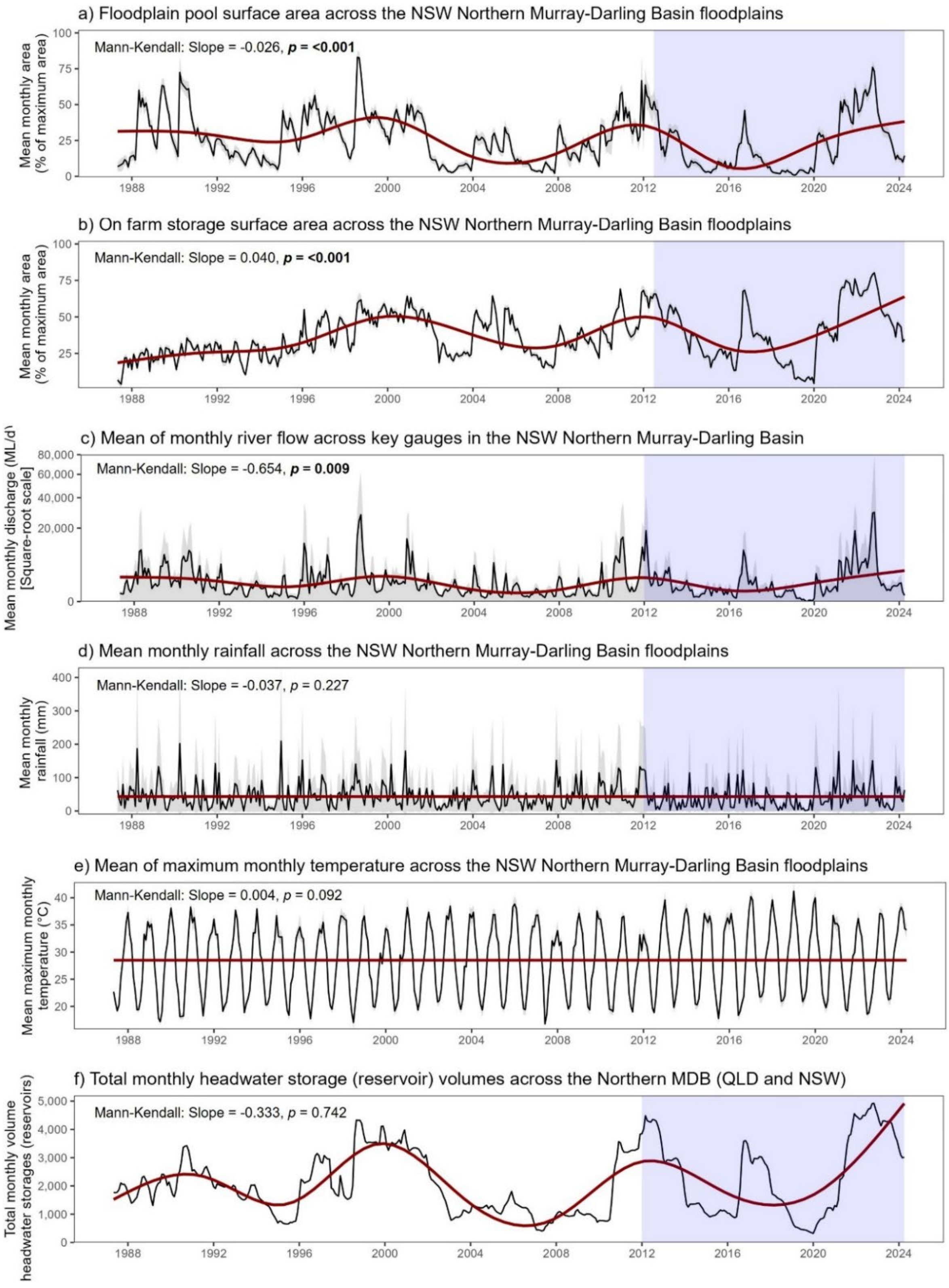


Figure 18: Time-series of monthly data for a) floodplain pool water surface area, b) on-farm storage water surface area, c) mean river flow, d) mean rainfall on the floodplain, e) maximum air temperature on the floodplain, and f) total headwater storage volumes. a) - e) represent means of monthly data with upper and lower 95th confidence intervals for sites within the floodplains of the NSW Border Rivers, Gwydir, Namoi, Macquarie and Barwon-Darling. f) is the total monthly data for all storages in Queensland and NSW to account for impacts into the Barwon-Darling. The trend line is a generalised additive model and Mann-Kendall shows the Sen's Slope (direction of change) and significance value (p) for the trend in the data

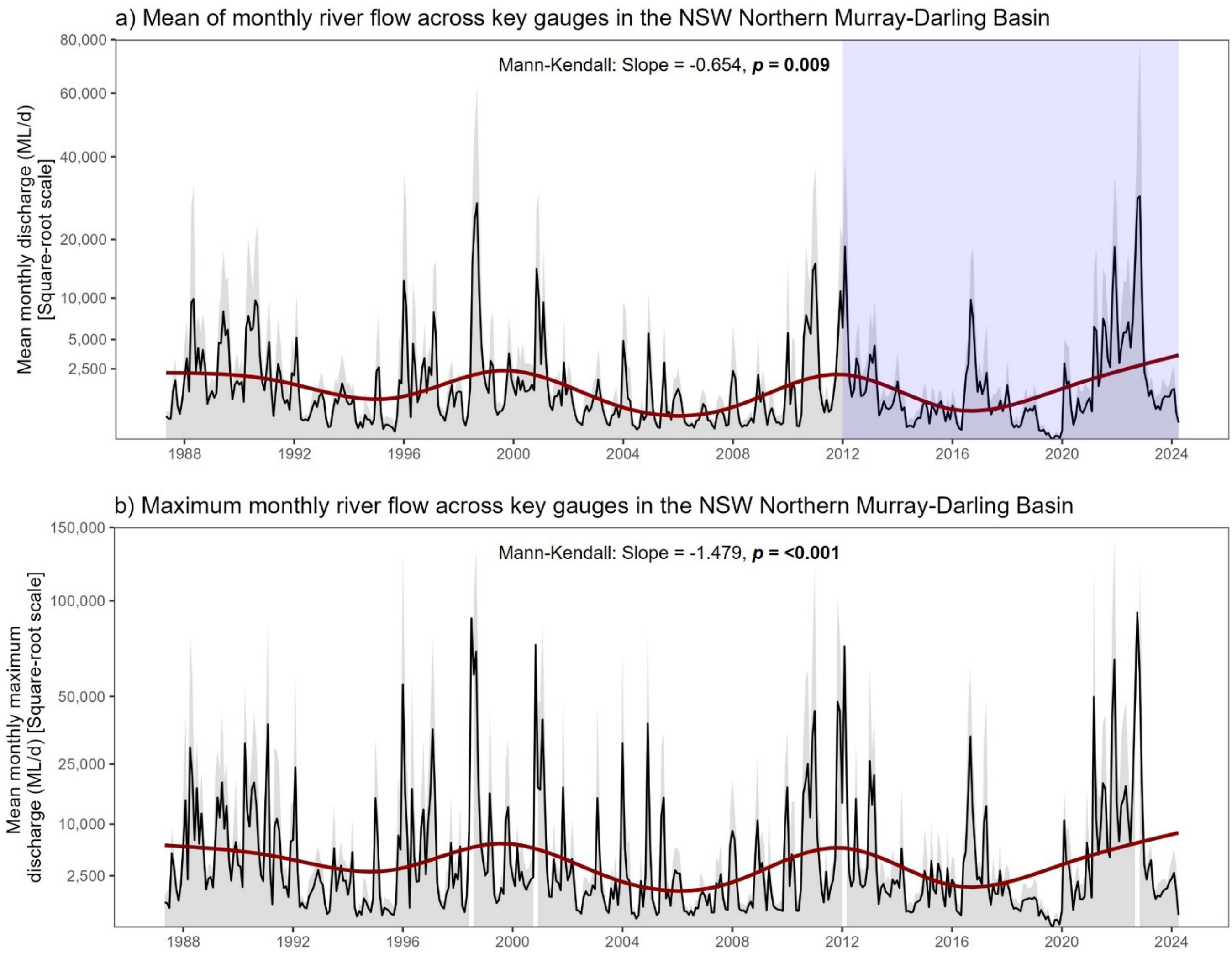


Figure 19: Long-term trends in river flows averaged across the NSW Border Rivers, Gwydir, Namoi, Macquarie and Barwon-Darling floodplain (restricted to one gauge per valley). a) shows the mean monthly river flow (ML/day), and b) is the mean of the maximum monthly river flow (ML/day) across all five valleys from 1987 to 2024. The shading in panels represents the Basin Plan period. The trend line is a generalised additive model and Mann-Kendall shows the Sen's Slope (direction of change) and significance value (p) for the trend in the data. Gauges include: 422002, 416201A, 418004, 419039 and 421090+421088 for the Barwon-Darling, NSW Border Rivers, Gwydir, Namoi and Macquarie valleys, respectively

3.2.1.2 Long-term changes at the valley scale

3.2.1.2.1 Macquarie

The Macquarie valley was the only valley that did not have a significant trend of reduced floodplain pool water surface area since 1987 (Table 7, Figure 20). There was also no significant declining trend in rainfall or mean monthly river flow (Figure 21). The Macquarie valley had contrasting trends for water development, with a significant trend of increased on-farm storage area and a trend of decreasing storage volumes held in headwater storages (Table 7). Average maximum temperatures across the Macquarie floodplain are also increasing (Table 7).

3.2.1.2.2 Namoi

The Namoi valley had the highest rate of significant decline in floodplain pool water surface area when comparing relative slopes (Table 7, Figure 20). The trend in mean monthly rainfall (Figure 21) and monthly mean and maximum river flow within the Namoi is also declining significantly, whilst on-farm storage surface area and maximum temperatures are increasing (Table 7).

3.2.1.2.3 Gwydir

The Gwydir valley had a relatively high rate of decline in floodplain pool water surface area between 1987 and 2024 (Table 7). It also has a significant increase in headwater storage volumes but no significant trend of increased on-farm storages within the same period (Table 7). The Gwydir did not show a significantly declining trend in mean monthly river flow even though floodplain pool inundation is declining (Table 7, Figure 20). However, there is a reduction in mean monthly rainfall across the catchment (Table 7, Figure 21).

3.2.1.2.4 NSW Border Rivers

Floodplain pool water surface area is declining significantly in this valley (Table 7, Figure 20), with mean monthly rainfall in both the NSW and Queensland Border Rivers also declining (Figure 21). Mean monthly river flows appear to remain relatively stable (Table 7). The largest trend in increased headwater storage volume was recorded within the NSW Border Rivers, more than double the slope of any other valley (Table 7).

3.2.1.2.5 Barwon-Darling

The Barwon-Darling had the greatest decline in floodplain water pool surface area when comparing raw surface area change (Figure 20). However, this is due to the large total surface area within the floodplain. When the slopes were standardised across valleys, the rate of decline was still significant, but the slope was not as steep as the Namoi and Gwydir (Table 7). There was a significant decline in mean and maximum monthly river flows within the Barwon-Darling, and 5 of the 7 key tributary catchments (including QLD) had a reduction in mean monthly rainfall (Table 7, Figure 21). In contrast to these declines, on-farm storage areas increased alongside maximum temperatures within the valley (Table 7).

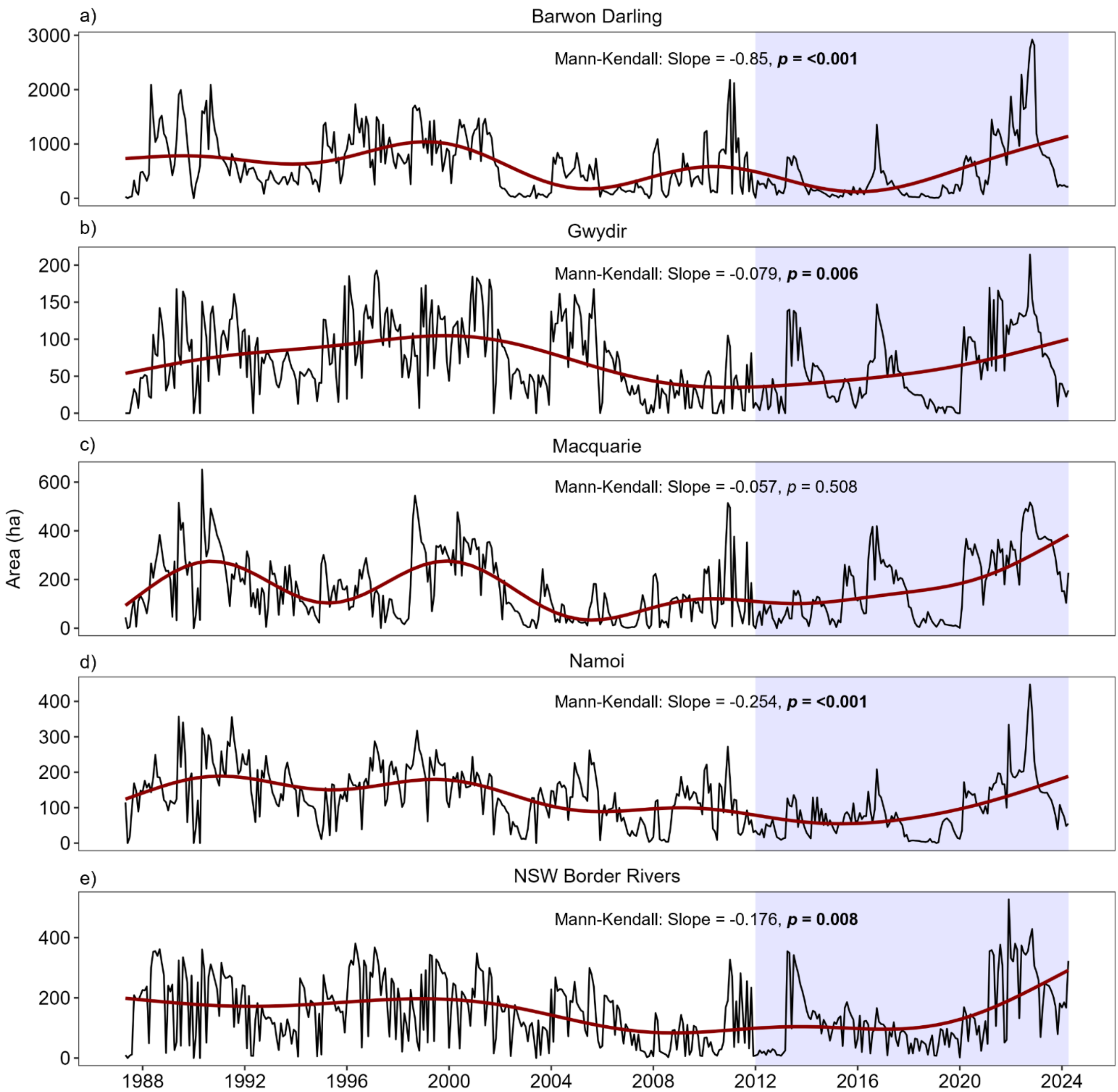


Figure 20: Total water surface area (ha) in all studied floodplain pools across the northern Murray–Darling Basin from 1987 to 2024 within the a) Barwon-Darling, b) Gwydir, c) Macquarie, d) Namoi and e) NSW Border Rivers valleys. The shading in panels represents the Basin Plan period. The trend line is a generalised additive model and Mann-Kendall shows the Sen's Slope (direction of change) and significance value (p) for the trend in the data

