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Floodplain connectivity and inundation

Environmental Outcomes Monitoring and Research Program Annual Report 2021-2022

Acknowledgement of Country

The Department of Planning and Environment acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past, present and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

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More information

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Cover image: Whittaker lagoon on the Gwydir floodplain. Photo: Tim Haeusler

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Contents

Abbreviations and Acronyms

	Description
ANAE	Australian National Aquatic Ecosystem
Basin Plan	Murray-Darling Basin Plan 2012
DEA	Digital Earth Australia
EOMRP	Environmental Outcomes Monitoring and Research Program
EWRs	Environmental Watering Requirements
Flow MER	Commonwealth Environmental Water Office Environmental Water MER program
FWI	Fisher’s Water Index
GEE	Google Earth Engine
MDB	Murray-Darling basin
MDBA	Murray-Darling Basin Authority
MER	Monitoring, evaluation and reporting
MIM	Multi Index Method
mNDWI	Modified Normalised Difference Water Index
NMDB	northern Murray-Darling basin
NSW	New South Wales
TCW	Tasselled Cap Wetness Index

Monitoring floodplain connectivity and inundation

The Lachlan River and Nerran Lake, part of the Cumbung Swamp.
Photo credit: Paul Packard DPE

Why are we monitoring river connectivity and inundation?

The connection between a river and its floodplain is known as floodplain connectivity. This connection occurs when the water in a river rises over the bank and spills onto the surrounding landscape, inundating the floodplain. These areas may also be inundated by overland flows from excess rainfall runoff within the catchment.

The frequency, timing and duration of floodplain connection and inundation events are important drivers of the overall health of floodplain ecosystems. Connecting flows move nutrients and sediments and enable native fish and other organisms to move between habitats. Inundation also provides water for floodplain vegetation and refuges like billabongs and lagoons, which are important habitats for native fish, frogs, turtles and mammals.

The floodplain inundation information generated in this theme is essential for linking changes in floodplain flora and fauna communities to the associated rainfall and river flow events. This allows us to better manage water to protect and enhance these floodplain environments for the plants and animals that live there. The projects which study the impacts of water management on floodplain flora and fauna are reported within the Water Dependent Fauna and Water Dependant Native Vegetation themes of the Environmental Outcomes Monitoring and Research Program (EOMRP).

Report purpose

The **2021-22 Annual Report** for the **floodplain connectivity and inundation theme** (this document) outlines completed activities and their findings under the EOMRP between July 2021 and June 2022. This annual report is one of a set of 5 different themes for the EOMRP:

1. Floodplain connectivity and inundation (this theme)
2. Water dependent fauna
3. Ecological processes
4. Water dependent native vegetation
5. Groundwater dependent ecosystems.

The EOMRP delivers information annually to meet several requirements for the Department of Planning and Environment – Water. These include NSW reporting obligations under the Basin Plan Schedule 12, performance indicator research, data collection and analysis to prepare and monitor - water sharing plans and floodplain management plans. The information also contributes to the NSW River Condition Index (RCI) tool, the High Ecological Value Aquatic Ecosystems (HEVAE) spatial layer, and the NSW State of the Environment Reports.

The EOMRP projects are staged over several years, building knowledge about water dependent ecosystems and their responses to water management plans, actions and decisions, allowing more informed water management decisions in the future. For further information about the EOMRP see the EOMRP website. Technical reports for each project will be published separately and made available on the department's website.

The EOMRP was designed to provide the ecological data required to implement the NSW Water Management Monitoring, Evaluation and Reporting (MER) framework (DPIE Water 2020) which addressed Basin Plan requirements. The EOMRP was extended in 2022 to cover coastal and non-Basin areas. A new framework designed specifically for the evaluation of all NSW water sharing plans is in development. The department is undertaking this work in response to the Natural Resources Commission findings and recommendations about the way we monitor, evaluate, and report information about water sharing plan outcomes.

Report structure

The **floodplain connectivity and inundation theme** is broken into three major projects which link to key components of floodplain hydrological processes. These projects are:

1. **Flood inundation mapping**

   This project maps inundation across floodplains. It will provide data for a variety of projects across various NSW reporting requirements.