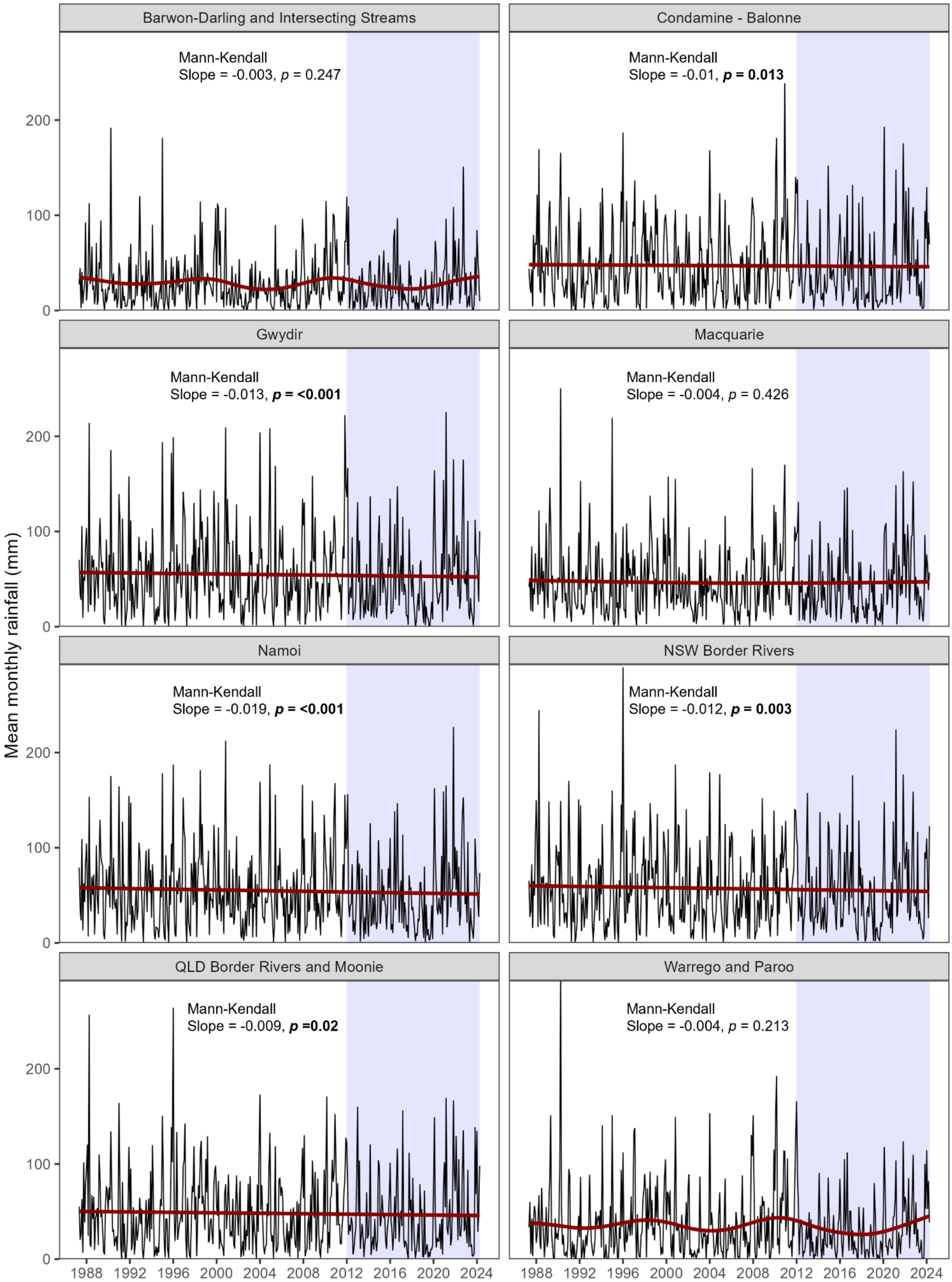


Figure 21: Mean monthly rainfall (mm) across the major catchments of the northern Murray–Darling Basin. The trend line is a generalised additive model and Mann-Kendall shows the Sen's Slope (direction of change) and significance value (p) for the trend in the data. The shading in panels represents the Basin Plan period

Table 7: Comparison of Mann-Kendall Sen's slope results and significance for monthly: mean floodplain pool water surface area; mean on-farm storage water surface area, mean monthly rainfall, mean monthly river flow, maximum monthly river flow, and mean monthly maximum temperature across the northern Murray–Darling Basin. Non-parametric Mann-Kendall tests were run on standardised data, with each variable converted to a % of the maximum within each dataset. Note: as NSW is the focus of this report, only Queensland rainfall data was analysed to assess changes in inflows into the Barwon-Darling and NSW Border Rivers

valley	Mean monthly floodplain pool surface area (% of max capacity/ month)	Mean monthly on-farm storage (% of max capacity/month)	Mean monthly storage volume in headwater storages (% of max capacity/month)	Mean monthly rainfall across the catchment (% of max mm/month)	Mean monthly river flow (% of max ML/month)	Maximum monthly river flow (% of max ML/month)	Mean monthly maximum temperature on the floodplain (% of maximum temp/month)
NSW Border Rivers	**-0.0151*****	**0.0535*****	**0.1055*****	**-0.0043****	-0.0003	-0.00009	**0.0092***
Gwydir	**-0.0391*****	0.0051	**0.0413****	**-0.0059*****	-0.0003	-0.0001	**0.0084*****
Namoi	**-0.0488*****	**0.0525*****	-0.0018	**-0.0083*****	**-0.003*****	**-0.0008****	**0.0059*****
Macquarie	-0.0106	**0.0398*****	**-0.0418***	-0.0014	-0.0050	-0.0141	**0.0066*****
Barwon-Darling	**-0.0248****	**0.0436***	-0.0319	-0.0017	**-0.0007*****	**-0.0011*****	**0.0088*****
Condamine-Balonne	Not assessed	Not assessed	Not assessed	**-0.0040***	Not assessed	Not assessed	Not assessed
QLD Border Rivers and Moonie	Not assessed	Not assessed	Not assessed	**-0.0032***	Not assessed	Not assessed	Not assessed
Warrego - Paroo	Not assessed	Not assessed	Not assessed	-0.0013	Not assessed	Not assessed	Not assessed

Note: The significance values are * = *p <0.05, ** = p <0.01, *** = p<0.001*

3.2.2 Changes to floodplain pool water surface area after Basin Plan implementation

3.2.2.1 Basin Plan changes at the valley scale

One of the key changes to water management that could influence the declining trends in floodplain pool water surface areas is the Basin Plan. The Basin Plan was developed in 2012 to manage the Basin connected system with full implementation of the plan ongoing. The analysis of floodplain pool water surface area before and after the Basin Plan presented here highlights that floodplain pool surface areas have decreased for most prioritised floodplain pools since the Basin Plan commenced in 2012 (Figure 22). This is primarily due to large reductions in water surface area within the Barwon-Darling valley and the Namoi valley (Figure 23). In total, 93% (86 of the 92) floodplain pools assessed within the Barwon-Darling valley and 85% (22 of 26) in the Namoi had a reduction in mean water surface area after the Basin Plan. This is compared to 69%, 45%, and 63% in the Gwydir, NSW Border Rivers and Macquarie, respectively.

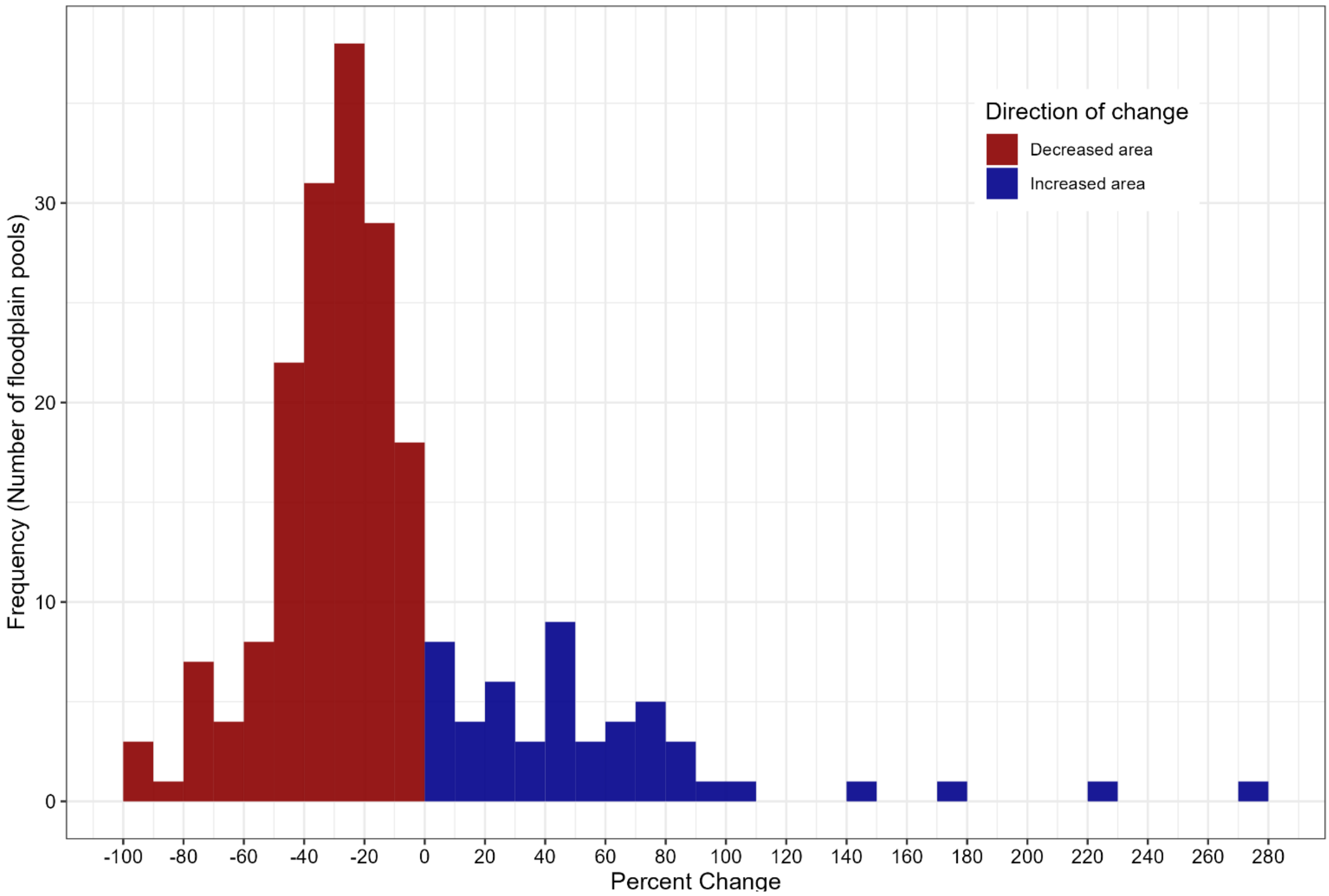


Figure 22: Percent change in surface areas within floodplain pools across the NSW northern Murray–Darling Basin before (Pre plan: May 1987 to November 2012) and after the Basin Plan (Plan: December 2012 – April 2024) was implemented. n = 295 months for the Pre plan period, and n = 149 months for the Plan period

The greatest decreased floodplain pool water surface areas occurred in the Namoi valley, in which the mean percent of total pool surface area decreased by 11.35% following the implementation of the Basin Plan. Large decreases are also evident in the Barwon-Darling (7.68%) and Gwydir (6.54%), whilst the NSW Border Rivers and Macquarie experienced minimal water surface area changes of -1.45% and -0.33% respectively.

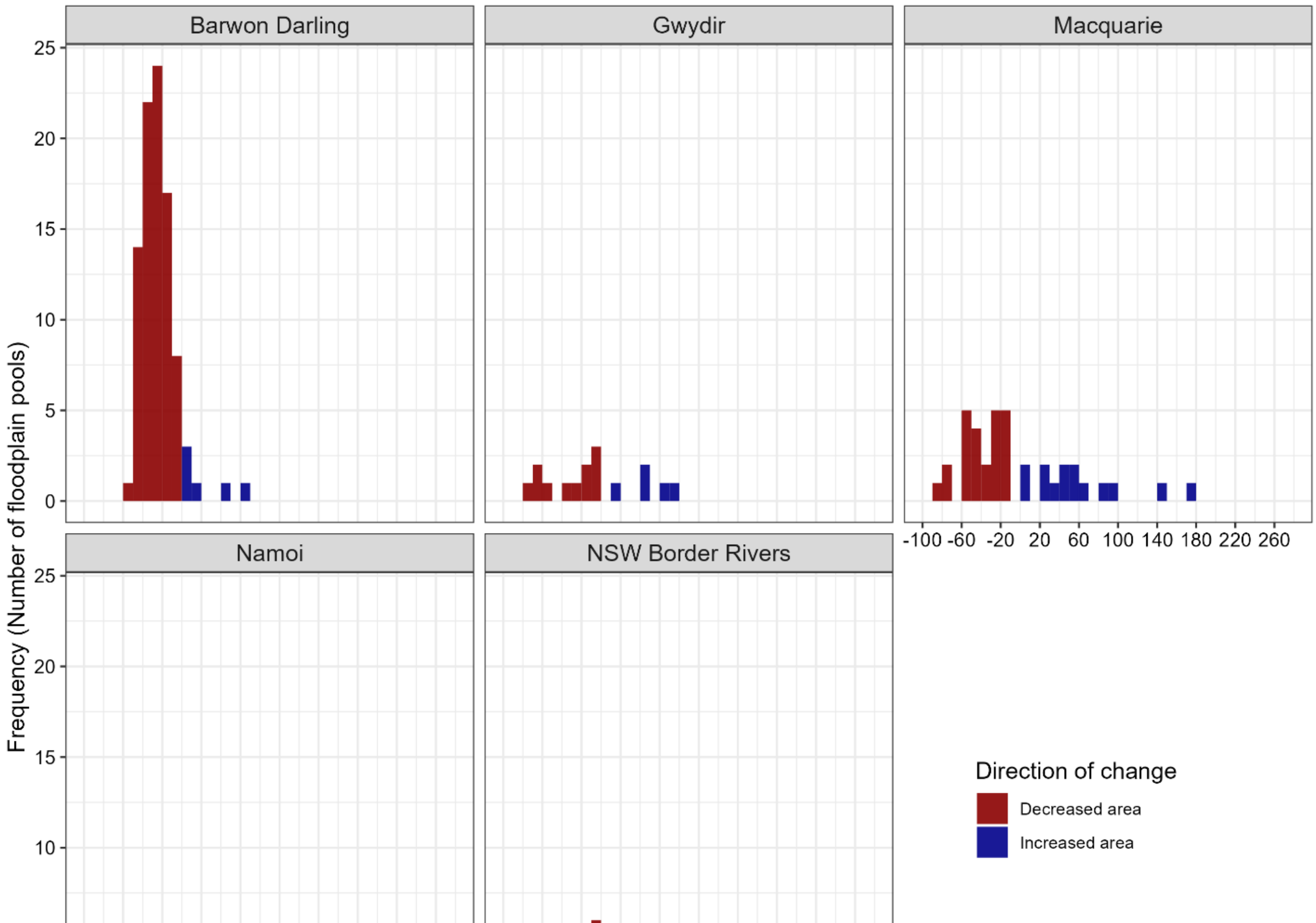


Figure 23: Percent change in surface areas within floodplain pools broken into the 5 NSW northern Murray–Darling Basin valleys before (Pre plan: May 1987 to November 2012) and after the Basin Plan (Plan: December 2012 – April 2024) was implemented. n = 295 months for the Pre plan period, and n = 149 months for the Plan period

3.2.2.2 Basin Plan changes at the site scale

Some of the broadscale valley changes can be further explained by an analysis of trends at a site scale. A time-series analysis of the change in monthly water surface area for the floodplain pools with the 20 largest reductions in mean area after Basin Plan commencement highlights that some of these changes are distinct, often occurring well before the Basin Plan commenced (Figure 24). Other changes appear to be gradual declines or possibly due to climatic variability. For example, at least 3 of the floodplain pools (NWB_00204, NWB_00203 and NWB_00205) show a distinct change in the early 2000s, suggesting the pools were highly modified or drained as inundation permanently ceased around this period (Figure 24).