2. **Flood hydrology – Overbank environmental water requirement validation**

   This project will assess the inundation patterns associated with the meeting of the overbank environmental water requirements stated in the long term water plans.

3. **Flood Hydrology - Flood area and pathways**

   (Not included in this report, project due to start in 2023)

The reporting for this theme is currently restricted to the NSW section of the northern Murray-Darling basin (Figure 1). Each project has key questions that relate to water management activities. The key project questions are targeted research questions this project is trying to answer, whilst the link to water management activities highlights the specific strategy or water sharing plan rule that a project aims to inform.

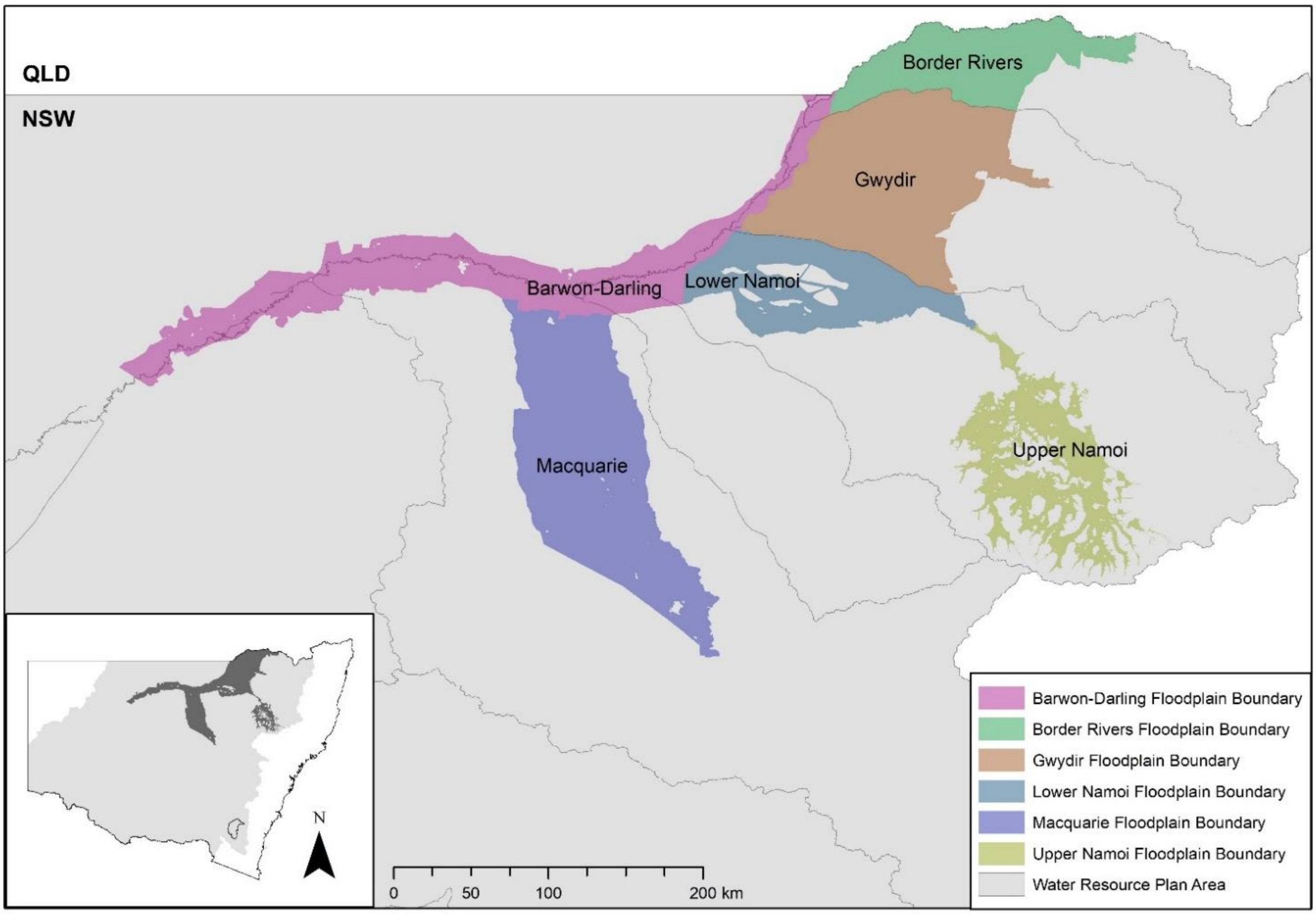

Figure 1. Map of the northern NSW Murray-Darling basin. The map shows the Murray-Darling basin water resource plan boundaries and floodplain management plan areas.

Drivers of environmental outcomes

The health of floodplain habitats is dependent on a wide range of factors, many of which are beyond the control of water resource managers. These include climate, invasive pests (for example carp), fire, disease, pollution, habitat loss and climate change. However, one of the key drivers of environmental outcomes in floodplain environments is river flows and floodplain inundation. In particular, the location, magnitude, timing, frequency and duration of inundation from overbank river flows and overland rainfall run-off, all of which are impacted by water management activities.

In NSW, connectivity and inundation of the floodplain is primarily managed by the water resource plans prepared under the *Basin Plan (2012),* which incorporate water sharing plans developed under the NSW *Water Management Act (2000)*. Water sharing plans share water between people and the environment by establishing access rules, protecting environmental health, and ensuring the long–term sustainability of resources by requiring water users to hold licences to take water. Floodplain management plans ensure the appropriate development of floodplains by licensing any works which may impact the way water flows across the floodplain.

Water management within NSW also aims to ensure adequate delivery of identified flow types to meet environmental water needs of water dependent flora and fauna. Each flow type influences a range of habitats and organisms. These flow types can be broken into broad categories; cease to flows, low flows (and baseflows), fresh flows, bankfull, and overbank flows (Figure 2). The river flows which most influence floodplain habitats are bankfull and overbank flows.

This report focuses on the environmental outcomes that are influenced by the bankfull and overbank components of river flow, and the associated water management actions in NSW.