In contrast, some floodplain pools remain inundated up until the end of the analysis, but the duration of inundation is reduced, and the water surface areas generally declining (for example, NWB_00106, NWB_00121, NWB_00238, NWB_00269, and NWB_00271) (Figure 24). An example of this occurred in the Gwydir valley, where the floodplain pool NWB_00271 became highly ephemeral after early 2002, coinciding with the development of an on-farm storage and larger crop areas (Figure 25).

Positive changes to floodplain pool water surface areas have also occurred since the Basin Plan commenced (Figure 26). While these changes are not as prevalent as the reductions recorded across floodplain pools in the northern Murray–Darling Basin, they are critical for supporting floodplain ecosystems. Some of the floodplain pools have improved by a mean of 0.4 hectares or more (20 largest improvements) after the Basin Plan commenced and show substantial and distinct changes around 2012 (Figure 26). Specifically, NWB_00184, NWB_00185, NWB_00186 and NWB_00187, which are within the Macquarie Marshes and can receive environmental water deliveries.

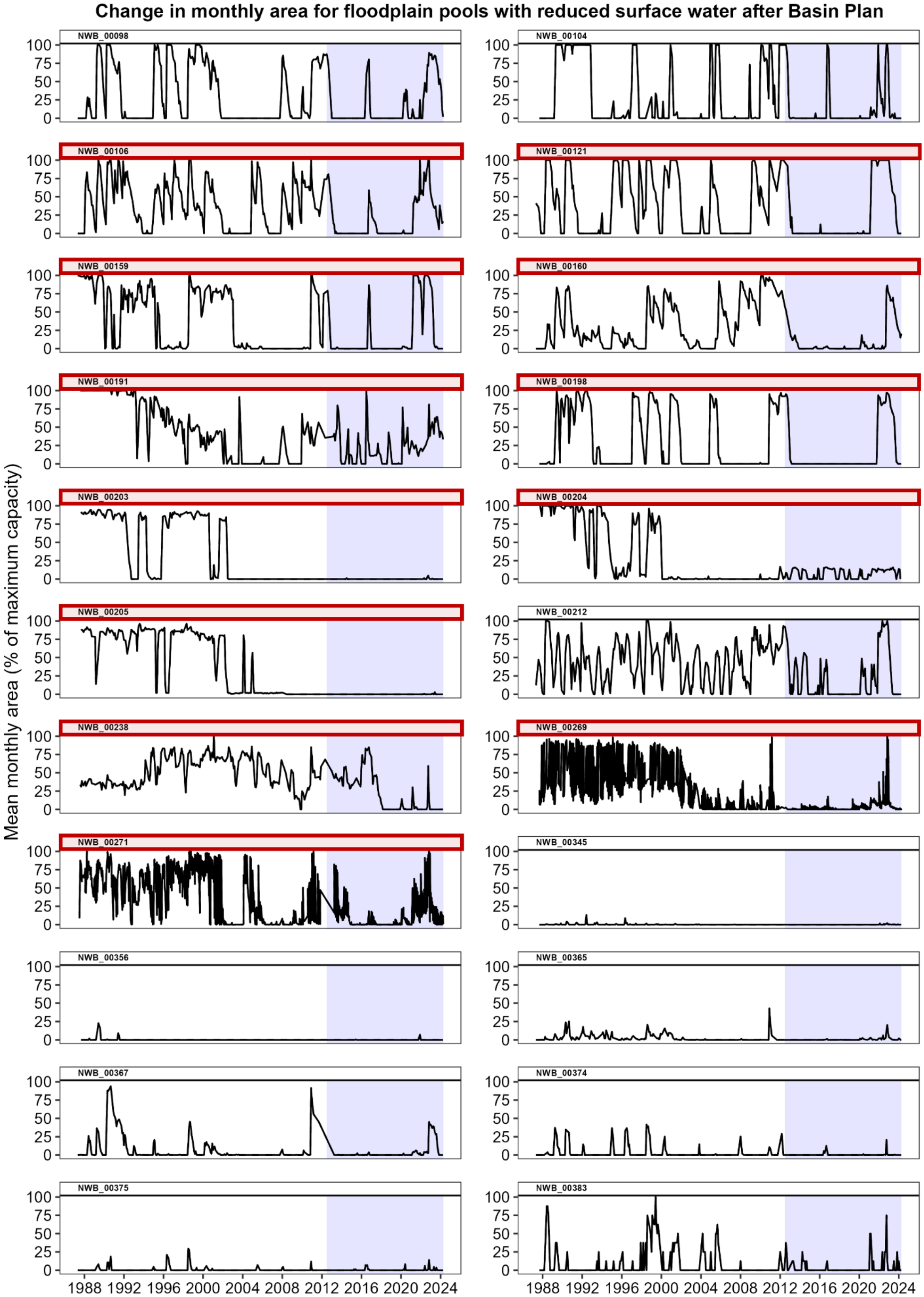
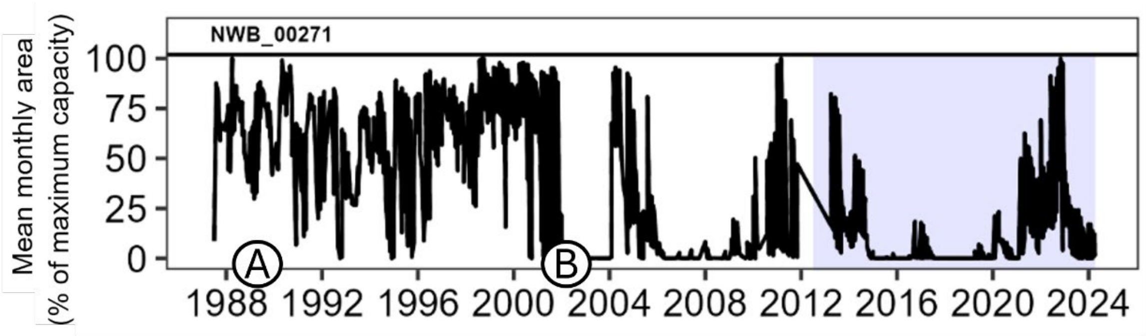


Figure 24: Floodplain pools which showed the largest average area reductions after the Basin Plan commenced (20 largest reductions in area). Red boxes highlight the pools that have obvious changes within the time-series data. NWB = the unique floodplain pool identification



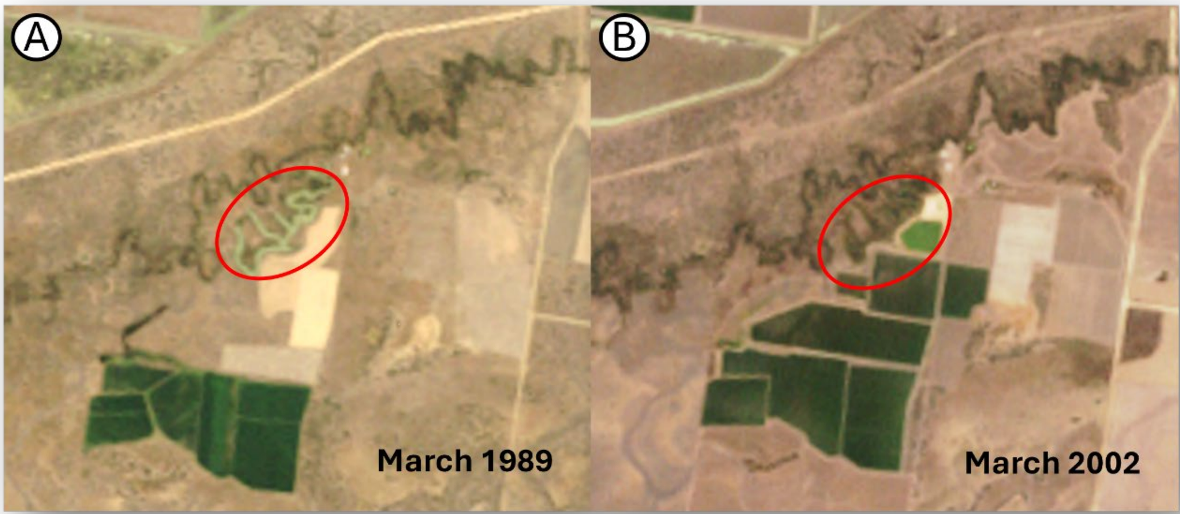


Figure 25: An example of a significant change in water surface areas within a floodplain pool in the Gwydir valley. The time-series plot shows the changes in surface area since May 1987, whilst the two Landsat images show the change from a natural lagoon in (A), possibly used as a storage in 1989, which then becomes more ephemeral after storage and crop development in 2002 (B). Landsat images sourced on 7/01/2025 from EO Browser (https://apps.sentinel-hub.com/eo-browser)

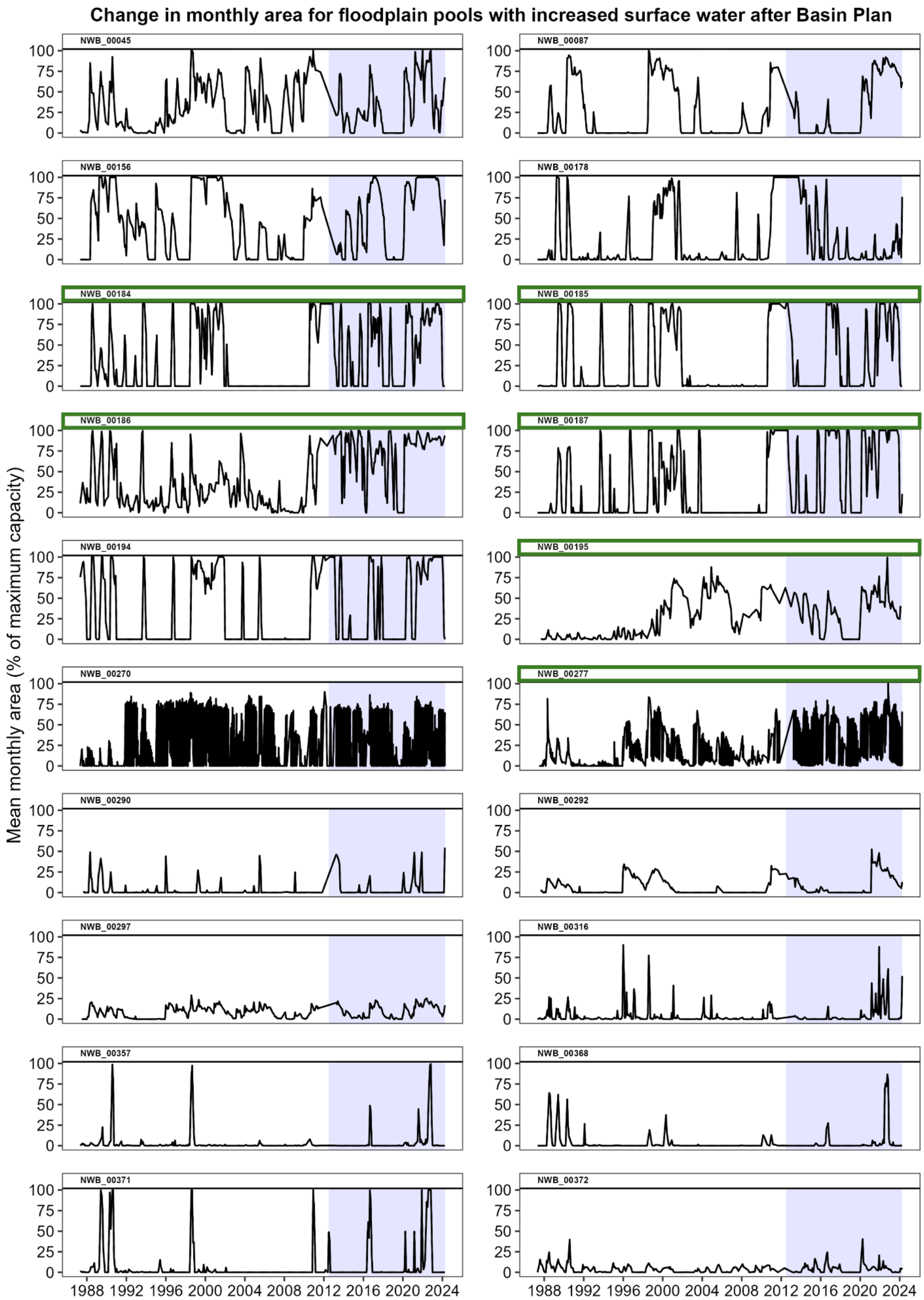


Figure 26: Floodplain pools which showed the largest average area improvements after the Basin Plan was implemented (20 largest improvements in the area). Green boxes highlight the pools that have obvious changes within the time-series data. NWB = the unique floodplain pool identification

3.2.2.3 Basin Plan changes in the Barwon-Darling

The Barwon-Darling floodplain receives tributary flows from numerous large rivers and has the greatest number of floodplain pools in the northern Murray–Darling Basin. In total, 38% of the pools identified in this study and more than 1,149 hectares of pool surface area are in the Barwon-Darling (Table 4). This makes the Barwon-Darling a critical floodplain pool hotspot for the northern Murray–Darling Basin.

The floodplain suffers from cumulative impacts due to development within the tributary valleys, including from diversions into on-farm storages, headwater flow capture into large reservoirs (for example, Copeton Dam), in-channel and floodplain diversions, as well as floodplain structures within tributary valleys. The Barwon-Darling valley itself also has a large volume of water entitlement and on-farm storages. In addition, the delivery of environmental water is restricted as the supply point (that is, storages) of environmental water are within the headwaters of tributary valleys, which means the receiving Barwon-Darling floodplain pools rely primarily on natural events, and the protection of these events.

The long-term trend in floodplain pool water surface areas within the Barwon-Darling has been in decline since 1987, whilst the on-farm storage water surface areas increased (Table 7, Figure 27). This declining trend is driven primarily by the periods of higher water surface areas between 1987 and 2002 and long periods of low water surface areas after 2002. The Barwon-Darling received at least two distinct periods of high inundation around 2010–12 and 2021–23. These periods were relatively short-lived compared to the periods prior to 2002. Further, the implementation of the Basin Plan has provided no clear signal in improved floodplain pool inundation, both on a valley scale (Figure 23 and Figure 27) and site scale (Figure 28).

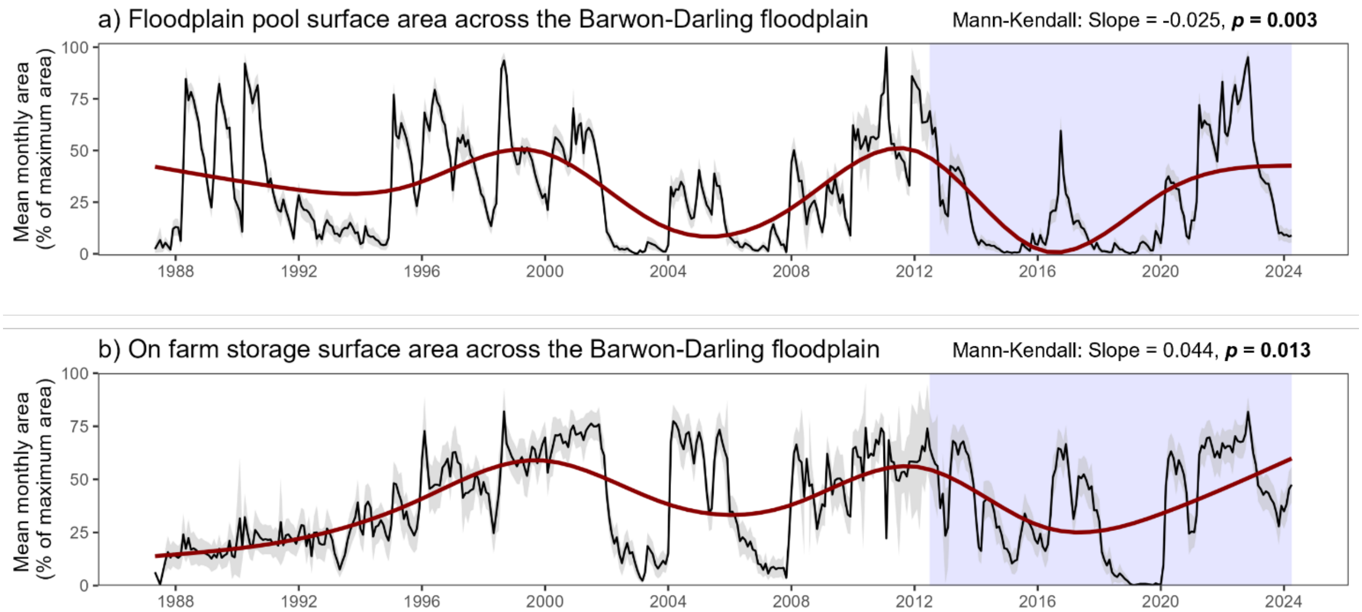


Figure 27: Time-series of monthly data for a) floodplain pool surface areas, b) on-farm storage areas in the Barwon-Darling valley. Both plots represent means of monthly data with upper and lower 95th confidence intervals in grey shading. GAM shows the generalised additive model significance value (p) for equation = variable ~ s(Date) and Kendall shows the Sen’s Slope (direction of change) and significance value (p) for the trend in the data

A time-series analysis of mean monthly water surface area changes for 6 key named floodplain pools in the Barwon-Darling (Figure 28) highlights no obvious trends after the Basin Plan was implemented. These floodplain pools appear to remain variable over time, with some evidence to suggest a decline.