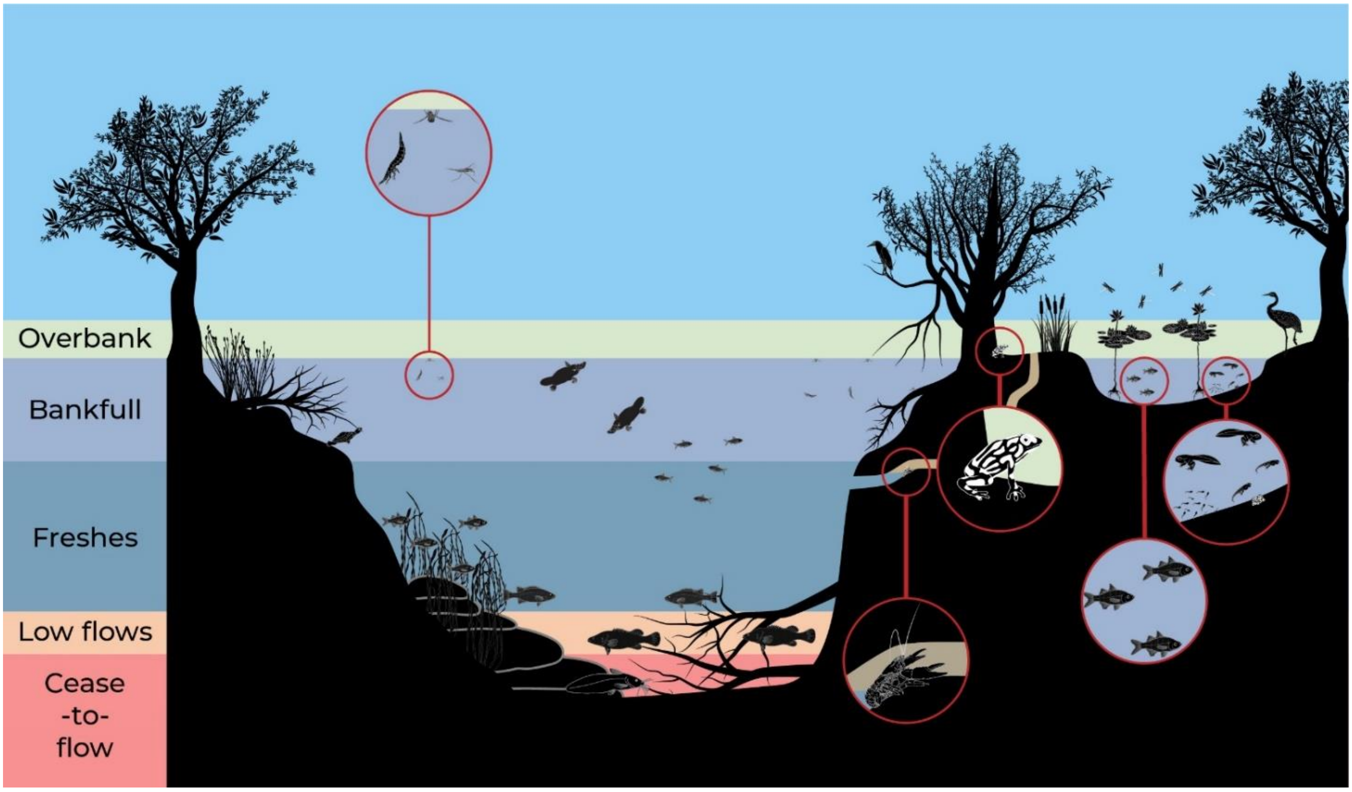

Figure 2. Conceptual model of the main flow categories and what areas of a river they influence. This theme relates to the bankfull and overbank flow categories.

Floodplain connectivity

Flood inundation mapping

Project team

Tim Haeusler, Daniel Coleman, Sara Shaeri Karimi, Lauren MacRae, Anna Helfensdorfer.

Project collaborators

This project is led by the department.

Introduction

The frequency, timing and duration of floodplain inundation is a key driver of ecological outcomes on floodplains (such as vegetation community health, fish survival and breeding). We are developing and applying a method suitable for remotely mapping floodplain inundation across the northern Murray Darling basin. This will allow us to better understand patterns of floodplain inundation. This floodplain inundation mapping is a key first step in providing data for a range of projects across the EOMRP, including the Floodplain Connectivity and Inundation theme projects described below, as well as projects in the water dependent native fauna and vegetation themes.

The outcomes of this project will enable the creation of a range of tailored map products and other inundation data for use in other themes. These products will show the extent and duration of inundation across the floodplain and identify significant flow paths.

Project aims

We are developing floodplain inundation maps to answer the following questions:

Key project questions

- Can floodplain inundation be mapped using a process which is repeatable and largely automated?
- What areas of the northern basin floodplains have been inundated since December 2018*?
- What was the duration of each inundation event?

**This date represents the first availability of Sentinel-2 satellite imagery.*

Link to water management activities

- Provide data for the ongoing monitoring and evaluation of the Basin Plan under Matter 8, Schedule 12, specifically the River Flows and Connectivity and the Vegetation themes in each of the Schedule J monitoring evaluation and reporting plans for the northern basin water resource plans.

- Contribute to the monitoring and evaluation of the floodplain management plans established under Section 50 of the NSW *Water Management Act 2000*. Specifically, to assess the extent to which flood works have altered flood connectivity to flood-dependent ecological assets (such as floodplain pools, wetlands and vegetation communities) and values in the floodplain.

Methods

Validation and analysis of existing methods for detecting floodplain inundation

Remote sensing methods rely on different features on the Earth's surface, such as vegetation or water, reflecting different wavelengths of light. Spectral indices are formulas that combine the reflectance values at different wavelengths to produce a single number. To classify something as belonging, or not belonging, to a specific category such as water or soil, a 'threshold' is applied (a reference value) to this number. Common spectral indices for detecting water on Earth's surface include: the modified Normalised Difference Water Index (mNDWI) (Xu 2006), Fisher's water index (FWI) (Fisher et al. 2016) and the Tasseled Cap Wetness Index (TCW) (Crist 1985). Each index has strengths and weaknesses in how they deal with factors such as soil colour, water turbidity and vegetation cover.

Specific methods to detect the presence of water across a landscape are tailored to the scale, environmental conditions, and application for which they were developed. For instance, the 10 m resolution Dynamic World dataset (Brown et al. 2022) is widely used for landcover mapping, however the global-scale of this method may not provide the highest accuracy for water detection in the northern Murray-Darling basin given the unique set of conditions across these floodplains. The highly turbid water in these catchments requires modification of thresholds used in parts of the world where there is clearer water. Water detection under areas of dense vegetation cover, such as the highly significant Gwydir Wetlands or Macquarie Marshes, presents a further difficulty.

A primary component of this project was the validation and analysis of existing water detection methodologies against ground-truthed inundation extents by comparing them to high resolution satellite imagery and oblique aerial imagery. We considered water indices including FWI, mNDWI, TCW and the Water in Wetlands index and the application of different classification thresholds. We also considered and undertook detailed testing of the appropriateness of using Sentinel-1 radar, Sentinel-2, Landsat or the Dynamic world dataset for the spatial and temporal scale of interest.

We found that the recent multi-index method developed by Ticehurst et al. (2022) provided the most accurate and efficient detection of water . This method combines the strengths of different indices by applying them to the section of landscape to which they are most suited. We have further modified this method to utilise the higher-resolution Sentinel-2 imagery instead of Landsat, and a new version of the TCW index optimised for Sentinel-2 obtained from the University of Bonn Index Database. Furthermore, river zone boundaries were refined by applying a graded buffer based on Strahler stream order (Strahler 1957).

Inundation mapping

The inundation mapping methods are described briefly below. Detailed methods are available in

Appendix 1 – detailed inundation mapping methods.

Inundation mapping is currently restricted to the areas identified as floodplains in the NSW floodplain management plans of each of the northern Murray-Darling basin catchments. The identified area was classified into river, wetland and other landscape zones using existing datasets.

Google Earth Engine, a cloud-based geospatial computing platform, was used to detect water using three indices: mNDWI (using 2 different threshold values), FWI and TCW. A water map for each of these indices was created for all available low-cloud Sentinel-2 images. A final inundation map for each Sentinel-2 image was produced in the statistical package R (R Core Team 2020) by combining the water maps for each landscape zone, using the index most suited to represent that zone (Table 1).

Table 1: Landscape zones, indices and thresholds used in the MIM method for the northern Murray-Darling basin floodplains.

Landscape zone	Index Used	Threshold Used
Rivers **River area including a variable buffer based on Strahler stream order**	Modified Normalised Difference Water Index (mNDWI)	-0.3
Wetlands **Australian National Aquatic Ecosystem (ANAE) defined wetlands, including natural perennial and temporary lakes, billabongs and floodplains**	Tasseled Cap Wetness Index (TCW)	-0.035
Other **Any area outside of river and wetlands zones**	Fisher's Water Index (FWI) Modified Normalised Difference Water Index (mNDWI) (maximum extent between FWI and mNDWI)	0.630

This method presents a number of strengths and limitations in its use for mapping floodplain areas of the northern Murray-Darling basin:

Strengths:

- The workflow can be easily applied to different areas.
- Fully automated after specifying the area of interest and time periods.
- Short processing time through access to Google's high-performance computing resources.
- High spatial and temporal resolution of Sentinel-2 imagery allows near-real time inundation monitoring.

Limitations:

- False positives due to the accuracy of established boundaries for the 3 different zones.
- Difficulties with detecting inundation in densely vegetated areas which can result in underestimation of inundation areas in these habitats.
- Difficulties capturing the flood peak due to cloud cover.

Results

Inundation maps are being produced for each northern Murray-Darling basin catchment for all available Sentinel-2 images with low-cloud coverage. As the atmospherically corrected surface reflection Sentinel-2 dataset began in December 2018, the method can only be applied to images acquired since this date. Table 2 identifies the number of low-cloud images available for each northern Murray-Darling basin floodplain area.