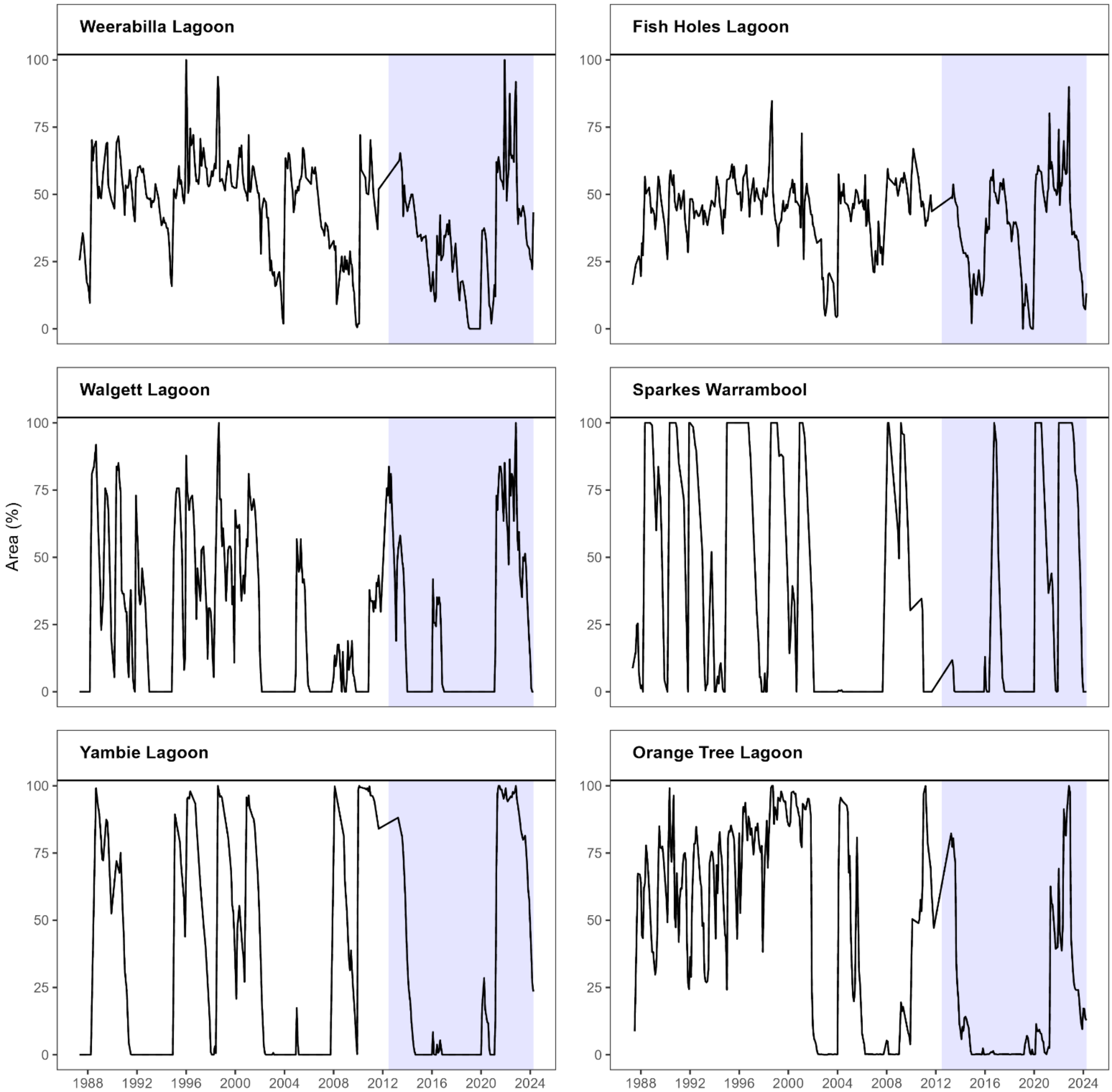


Figure 28: Mean monthly water surface area as a percent (%) of the maximum floodplain pool water surface area for 6 key floodplain pools in the Barwon-Darling valley. The light blue shading shows when the Basin Plan was implemented

3.2.2.4 Basin Plan changes due to environmental water

One of the main tools provided by the Basin Plan to improve the health of floodplain pools is the delivery of additional purchased environmental water, which contributes to the water already available by NSW water sharing plans (for example, the Gwydir Environmental Water Allowance). This purchased environmental water is considered discretionary as it can be delivered as desired by the environmental water manager. The water is allocated to key assets to maximise environmental benefits and mitigate potential risks.

3.2.2.4.1 Gwydir valley

A case study in the Gwydir valley shows that the use of environmental water influences the surface area retention of floodplain pools (Figure 29). Talmoi Waterhole, Baroona Waterhole and Racecourse Lagoon do not receive discretionary environmental water due to constraints in delivering water to these locations. These pools showed significant variability in water surface area and persistence across the period of available data, with a general trend towards increased drying post-2012 (Figure 29, Panel 1). These pools were observed to have an average increase of 14.3% in time spent completely dry and a 9% reduction in time spent when over half of the total surface area is inundated.

In contrast, the delivery of discretionary environmental water to Bunnor Waterbird Lagoon has led to improvements in both persistence and surface area retention. Since 2012, this pool has been observed to have a 43% reduction in drying events and an 83% increase in the time spent at over half of the total surface area. Other sites have also been maintained by environmental water, with no major reductions occurring for the Gingham Waterhole (downstream of Bunnor), which had a 1% decrease in time spent dry and a 1% increase in time spent over half of the total surface area. Conversely, e-water has resulted in no improvement for Boyanga Waterhole (downstream of Gingham Waterhole), which is observed to behave similarly to a pool not receiving e-water deliveries, with a 30% increase in time spent dry and 28% decrease in time spent at over half of the total surface area. These varied outcomes suggest that while the Basin Plan has contributed to improving the surface area and retention of some floodplain pools, its impact is not uniform.

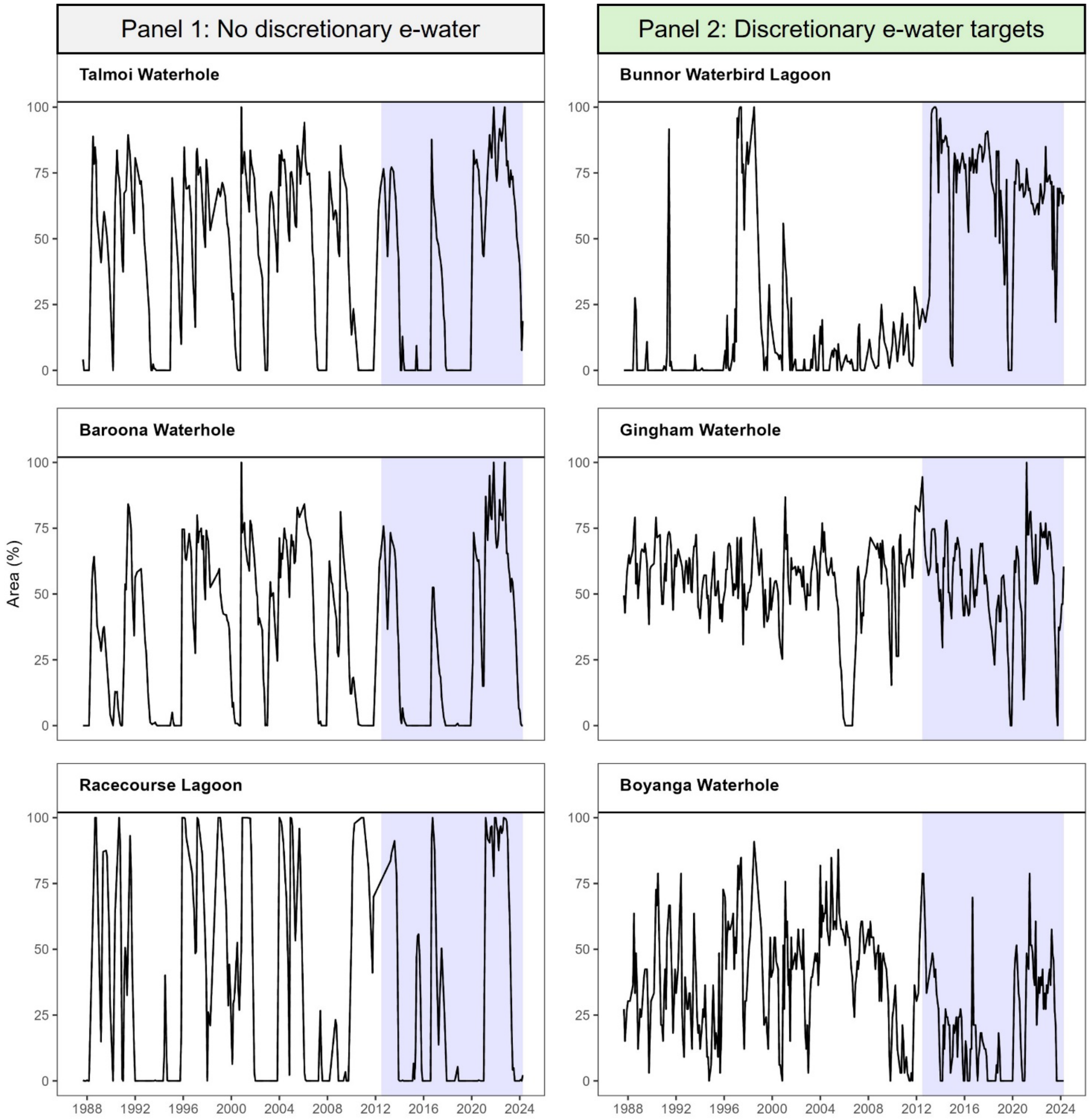


Figure 29: Surface area as a percent (%) of the maximum surface area for 6 key floodplain pools in the Gwydir valley. The left panel (panel 1) shows 3 sites that are not targets for discretionary environmental water due to the constraints in delivering water to these lagoons. The right panel shows 3 sites that all fall within the Gingham watercourse and can be targeted with discretionary environmental water. The light blue shading shows when the Basin Plan was implemented

3.2.2.4.2 Macquarie valley

A second case study in the Macquarie valley shows that the delivery of environmental water has had positive impacts on the surface area retention of floodplain pools within core wetlands.

Two unnamed floodplain pools within the Macquarie valley (NWB_00178 and NWB_00191) do not receive discretionary e-water due to constraints in delivering water to these locations. These pools showed different surface area and drying responses post-2012 (Figure 30, Panel 1). NWB_00178 showed no change in the percent of the time at over half of the total surface area, however, showed a 32% decrease in time dry. Conversely, NWB_00191 showed a 32% reduction in the time over half the total surface area, but no change in time dry. This is in comparison to two discretionary e-water targets (NWB_00187, NWB_00186) that have had substantial improvements since 2012.

The delivery of discretionary e-water to NWB_00187 has led to improvements in both persistence surface area retention. Since 2012, this pool has been observed to have a 35% reduction in time spent dry and a 32% increase in time spent at over half of the total surface area. A second pool capable of receiving e-water, NWB_00186, showed a 67% increase in time spent at over half the total surface area but no change in time dry. Although the time spent dry remained constant or improved regardless of the delivery of e-water across all sites, surface area retention improvements were only seen in pools that received discretionary e-water. This shows that the Basin Plan and associated water sharing plan environmental allowances are contributing to improved surface area retention of pools in the Macquarie valley.

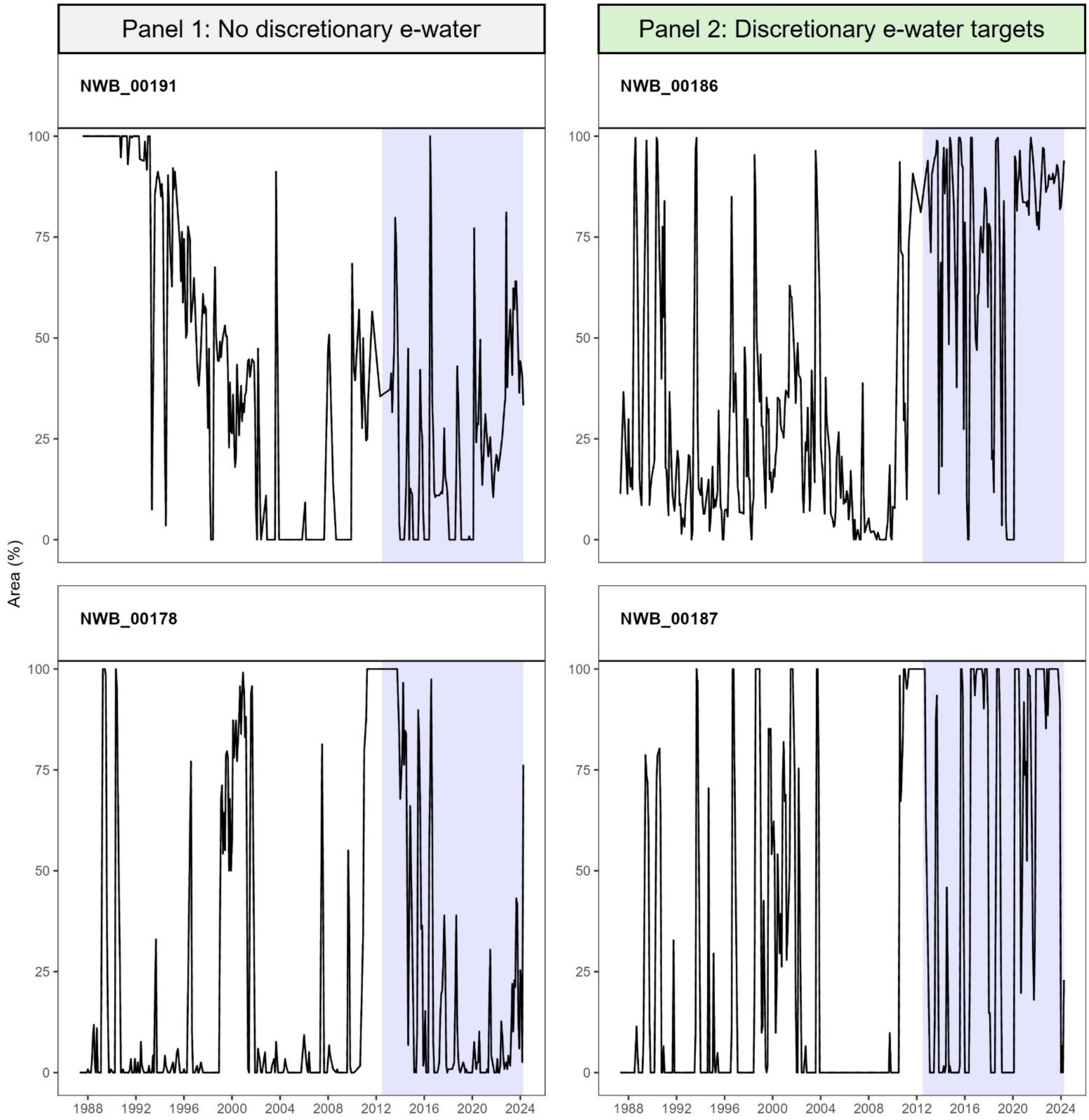


Figure 30: Surface area as a percent (%) of the maximum surface area for 4 floodplain pools (NWB_ID = unnamed lagoons) in the Macquarie valley. The left panel (panel 1) shows 2 sites that have not received discretionary environmental water due to the constraints in delivering water to these floodplain pools. The right panel shows 2 sites that are within the Macquarie Marshes and can be targeted with discretionary environmental water. The light blue shading shows when the Basin Plan was implemented

3.3 Water-dependent fauna and floodplain pools

There are two key questions we aim to answer to understand what water-dependent fauna use floodplain pools and the importance of connectivity and inundation, these are:

Section 3.3.1: Q1 What fauna do floodplain pools support in the northern Murray–Darling Basin?