Table 2. The number of images processed to produce inundation maps for each floodplain area in the northern Murray-Darling basin (image availability from 14/12/2018-31/12/2022).

Floodplain area	Number of Sentinel-2 images available
Gwydir	469
Border Rivers	461
Lower Namoi	446
Upper Namoi	456
Lower Barwon-Darling	686
Upper Barwon-Darling	471
Macquarie	487

An example of the inundation maps currently being produced is shown in

Figure 3. This inundation map was produced using the multi-index method from an image captured on 6 June 2022. A comparison is shown against a drone image taken on the 7 June 2022 (Figure 4) during field work for the Floodplain Pools Fauna project (see EOMRP Theme 4). The inundation mapping closely represents what was observed in the field.

Figure 3. A map of inundation extent of Talmoi waterhole on the Gwydir floodplain produced from Sentinel 2 satellite imagery acquired on 6th June 2022

Figure 4. An oblique aerial image of Talmoi waterhole on the Gwydir floodplain taken on 7th June 2022.

The inundation maps produced will be used for further monitoring and analysis for multiple projects across the EOMRP themes. For example, they can be used to calculate the percentage of time an area is inundated (inundation frequency), and to assess spatial and temporal patterns of inundation across a catchment. This can be displayed in an inundation frequency map, which shows the percentage of time that a pixel is wet based on the total number of available images over the time frame. An example of an inundation frequency map for the Border Rivers catchment between December 2018 and September 2022 is shown in 5c. In this example, the northern section is the most frequently inundated part of the valley, followed by the central band of the catchment. The southern section of the catchment has been the least frequently inundated with an inundated percentage of less than 10.