Section 3.3.2: Q2 What is the influence of floodplain pool characteristics on the presence of key fauna species in floodplain pools?

3.3.1 Fauna within the floodplain pools of the northern Murray–Darling Basin

3.3.1.1 Fauna richness and composition

A total of 75 different fauna taxa were recorded across the 35 pools sampled between 2021–23. Forty (53%) of the taxa detected are considered water-dependent, including native fish, waterbirds, turtles, frogs and rakali. The most common species was spangled perch (*Leiopotherapon unicolor*), which was found at all sites, followed closely by the bony herring (*Nematalosa erebi*) found at 34 sites and golden perch (*Macquaria ambigua*) found at 27 sites (Figure 31, Figure 32). Waterbirds were the most diverse (20 taxa) and second most common group of fauna, specifically the Australian wood duck (*Chenonetta jubata*), little pied cormorant (*Microcarbo melanoleucos*), little black cormorant (*Phalacrocorax sulcirostris*), and the Nankeen night heron (*Nycticorax caledonicus*). Some of the rarer fauna included the threatened blue-billed duck (*Oxyura australis*) and Murray cod (*Maccullochella peelii*), which were only detected at one site (Figure 31).

At a site scale, the highest fauna richness was recorded at the Gingham Waterhole within the Gwydir valley (13 taxa), followed by the Myall Camp Warrambool site in the Namoi valley (12 taxa). The lowest number of fauna taxa was detected at Maynes Lagoon and Carwall Waterhole in the NSW Border Rivers, with only 5 taxa found (Figure 33). Rakali and turtles were only present at 7 and 9 sites, respectively. The maximum number of native fish species detected was 6, at the Goonal Creek site within the Gwydir valley and Gulligal Lagoon in the Namoi. The species at both sites were the same: golden perch, spangled perch, bony herring, Murray–Darling rainbowfish, Australian smelt, and carp gudgeon. Site based records are provided in Appendix 7.3.

Whilst water-dependent fauna were the target of this study, 35 other fauna species or taxa were also recorded across the 35 floodplain pools. This suggests that floodplain pool habitats are also important for terrestrial fauna that are not considered water-dependent fauna. The species included a range of mammals and birds, such as the swamp wallaby, sugar glider, emu, tawny frogmouth, white plumed honeyeater and cockatiels. A full list of terrestrial species is provided in Appendix 7.4.

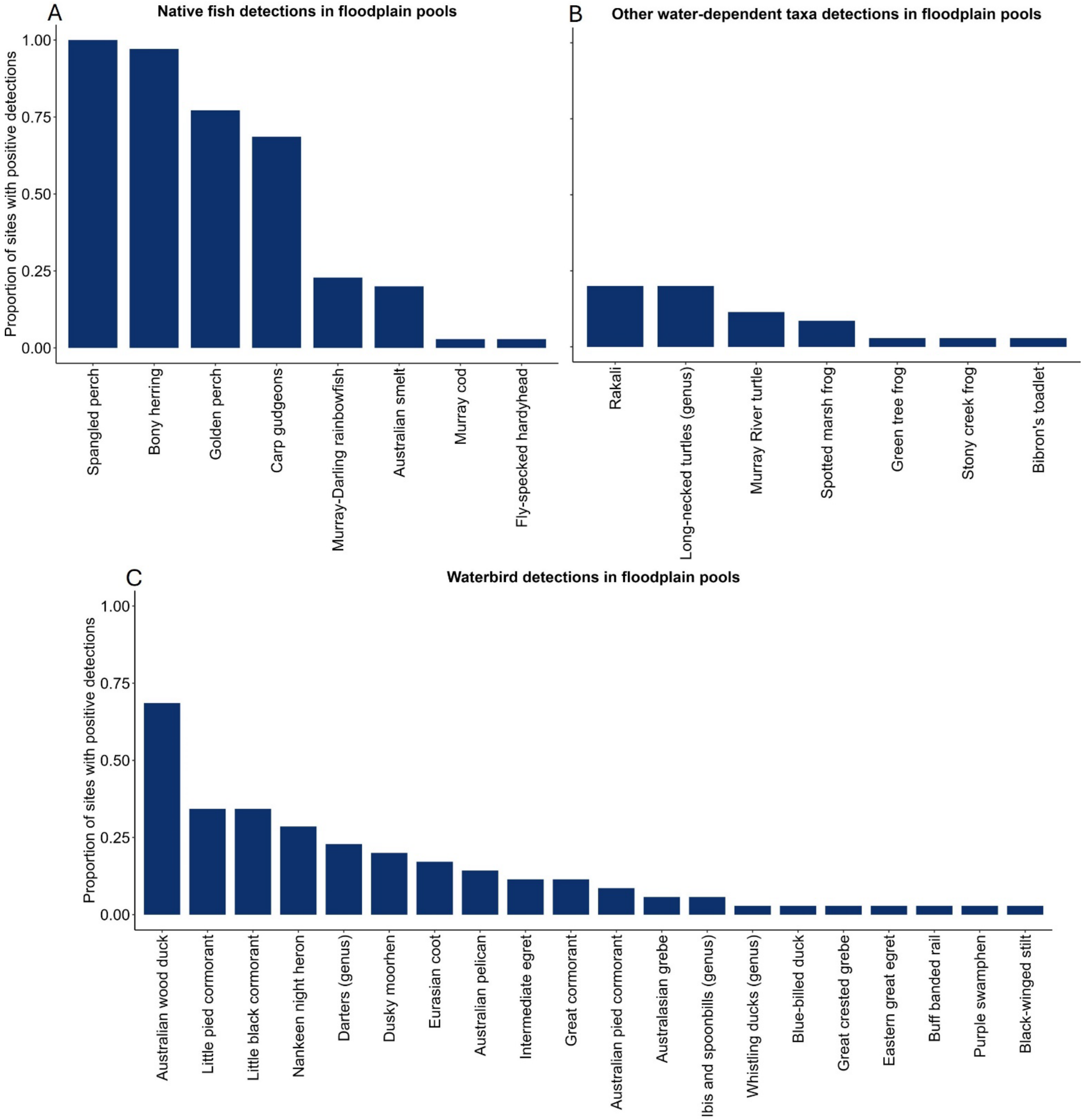


Figure 31: The proportion of sites (total sites = 35) that had positive detections for (A) native fish taxa, (B) other water-dependent taxa, and (C) waterbird taxa

Figure 32: Images of the 8 most common water-dependent fauna found across 35 floodplain pools in the northern Murray–Darling Basin, along with the number of sites where they were detected, are shown. A. spangled perch (Leiopotherapon unicolor), B. bony herring (Nematalosa erebi), C. golden perch (Macquaria ambigua), D. Australian wood duck (Chenonetta jubata), E. western carp gudgeon (Hypseleotris klunzingeri), F. little pied cormorant (Microcarbo melanoleucos), G. little black cormorant (Phalacrocorax sulcirostris), and H. Nankeen night heron (Nycticorax caledonicus). Photo credits: A, B, C, E from Gunther Schmida, D and H from Ed Dunens, F from Lip Kee, and G from Bernard Spragg

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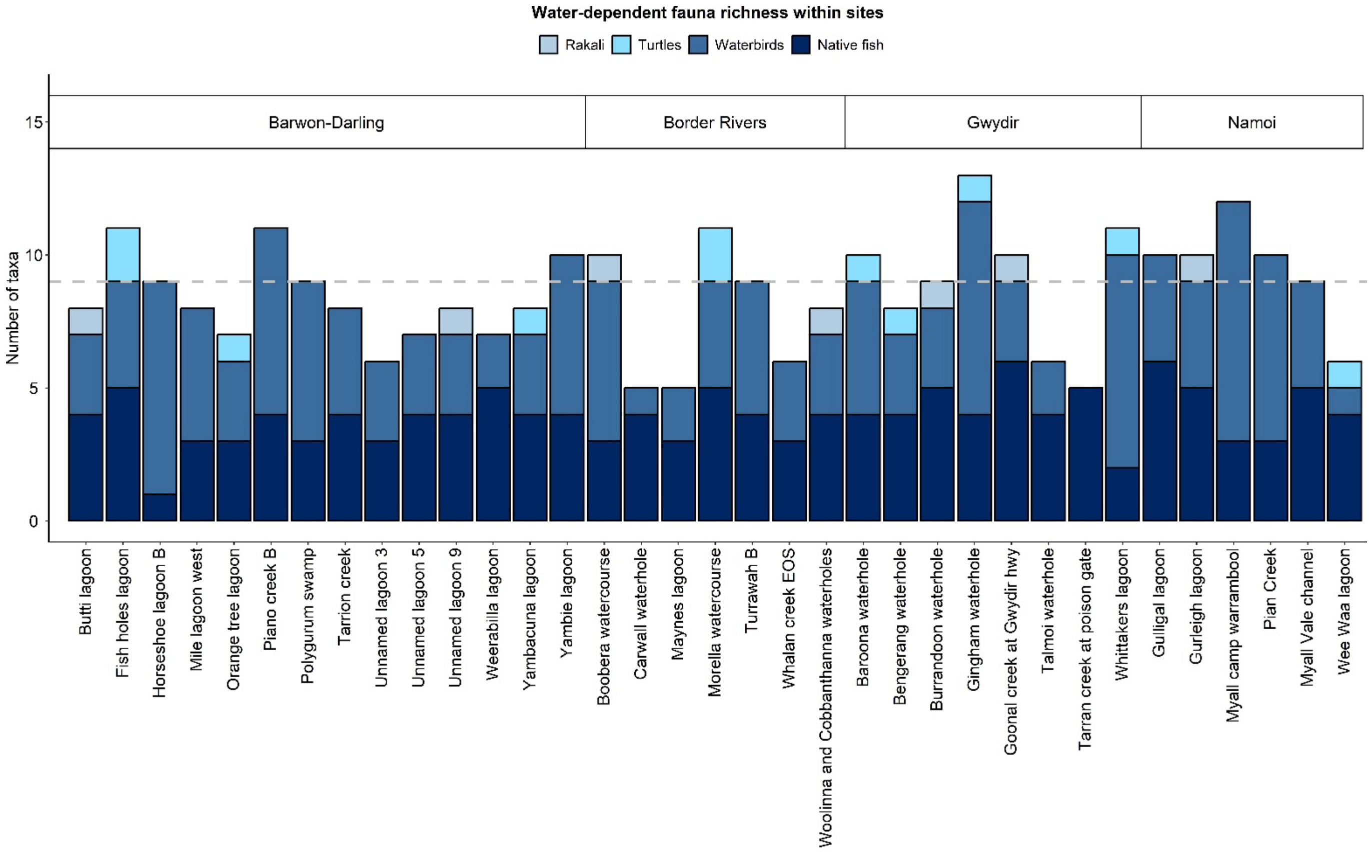

Figure 33: Total number of taxa detected at each site, broken into native fish, rakali (water rat), turtles and waterbirds. The grey dashed line represents the median number of taxa across all 35 sites

3.3.1.1.1 Differences among valleys

There was no significant difference (F(3,31) = 2.22, p = 0.106) in the number of water-dependent taxa detected across each valley (Figure 34). However, the Barwon-Darling valley had relatively lower fauna richness compared to the Namoi and Gwydir. Some fauna were detected in at least one site across each of the valleys, for example, the Rakali (*Hydromys chrysogaster*), others were limited to one valley. For example, the blue-billed duck was only detected in the Barwon-Darling, and the fly-specked hardyhead (*Craterocephalus stercusmuscarum*) was only found in one site within the Namoi.

In contrast to fauna richness, the assemblage of different taxa across valleys was significantly different (F = 3.87, df = 3,31, p = 0.001, Figure 34). These differences were driven by the Barwon-Darling, which was significantly different to all other valleys (all pair-wise tests had a p value <0.01). Some of the key fauna driving these differences were the more frequent presence of the Murray–Darling rainbowfish, Murray River turtle, Australian pied cormorant, and darters of the genus Anhinga within the Barwon-Darling. The Barwon-Darling also had the only detections for the eastern great egret, black-winged stilt, great cormorant and blue-billed duck. In contrast, the Barwon-Darling had few or no sites, including the Nankeen night heron, dusky moorhen, plus Ibis and spoonbills from the genus Platalea.

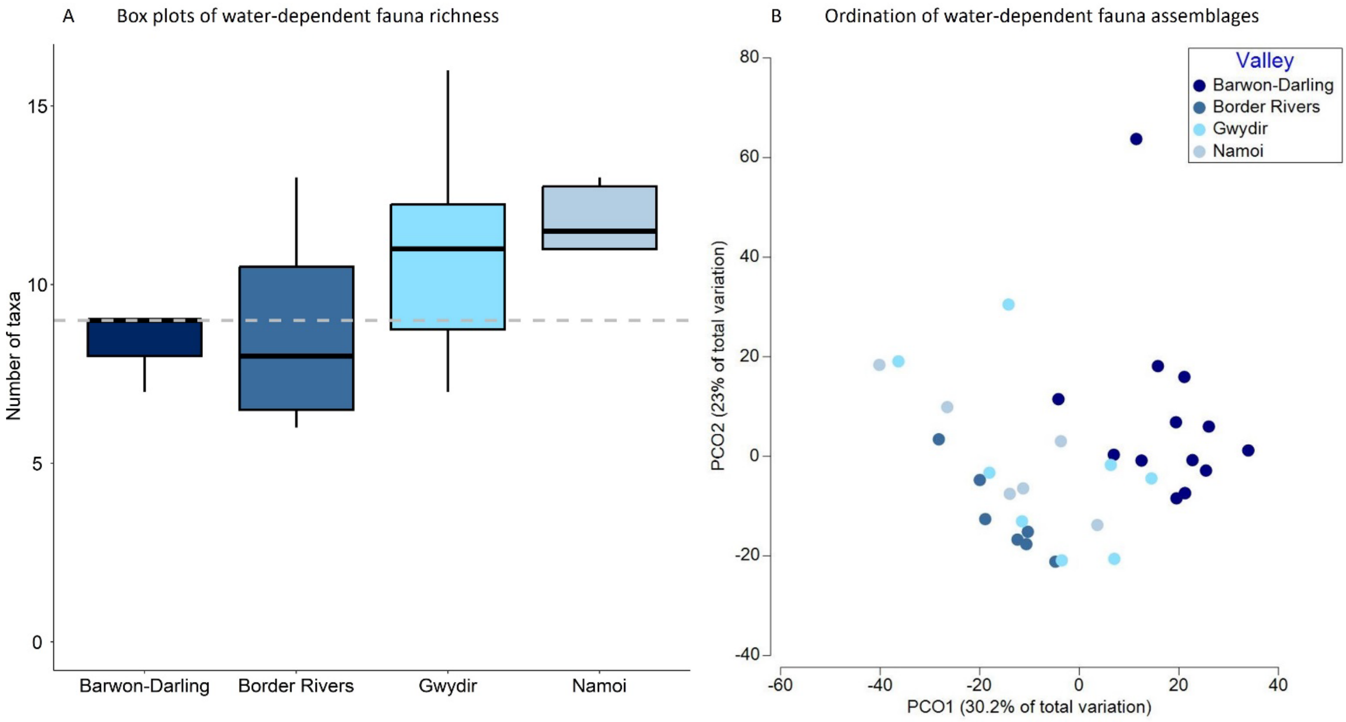

Figure 34: A. Box plots of the number of fauna taxa for native water-dependent fauna in the Barwon-Darling (sites = 14), Border Rivers (sites = 7), Gwydir (sites = 8), and Namoi (sites = 6) valleys. The grey dashed line represents the median number of taxa across all 35 sites. B. Principal Coordinate Analysis (PCoA) of fauna community Bray-Curtis dissimilarities for the 4 valleys. The PCoA is based on the presence/absence of native fish, waterbirds, rakali and turtles

3.3.2 Influence of floodplain pool characteristics on the presence of key fauna

3.3.2.1 Presence of key fauna and floodplain pool characteristics

We investigated the influence of a range of floodplain pool characteristics on the diversity of waterbirds and native fish, as well as the presence of key fauna. The key fauna investigated were the 8 most common species listed in Figure 32.

3.3.2.1.1 Golden perch

Golden perch were detected at 27 of the 35 (77%) floodplain pool sites (Figure 35). However, there was no significant association between the presence of golden perch and the floodplain pool predictors: surface area, depth, maximum water persistence, time since last connection, minimum flow path distance, and vegetation structural diversity. The odds of golden perch occurring at any one site were relatively high and likely to be due to chance based on the marginally significant intercept (Estimate = 8.67, SE = 4.89, z = 1.77, p = 0.077. Table 11 Appendix 7.5).

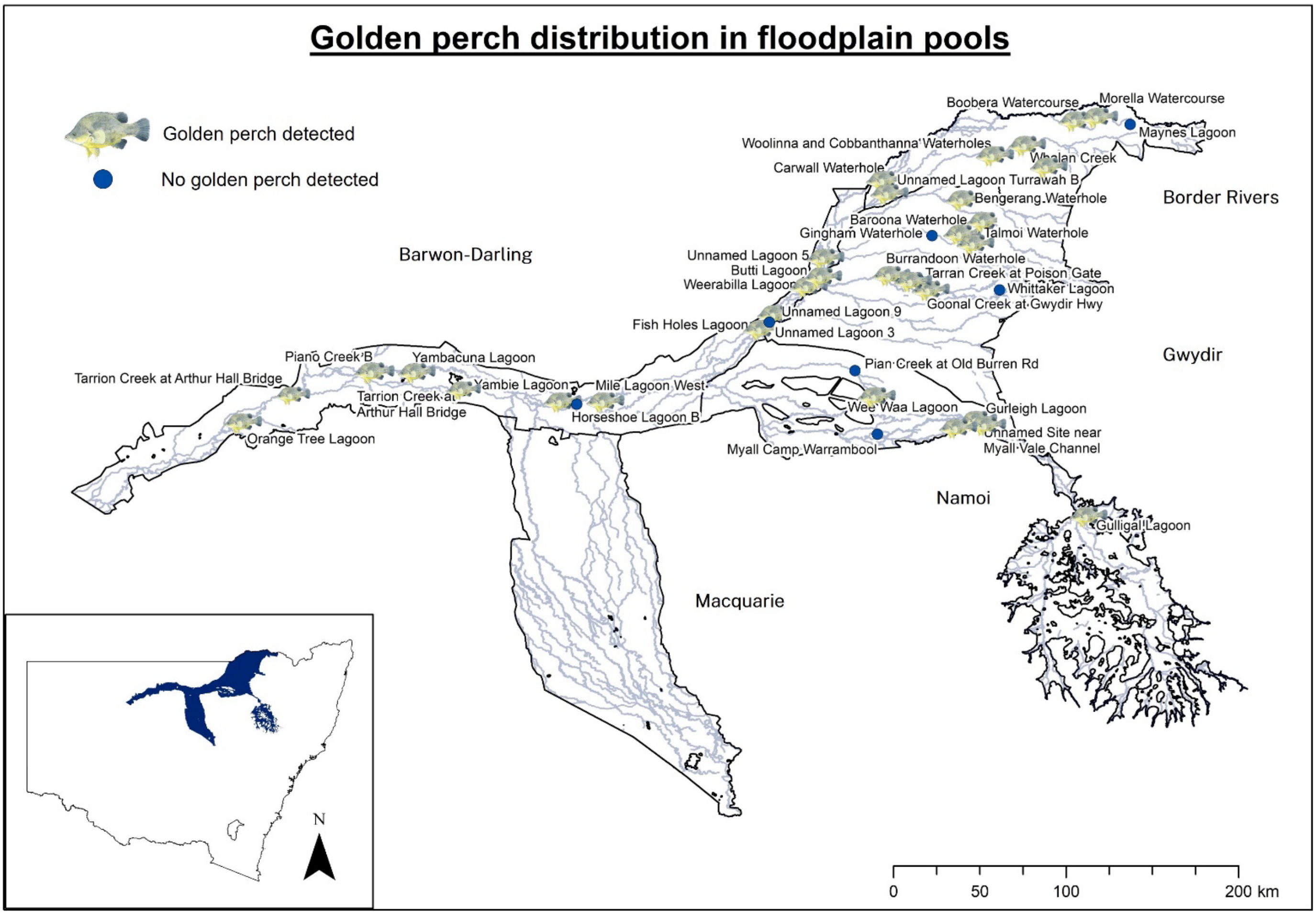

Figure 35: Distribution of golden perch across the surveyed floodplain pool sites. Note that the blue circles have not been sampled yet

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3.3.2.1.2 Carp gudgeons

Carp gudgeons of the genus Hypseleotris were detected at 24 of the 35 (69%) floodplain pool sites. There was a significant association between the presence of carp gudgeons and increased pool depth (Estimate = 0.05, SE = 0.03, z = 1.83, p = 0.07) and increased time since the last connection (Estimate = -0.06, SE = 0.03, z = 2.20, p = 0.03) (Figure 36, Table 11 in Appendix 7.5). No other tested pool characteristics were associated with the presence of this genus.

3.3.2.1.3 Murray–Darling rainbowfish

Murray–Darling rainbowfish were detected at 8 of the 35 (23%) floodplain pool sites. There was no significant association between the presence of this species and the floodplain pool predictors used in this analysis: surface area, depth, maximum water persistence, time since last connection, minimum flow path distance, and vegetation structural diversity.

3.3.2.1.4 Australian smelt

Australian smelt were detected at 7 of the 35 (20%) floodplain pool sites. There was a significant association between the presence of Australian smelt and increased pool depth (Estimate = 0.09, SE = 0.04, z = 2.23, p = 0.03) and reduced time since the last connection (Estimate = -0.06, SE = 0.03, z = -1.87, p = 0.06) (Figure 36, Table 11 in Appendix 7.5). No other tested pool characteristics were associated with the presence of this species. Surprisingly, there were no detections of Australian smelt in the Barwon-Darling floodplain pools, even though they are found within the main channel (Schilling & Crook, 2023).

3.3.2.1.5 Australian wood duck

Australian wood ducks were detected at 24 of the 35 (69%) floodplain pool sites. There was no significant association between the presence of wood ducks and the floodplain pool predictors used in this analysis: surface area, depth, maximum water persistence, time since last connection, minimum flow path distance, and vegetation structural diversity (Table 12 in Appendix 7.5).

3.3.2.1.6 Little pied cormorant

Little pied cormorants were detected at 12 of the 35 (34%) floodplain pool sites. There was no significant association between the presence of little pied cormorants and the floodplain pool predictors used in this analysis: surface area, depth, maximum water persistence, time since last connection, minimum flow path distance, and vegetation structural diversity.

3.3.2.1.7 Little black cormorant

Little black cormorants occurred at 12 of the 35 (34%) floodplain pool sites. There was a significant association between the presence of little black cormorants and reduced surface area (Estimate = -0.09, SE = 0.02, z = -2.52, p = 0.012) and increased maximum persistence of a pool (Estimate = 0.05, SE = 0.03, z = 1.98, p = 0.048) (Figure 36, Table 12 in Appendix 7.5). However, the slope of the model indicates that the influence on presence is relatively minor. No other tested pool characteristics were associated with the presence of this species.

3.3.2.1.8 Nankeen night heron

Nankeen night herons occurred at 10 of the 35 (29%) floodplain pool sites. There was a significant association between the presence of Nankeen night herons and reduced time since the last connection (Estimate = -0.05, SE = 0.03, z = -1.7, p = 0.09) (Figure 36, Table 12 in Appendix 7.5). No other tested pool characteristics were associated with the presence of this genus.

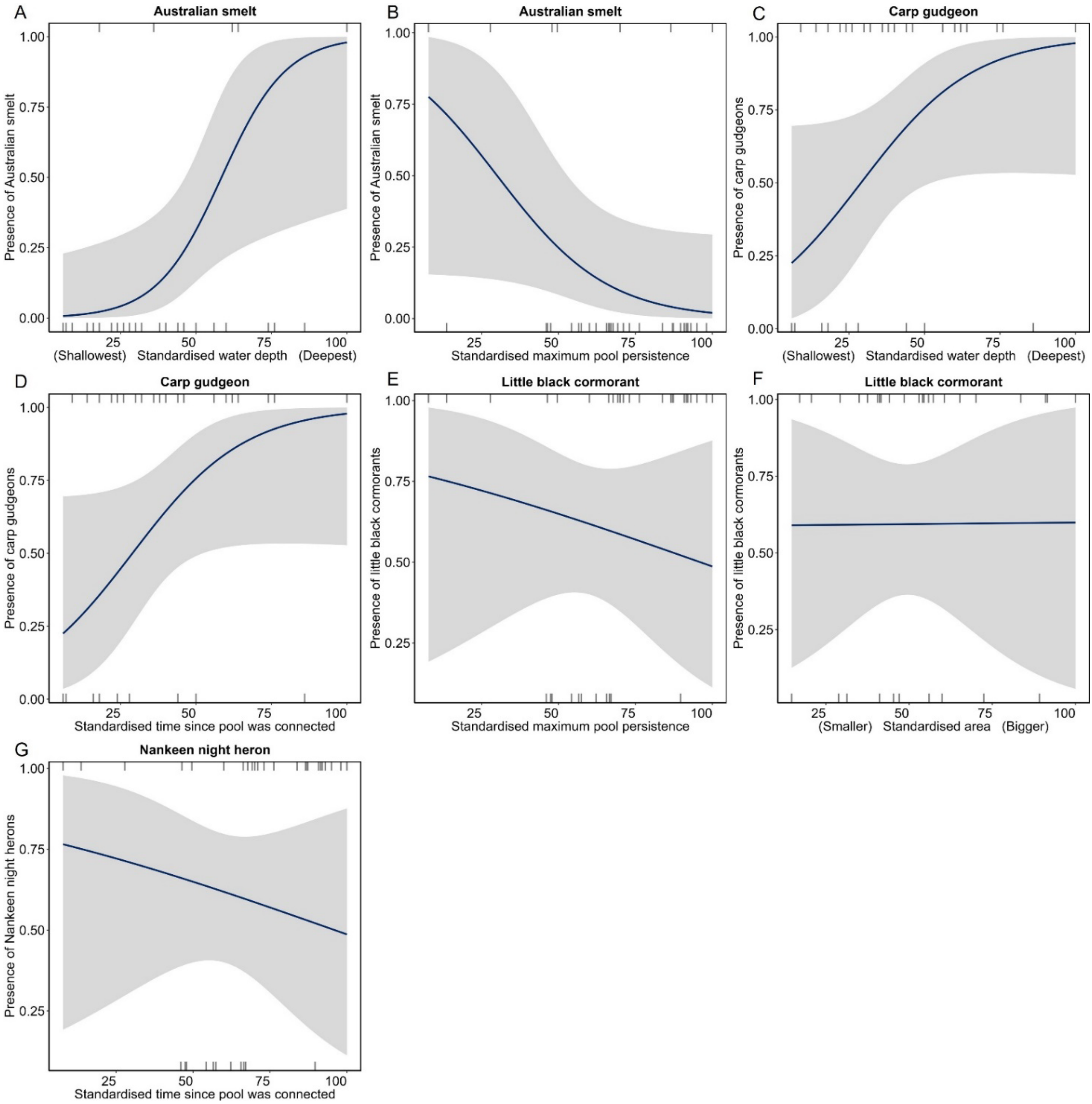

Figure 36: Partial effect plots showing the relationship between the key floodplain pool characteristics that were significantly associated ($p < 0.05$) with the presence of (A-B) Australian smelt, (C-D) Carp gudgeon, (E-F) little black cormorant, and (G) Nankeen night heron. All pool characteristics are standardised on a scale of 0 to 100

4 Discussion

Floodplain pools are represented by diverse physical forms in the landscape and include lagoons, waterholes, cowals, billabongs, warrambools, lakes and anabranch pools. They are a key feature of the landscape in the northern Murray–Darling Basin and provide important permanent and temporary habitat for fish, frogs, reptiles and other fauna species. Despite this, there has been little monitoring outside of the iconic terminal wetlands (for example, the Gwydir Wetlands, Macquarie Marshes) or fish-specific studies (Closs *et al.*, 2005), with very little known about the characteristics of floodplain pools or the fauna that they support. Further, many of them are on private land and are difficult to access.

Water infrastructure development in the northern Murray–Darling Basin has fundamentally altered the connectivity between the river channel and its floodplain, impacting the movement of water-dependent fauna and the accessibility and quality of floodplain pool habitats (Arthington & Balcombe, 2011). To our knowledge, this work presents the first attempt at identifying the large number of floodplain pools across the entire northern Murray–Darling Basin region, documenting the diversity of water-dependent species found within them, and assessing long-term changes to their persistence alongside water resource development and major water management changes.

Floodplain pools of the northern Murray–Darling Basin

Our analyses of satellite imagery identified 1,075 notable floodplain pools across the Barwon-Darling, NSW Border Rivers, Gwydir, Namoi and Macquarie valleys of the NSW portion of the northern Murray–Darling Basin. These pools are deemed valuable as they provide important habitat for water-dependent species, especially as refugia between floods, and due to the combination of their relatively large size (>0.27 ha) and persistence on the floodplain (>20% of the time). Floodplain pool occurrence is widespread across each valley and is a key feature of the landscape, particularly in the Barwon-Darling valley, where 38% of pools have been identified.

Long-term changes and the influence of water management on the inundation and persistence floodplain pools

Floodplain pool habitats naturally rely on overbank events and overland flows to flush and fill pools; the timing, magnitude, frequency and duration of which have been significantly altered by river regulation (Maheshwari, Walker & McMahon, 1995; Ward & Stanford, 1995). Overall, our analysis highlights that considerable development of on-farm storage water surface area in the northern Murray–Darling Basin has occurred since 1987. An estimated 2.5-fold increase up until 2024, equating to approximately 32 gigalitres per year has been documented by others (Brown *et al.*, 2022). However, our analysis suggests that the peak in water held within on-farm storages ramped up until around 2001 where it stabilised for nearly 20 years (Figure 37). There is evidence of some small increase again in 2021 (Figure 37) possible due to sustained wet conditions. These changes have occurred even after the implementation of the 93/94 Murray–Darling Basin Cap but appear to have been managed or constrained since the introduction of the *Water Management Act 2000*, the first Water Sharing Plan, and the *Water Act 2007* (Figure 37).

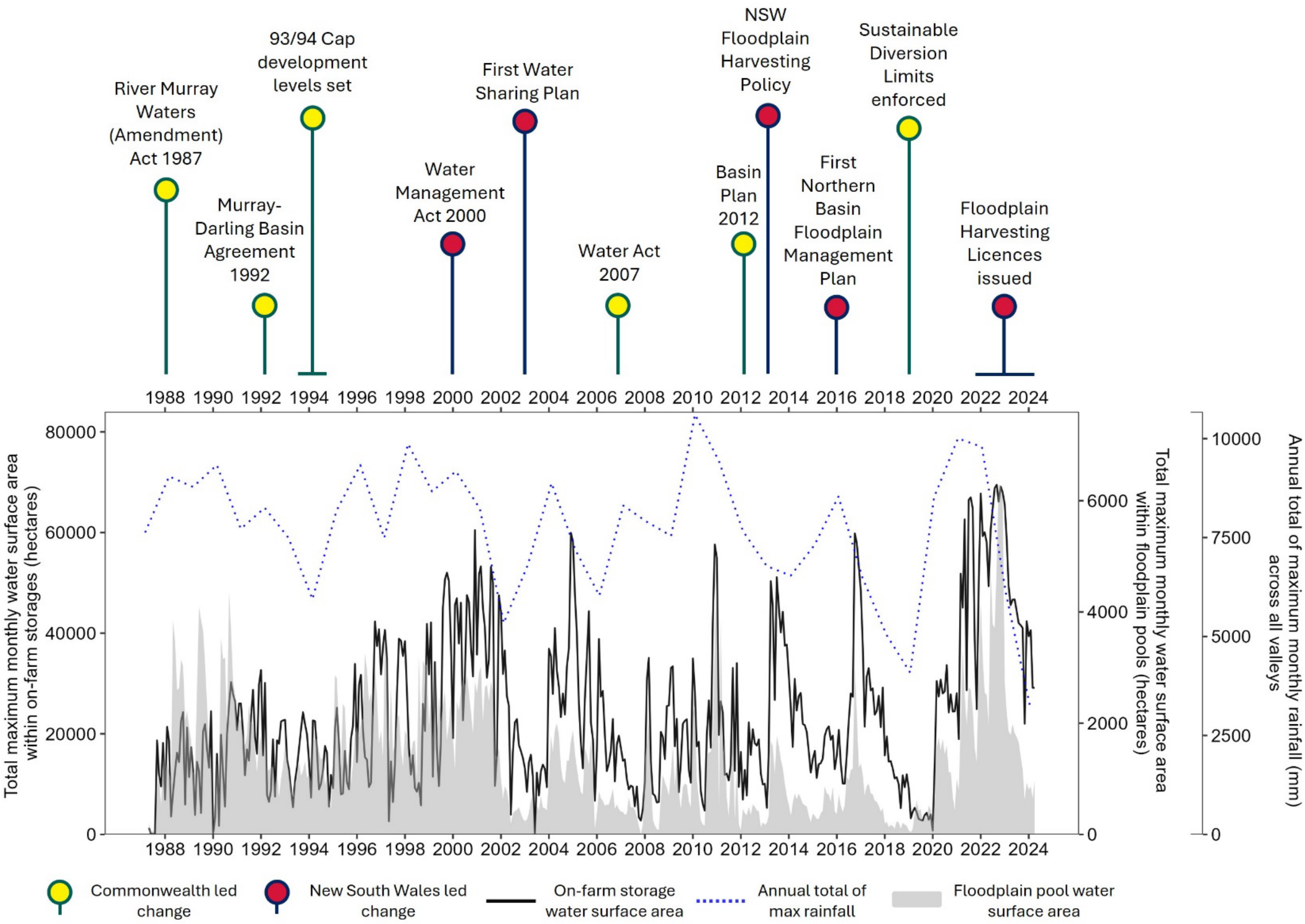

Figure 37: Summary of surface water areas within storages, floodplain pools and the key water management changes relevant to floodplains in the NSW northern Murray–Darling Basin. The figure shows the long-term changes to total maximum monthly on-farm storage surface area, total maximum monthly floodplain pool water surface area, and annual total maximum monthly rainfall across the 5 NSW valleys from May 1987 – April 2024

The water surface area of the 212 floodplain pools with suitable data availability has followed an inverse trend to on-farm storage area, with the area of water in pools decreasing over time. While reduced river flow has been correlated with increased development across the northern Murray–Darling Basin catchments (Brown *et al.*, 2022), we show that, along with reduced maximum and mean streamflow, rainfall has decreased in many catchments, and air temperatures on the floodplain are increasing. This suggests that on-farm water storage areas have largely avoided the impacts of increased temperatures, reduced rainfall and declining river flows when compared to the changes in floodplain pool water surface areas and are likely to be contributing to the changes seen in floodplain pool habitats but importantly are not solely responsible for these changes with climate a major driving factor.

Waterbirds act as an indicator of habitat decline, with reduced streamflow caused by increased water diversions a key contributor (Brandis *et al.*, 2018). The results of the latest eastern Australian waterbird survey reveal a significant reduction in waterbird abundance to well below the long-term average, and breeding abundance among the lowest on record (Porter *et al.*, 2024). A primary driver of this decline is reduced wetland (including floodplain pool) habitat availability, as both total area and persistence has reduced (Porter *et al.*, 2024). The decline in floodplain pool water surface areas presented here support this and demonstrates a declining trend in water availability for floodplain habitats across the northern Murray–Darling Basin. Specifically as the period of higher waterbird abundance recorded (Porter *et al.*, 2024) also occurs during a period (prior to 2001) where there was higher and more stable floodplain pool surface areas for more than a decade (Figure 37). There are however key examples of localised success for waterbirds, where environmental water has been delivered to floodplain pools within core wetlands in the northern Murray–Darling Basin. For example, the changes to water surface areas for Bunnor Lagoon in the Gwydir were enhanced after the Basin Plan was implemented which has also benefited waterbirds. Find more information about waterbird surveys at: Water for the environment outcomes.

The NSW and Australian Governments have introduced numerous water management reforms since 1987 aimed at managing water resources equitably (key changes shown in Figure 37). There has also been an accelerated compliance program in the northern Murray–Darling Basin as part of the Healthy Floodplains Project. This has targeted priority flood works in the northern Murray–Darling Basin to improve flood flow connectivity to cultural and environmental assets. The Basin Plan is one of the major changes within the Murray–Darling Basin but has so far had limited influence on water surface areas of floodplain pools outside of core wetlands in the northern Murray–Darling Basin. Since the commencement of the Basin Plan, pool water surface areas have declined across most prioritised floodplain pools in 4 of the 5 valleys, with particularly notable declines in the Barwon-Darling and Namoi valleys. Our site scale analyses demonstrate that this trend is partly explained by distinct changes, for example, the draining or diversion of water from individual pools, and partly through gradual decline due to climatic variation (for example, reduced rainfall) or alteration to the inundation regime. Only the Macquarie valley appears to be against this trend, with no significant broad-scale long-term increase or decrease in floodplain pool water surface area, mean and maximum monthly river flow, and mean monthly rainfall.

The primary mechanism within the Basin Plan aimed at protecting or improving water-dependent ecosystems is through environmental water entitlements and delivery of this water to targeted sites. Many pools receiving environmental water have shown an increase in water surface area since the implementation of the Basin Plan, however, this is not a uniform trend with considerable variance between pools. There were distinct benefits of improved water surface area retention in floodplain pools that were in or near the core wetlands within the Macquarie and Gwydir valleys. These sites are priority environmental assets like Bunnor waterbird lagoon and have benefited from the Basin Plan through improved water surface areas. However, most of the identified floodplain pools are located outside of the floodplain areas capable of receiving environmental water delivery, which is typically, but not always limited to terminal wetlands.

Broadscale improvements to floodplain pools are better targeted through reduced water diversions and improved flood pathways rather than direct watering with environmental water due to delivery constraints. The NSW Government recently developed floodplain management plans in the northern Murray–Darling Basin, and licenced floodplain diversions through the Floodplain Harvesting Policy with an overarching aim to improve floodplain connectivity and return water use within legal limits. This data set provides a baseline which can be used to assess the effectiveness of floodplain management reforms, for example the Healthy Floodplains Project.

Water-dependent fauna and floodplain pools

The diversity of fauna detected within our 35 floodplain pools included 75 different taxa, 40 of which represent water-dependent fauna. The key groups included native fish, waterbirds, turtles, frogs and rakali. This diversity varied across the 35 sites, and across valleys, with the Barwon-Darling having lower diversity compared to the Namoi, Gwydir and the NSW Border Rivers. The Barwon-Darling also had a different fauna assemblage than the other valleys.

Our analysis of floodplain pool water surface area within the Barwon-Darling valley also highlights this valley as a floodplain pool hotspot and an area of concern, with substantial reductions in floodplain pool water surface areas since 1987. There has also been no detectable improvement in floodplain pool water surface areas associated with the implementation of the Basin Plan within the Barwon-Darling. However, there is some evidence of environmental water supporting floodplain pool outcomes at sites in other valleys, with the Gingham Waterhole a key site for environmental water delivery in the Gwydir, and the floodplain pool with the highest diversity of water-dependent fauna in this study.

The most common species detected across all sites were native fish, specifically spangled perch, bony herring and golden perch. All three of these fish species are medium to large-bodied fish species that are wide-spread within the Murray–Darling Basin. Golden perch is a flow-responsive species (Koster *et al.*, 2017; Thiem *et al.*, 2023), but is not considered a floodplain specialist, preferring main channel habitats. Surprisingly, we detected this species at 77% of our floodplain pool sites. It is unclear if golden perch DNA was detected due to passive dispersal of eggs or fry during recent flood events or due to active movement by older life stages, or a combination of both. The presence of spangled perch and bony bream at most of the study sites is unsurprising as spangled perch are considered an ‘extreme disperser’ (Schmidt, Huey & Hughes, 2018) and will use floods to move to new habitats (Ellis *et al.*, 2015), whilst bony bream is a hyper abundant species, known to spawn during flood and non-flood periods (Gehrke *et al.*, 1995; Stocks *et al.*, 2020). Both species also have high fecundity, low juvenile survivorship and can periodically inhabit suitable environments (Arthington & Balcombe, 2011), similar to ephemeral, intermittent or even permanent floodplain pools. Regardless of their prevalence, they are a key food source for waterbirds and other predators like the broad-shelled turtle (Figure 38) and the eastern long-neck turtle.

The frequency of golden perch, spangled perch and bony bream detection (>77% of sites) suggests that these species will inhabit floodplain pools almost at random, with no preferences, particularly when the inundation of the floodplain is widespread as it was during our study period. Still, we expected the persistence and degree of connectivity of a floodplain pool to be associated with the presence of less common native fish species found within our study sites. Particularly, as inundation and the persistence of water are critical to the survival of native fish between flood events. This was not the case for most species, although the depth of a pool and the time since it was last connected was important for carp gudgeons and Australian smelt. It is possible that species population structure varies with these factors, which would require additional surveys to establish fish size and abundance.

Figure 38: A picture of a broad-shelled turtle (Chelodina expansa), one of the turtle species that inhabits floodplain pools. Photo credit: Daniel Coleman

Waterbirds were the next most common group of water-dependent fauna detected within our floodplain pool sites, with 20 different taxa recorded. The dominant species were the Australian wood duck, little pied and the little black cormorant, and the Nankeen night heron. Waterbird breeding events are known to respond to floodplain inundation (Arthur *et al.*, 2012; Brandis & Bino, 2016), and are supported by breeding and nursery habitats within wetlands (Bino, Kingsford & Porter, 2015). Unlike other water-dependent species, waterbirds can travel large overland distances to find preferred habitats based on water availability and food resources (Roshier, Doerr & Doerr, 2008; Nicol, Lloyd-Jones & McGinness, 2024).

We expected waterbird detection (i.e. presence, not abundance) to be more frequent in more permanent or better-connected floodplain pools due to the long-term available water, or the enhanced productivity (i.e. food resources) of recently inundated pools. However, only 2 of the 4 species we tested had an association with these factors, with the little pied cormorants preferring larger, more permanent pools and the Nankeen night heron more frequently occurring at sites that were connected and inundated recently.

Whilst we have found variable responses of individual species to floodplain pool characteristics, including water permanence, it remains clear that these habitats support a diverse range of both water-dependent and terrestrial taxa across the broader floodplain landscape. The long-term protection of the northern Murray–Darling Basin floodplain pools and the species they support is therefore dependent on maintaining, and wherever possible improving, the connectivity to floodplain pools and water persistence within them.

5 Next steps

This section provides a high-level summary of any key knowledge gaps and the next steps in research, monitoring and evaluation for floodplain pools:

- this project has focussed on the northern Murray–Darling Basin. The next step would be to repeat this project in the NSW southern Murray–Darling Basin
- many floodplain pools are highly modified (for example, pumps and irrigation canals) or impacted by the diversion of flows from upstream floodplain structures (such as levees). The impact of floodplain structures and works are addressed in valley-specific floodplain management plans. They have not been assessed as part of this study since it is largely outside the scope of the Basin Plan. The department is now assessing these impacts through the Improving Floodplain Connections program
- estimating the surface area of floodplain pools using Landsat imagery is an effective method for most pools in the northern Murray–Darling Basin. By automating this process, we can observe changes to these floodplain pools from 1987 to 2024, from the individual pool up to the landscape-scale. This dataset will enable us to provide time effective monitoring and evaluation to assess the effectiveness of floodplain management plans, the floodplain harvesting policy, and full implementation of the Basin Plan in restoring or improving inundation durations for floodplain pools
- ongoing monitoring of fauna through eDNA surveys should continue as they are a cost-effective way to contribute to our understanding of changes in fauna communities over time, particularly between flood events. Continued monitoring will provide supporting information to assess the influence of the introduction of floodplain management plans, the floodplain harvesting policy, and full implementation of the Basin Plan on the diversity and species assemblages supported by floodplain pool habitats
- it remains unclear if the inundation, persistence and type of habitat influences the abundance of different species at a site. Additional population level surveys would improve our understanding of floodplain pool significance but would require significant resourcing
- many of the important floodplain pools are naturally ephemeral, intermittent or have slowly changed to become dryer through time. Although the level of permanence and the natural rate of drying of these waterbodies is critical, we still do not know how important these aquatic refuges are for terrestrial (non-water-dependent) animals. Not only their importance as refuges when inundated, but also as sources of protein and nutrients for animals that feed on stranded aquatic fauna as pools dry.

6 References

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7 Appendices

7.1 Summary of relevant legislation for NSW floodplains

Table 8: Summary of key environmental objectives within the Basin Plan 2012, the Water Management Act 2000, NSW water sharing plans, and NSW floodplain management plans

Plan	Objective
Basin Plan 2012	Part 2 – 8.04 (a) to protect and restore water-dependent ecosystems of the Murray–Darling Basin; and
Water Management Act 2000	Chapter 1 – 3 (b) to protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality
NSW water sharing plans	Part 2 – 9 (2a) to protect and contribute to the enhancement of the following over the term of this Plan: (i.) The recorded distribution or extent, and population structure, of target ecological populations. (ii.) The longitudinal and lateral connectivity within and between water sources to support target ecological processes. Part 2 – 9 (2b) to support environmental watering in the water source to contribute to maintaining or enhancing ecological condition in streams, riparian zones, dependent wetlands and floodplains.
NSW floodplain management plans	Part 2 – 9 (a) to protect and contribute to the enhancement of the following over the term of this Plan: (a) facilitate the orderly passage of floodwaters through the Floodplain, (d) to maintain flood connectivity to wetlands, other floodplain ecosystems, and areas of groundwater recharge in the floodplain, and (e) to contribute to the protection of flood-dependent ecological assets and flood-dependent ecological values in the Floodplain,

7.2 Vegetation score schema

Table 9: Vegetation schema used to assign vegetation condition scores and structural diversity scores to floodplain pools

NSW Plant Community Type	Attribute	Attribute Description	Logic statement	Good (%)	Inter-mediate (%)	Poor (%)	Very Poor (%)	Good (Score)	Inter-mediate (Score)	Poor (Score)	Very Poor (Score)
Coolibah wetland woodland	Bare Ground and Litter	Sum of %cover of Bare Ground and Litter	Litter and Bare Ground = %Bare Ground + %Litter	<10	>10 - ≤40	>40 - ≤60	>60	2	1.5	1	0
Coolibah wetland woodland	Terrestrial cover	Sum of %FC terrestrial cover categories except tree cover	Terrestrial cover = (%FC Non aquatic ground cover (Herbs and forbs) + %FC Native Grasses + %FC Shrubs)	≥70	<70 - ≥40	<40 - ≥20	<20	4	3	2	0
Coolibah wetland woodland	Aquatic Cover	Sum of %FC aquatic cover categories except flooded forest	Aquatic cover = (%FC Tall emergent aquatic species + %FC Short Emergent aquatic species + %FC Submerged aquatic species + %Floating aquatic species)	≥20 - ≥15	<15 - ≥10	<10 - ≥5	<5	4	3	2	0
Coolibah wetland woodland	Structural diversity	Number of structural categories except bare ground and litter	Structural diversity = count of categories (%FC Non aquatic ground cover (Herbs and forbs), %FC Grasses, %FC Shrubs, %cover Trees, %FC Tall emergent aquatic species, %FC Short Emergent aquatic species, %FC Submerged aquatic species, %Floating aquatic species, %Flooded Forest, % Bare water) where %FC >0, + Snags >0	11 - ≥8	<8 - ≥6	<6 - ≥4	<4	4	3	2	0
Coolibah wetland woodland	Bare water	% bare water	Bare water = % Bare Water	≥5	>5- ≥10	>10 - ≥15	>15	3	2	1	0
Coolibah wetland woodland	Cover trees	% FC of trees in the canopy	% Cover of trees = %Cover trees	≥30	<30 - ≥10	<10- ≥1	<1	3	2.5	2	0

7.3 Site based records of fauna

Table 10: List of fish species and the associated eDNA reads recorded at each floodplain pool site. Higher eDNA reads are generally reflective of greater fish biomass

valley	Floodplain pool (site)	Latitude	Longitude	Date	Golden perch	Murray cod	Spangled perch	Bony herring	Murray–Darling rainbowfish	Australian smelt	Fly-specked hardyhead	Genus of Carp gudgeons	Common carp	Eastern mosquitofish	Goldfish
Barwon-Darling	Butti lagoon	-29.438688	148.70965	1/03/2023	28676	0	15386	646759	0	0	0	9898	180800	2660	459776
Barwon-Darling	Fish holes lagoon	-29.712718	148.405997	1/03/2023	50445	0	151729	891954	3816	0	0	17653	715448	6916	134061
Barwon-Darling	Horseshoe lagoon B	-30.119021	147.451621	1/03/2023	0	0	5452	0	0	0	0	0	285435	170713	81883
Barwon-Darling	Mile lagoon west	-30.105989	147.571974	1/03/2023	15247	0	23563	438065	0	0	0	0	398422	5028	434790
Barwon-Darling	Orange tree lagoon	-30.220715	145.706576	1/03/2023	43142	0	111355	349347	0	0	0	0	450439	35018	357521
Barwon-Darling	Piano creek B	-29.953466	146.381316	1/03/2023	5183	0	27694	431583	0	0	0	659	364574	8278	357030
Barwon-Darling	Polygurum swamp	-30.065117	145.956253	1/03/2023	106331	0	36465	619998	0	0	0	0	192318	0	407880
Barwon-Darling	Tarrion creek	-30.046863	146.863242	1/03/2023	496	0	7204	1061001	0	0	0	297	165045	207	15974
Barwon-Darling	Unnamed lagoon 3	-29.706044	148.447518	1/03/2023	0	0	3872	257898	0	0	0	1928	208214	8330	482489
Barwon-Darling	Unnamed lagoon 5	-29.364006	148.709867	1/03/2023	65	0	63165	141084	3538	0	0	0	57056	59673	850276
Barwon-Darling	Unnamed lagoon 9	-29.663713	148.481141	1/03/2023	66699	0	32614	372847	0	0	0	12245	310287	9087	388831
Barwon-Darling	Weerabilla lagoon	-29.489582	148.662281	1/03/2023	123683	0	74016	764585	11475	0	0	14371	425968	0	153614
Barwon-Darling	Yambacuna lagoon	-29.962098	146.608352	1/03/2023	7833	0	33394	720735	1307	0	0	0	383979	5731	422951
Barwon-Darling	Yambie lagoon	-30.109651	147.394535	1/03/2023	6020	0	8337	429957	0	0	0	15988	394509	16577	213075

NSW Border Rivers	Boobera watercourse	-28.632744	150.075749	9/06/2022	0	0	18511	164249	0	0	0	1197	170284	29153	25125
NSW Border Rivers	Carwall waterhole	-28.98156	149.066785	9/06/2022	22665	0	78548	144968	0	0	0	262	209527	27520	13161
NSW Border Rivers	Maynes lagoon	-28.664404	150.333201	9/06/2022	0	0	134318	26213	0	0	0	38141	9032	0	22665
NSW Border Rivers	Morella watercourse	-28.617189	150.171942	9/06/2022	22299	0	32699	251222	0	7844	0	1566	140679	3785	77960
NSW Border Rivers	Turrawah B	-28.994564	149.085495	9/06/2022	89630	0	52267	399028	0	1230	0	0	387125	123497	79292
NSW Border Rivers	Whalan creek EOS	-29.0056618	149.092414	9/06/2022	222	0	39855	96213	0	0	0	0	455247	25720	63258
NSW Border Rivers	Woolinna and Cobbanthanna waterholes	-28.807493	149.654921	9/06/2022	5314	0	88168	193013	0	0	0	18767	152387	4998	30214
Gwydir	Baroona waterhole	-29.23893	149.47533	2/06/2022	16136	0	15133	134554	0	0	0	10169	518429	102926	143961
Gwydir	Bengerang waterhole	-29.0517	149.473596	2/06/2022	46853	3779	4258	201742	0	0	0	0	435622	67133	49120
Gwydir	Burrandoon waterhole	-29.45123119	149.094431	2/06/2022	262	0	469	5823	423	0	0	6525	41526	21705	109671
Gwydir	Gingham waterhole	-29.24240568	149.3069402	2/06/2022	0	0	233	55522	0	0	408	398	70906	12049	14449
Gwydir	Goonal creek at Gwydir hwy	-29.46318875	149.2324467	2/06/2022	848	0	1096	5299	117	1942	0	495	51947	10814	92313
Gwydir	Talmoi waterhole	-29.25597	149.53866	2/06/2022	16692	0	222289	341984	0	0	0	622	178635	6127	214685
Gwydir	Tarran creek at poison gate	-29.50980978	149.2770787	2/06/2022	9307	0	4141	93635	0	189	0	5684	49573	3513	10298
Gwydir	Whittakers lagoon	-29.5256	149.659269	2/06/2022	0	0	19748	7375	0	0	0	0	100	305662	22388
Namoi	Gulligal lagoon	-30.79864	150.14863	2/06/2022	10506	0	41776	713347	1843	9753	0	153282	168147	7526	62993
Namoi	Gurleigh lagoon	-30.216551	149.56675	2/06/2022	46609	0	55007	155705	0	12400	0	17369	334305	8642	169528
Namoi	Myall camp warrambool	-30.277346	149.022524	10/06/2022	0	0	20047	22758	0	0	0	91164	355978	30260	43601
Namoi	Myall Vale channel	-30.198309	149.545782	8/06/2022	0	0	28343	1187	3306	0	0	0	416719	6414	291016
Namoi	Pian Creek	-29.94614	148.9065	8/06/2022	6950	0	14417	97099	0	1437	0	31590	225967	10918	22283
Namoi	Wee Waa lagoon	-30.227828	149.444267	8/06/2022	17239	0	12394	620537	0	0	0	477183	316401	22289	55570

7.4 Site based records of terrestrial fauna

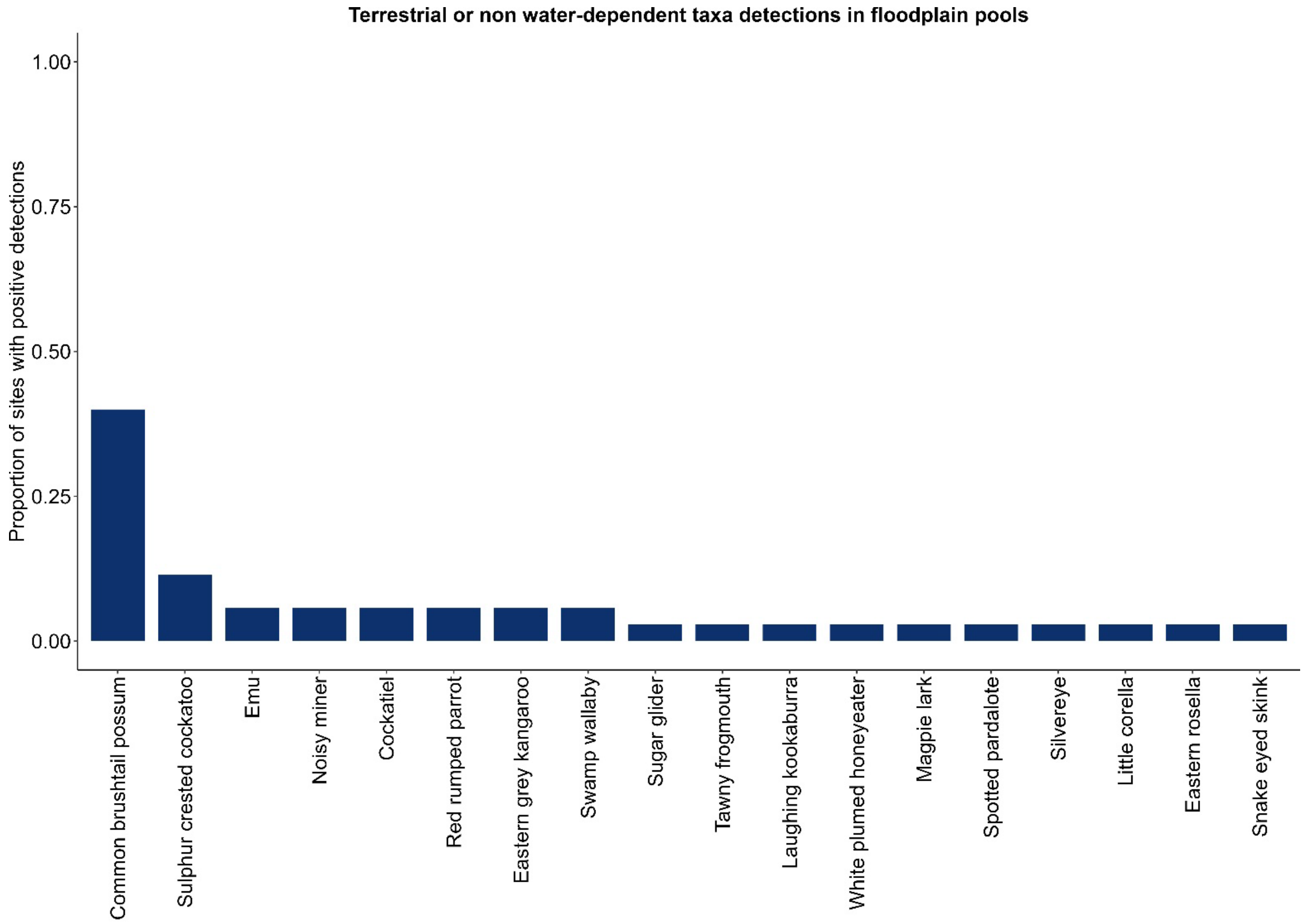

Figure 39: The proportion of sites (total sites = 35) that had positive detections for species that are not considered water-dependent taxa

7.5 Statistical results for key fauna presence and pool characteristics

Table 11: Generalised linear model (GLM) results for 4 of the key native fish found in floodplain pools within the northern Murray–Darling Basin

Taxa	Predictor	Estimate	Std. Error	Z value	p-value
Golden perch	**Intercept**	**8.67**	**4.89**	**1.77**	**0.08***
	Surface area	0.06	0.04	1.31	0.19
	Maximum water depth	0.02	0.04	0.50	0.62
	Maximum persistence	-0.02	0.03	-0.63	0.53
	Time since last connection	-0.08	0.05	-1.45	0.15
	Minimum flow path distance to main channel	-0.03	0.03	-1.07	0.29
	Vegetation structural diversity score	-0.05	0.04	-1.30	0.19
Australian smelt	Intercept	2.05	3.09	0.66	0.51
	Surface area	-0.06	0.04	-1.42	0.15
	Maximum water depth	**0.09**	**0.04**	**2.23**	**0.03****
	Maximum persistence	**-0.06**	**0.03**	**-1.87**	**0.06***
	Time since last connection	-0.02	0.03	-0.65	0.52
	Minimum flow path distance to main channel	-0.03	0.03	-0.79	0.43
	Vegetation structural diversity score	0.01	0.04	0.20	0.84
Murray–Darling rainbowfish	Intercept	3.60	2.75	1.31	0.19
	Surface area	-0.01	0.03	-0.36	0.72
	Maximum water depth	0.01	0.03	0.40	0.69
	Maximum persistence	-0.02	0.02	-0.76	0.45
	Time since last connection	-0.02	0.02	-1.17	0.24
	Minimum flow path distance to main channel	0.02	0.02	0.79	0.43
	Vegetation structural diversity score	-0.06	0.04	-1.55	0.12
Carp gudgeons	Intercept	-2.68	2.68	-1.00	0.32
	Surface area	0.00	0.03	0.01	0.99
	Maximum water depth	**0.05**	**0.03**	**1.83**	**0.07***
	Maximum persistence	-0.01	0.02	-0.57	0.57
	Time since last connection	**0.06**	**0.03**	**2.20**	**0.03****
	Minimum flow path distance to main channel	0.04	0.03	1.53	0.13
	Vegetation structural diversity score	-0.02	0.03	-0.76	0.45

***: p < 0.01
**: p < 0.05
*: p < 0.1

Table 12: Generalised linear model (GLM) results for 4 of the key waterbirds found in floodplain pools within the northern Murray–Darling Basin

Taxa	Predictor	Estimate	Std. Error	Z value	p-value
Australian wood duck	Intercept	0.21	2.29	0.09	0.93
	Surface area	0.00	0.02	-0.22	0.83
	Maximum persistence	0.02	0.02	0.89	0.38
	Time since last connection	0.02	0.02	1.05	0.30
	Vegetation condition score	0.01	0.03	0.36	0.72
	Vegetation percent cover	0.00	0.02	0.15	0.88
Little pied cormorant	Intercept	-1.19	2.16	-0.55	0.58
	Surface area	-0.01	0.03	-0.47	0.64
	Maximum persistence	0.01	0.02	0.45	0.65
	Time since last connection	-0.03	0.02	-1.27	0.21
	Vegetation condition score	0.04	0.02	1.57	0.12
	Vegetation percent cover	0.00	0.02	-0.09	0.93
	Fish biomass (eDNA concentration)	0.00	0.00	-0.71	0.48
Little black cormorant	Intercept	2.41	2.96	0.81	0.42
	Surface area	**-0.09**	**0.04**	**-2.52**	**0.012****
	Maximum persistence	**0.05**	**0.03**	**1.98**	**0.048****
	Time since last connection	-0.04	0.03	-1.39	0.17
	Vegetation condition score	0.00	0.03	-0.06	0.95
	Vegetation percent cover	-0.02	0.02	-1.05	0.30
	Fish biomass (eDNA concentration)	0.00	0.00	-0.01	1.00
Nankeen night heron	Intercept	2.34	2.35	0.99	0.32
	Surface area	-0.03	0.03	-1.23	0.22
	Maximum persistence	0.01	0.02	0.55	0.58
	Time since last connection	**-0.05**	**0.03**	**-1.70**	**0.09***
	Vegetation condition score	0.01	0.02	0.54	0.59
	Vegetation percent cover	-0.02	0.02	-1.04	0.30
	Fish biomass (eDNA concentration)	0.00	0.00	-1.11	0.27

***: p < 0.01
**: p < 0.05
*: p < 0.1