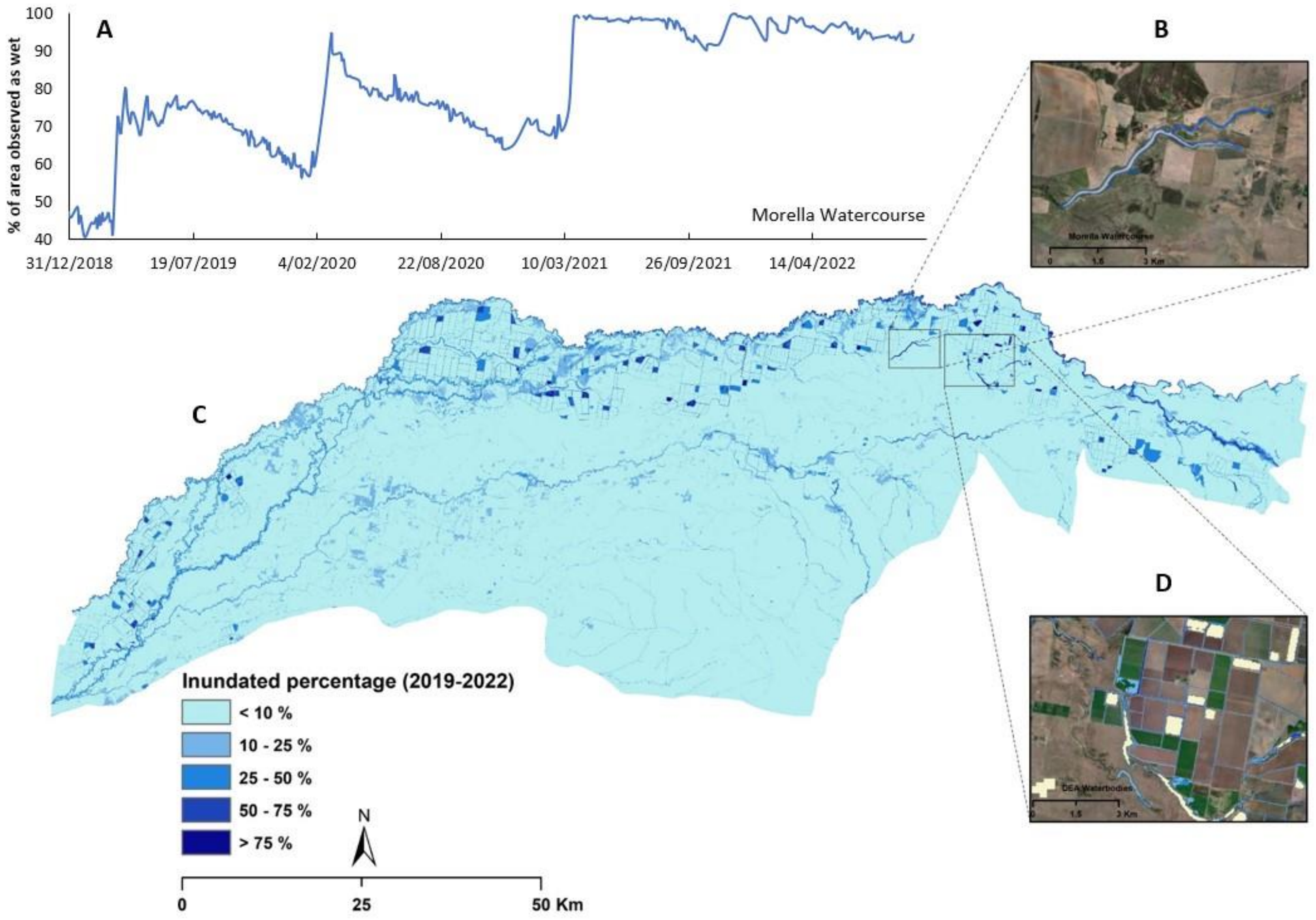

Figure 5. (A) time series of surface water extent change for Morella watercourse. (B) Morella watercourse boundary based on Digital Earth Australia waterbodies (yellow) and our inundation mapping (blue). (C) Percentage time inundated derived from Sentinel-2 inundation maps for the Border Rivers catchment from Dec 2018 to Sep 2022. (D) Comparison of persistent waterbodies derived from our inundation mapping (blue) and Digital Earth Australia waterbodies (cream).

The inundation frequency maps also facilitate tracking changes in the surface water extent of a pool over time. Figure 5a shows the surface water change between December 2018 and September 2022 for the Morella watercourse, located in the northeast of the Border Rivers floodplain (Figure 5b). Results such as this can be used in other flow-ecology studies, specifically looking for the effect of pool persistence on other ecological components of the floodplain.

Inundation maps will also be used to identify persistent waterbodies that are not detectable within the Landsat-derived waterbodies version 2 product of Digital Earth Australia, known as Digital Earth Australia waterbodies (Krause et al. 2021). A comparison between the Landsat-derived Digital Earth Australia waterbodies layer and the results of our inundation mapping is shown in Figure 5b and Figure 5d. The higher resolution of Sentinel-2 based mapping (10 m vs 30 m resolution) and combination of indices used produces a more accurate representation of inundation extent.

Data generated from our inundation maps can also be used to compare inundation extent between years to better understand the connectivity of floodplain systems. Figure 6 summarises the inundation frequency for the Border Rivers floodplain across four years. In addition, annual inundation frequency maps can be compared to the previous year to create an annual surface water change map (Figure 6).

Together, these results allow us to understand how water moves across the floodplain, and how this differs in wet and dry years. The Border Rivers floodplain generally shows an increasing trend in inundation frequency for the years 2020 and 2021 (Figure 6a and 6b) in the flood-prone areas (distributed in the north and centre of the floodplain), while in 2022 the total average number of times each pixel was inundated decreased (Figure 6c). These results were consistent with yearly rainfall differences published by the Bureau of Meteorology (Figure 11).

Table 3. Area inundated (km^2) within five inundation frequency categories across four years for the Border Rivers floodplain area.

Percentage of year inundated	2019	2020	2021	2022
< 10 %	5544.1	5373.8	4801.2	5084.2
10 – 25 %	31.9	141.9	365.8	156.4
25 – 50 %	20.8	54.3	262.1	80.1
50 – 75 %	13.7	26.7	90.1	50.4
> 75 %	10.9	24.6	102.2	250.3

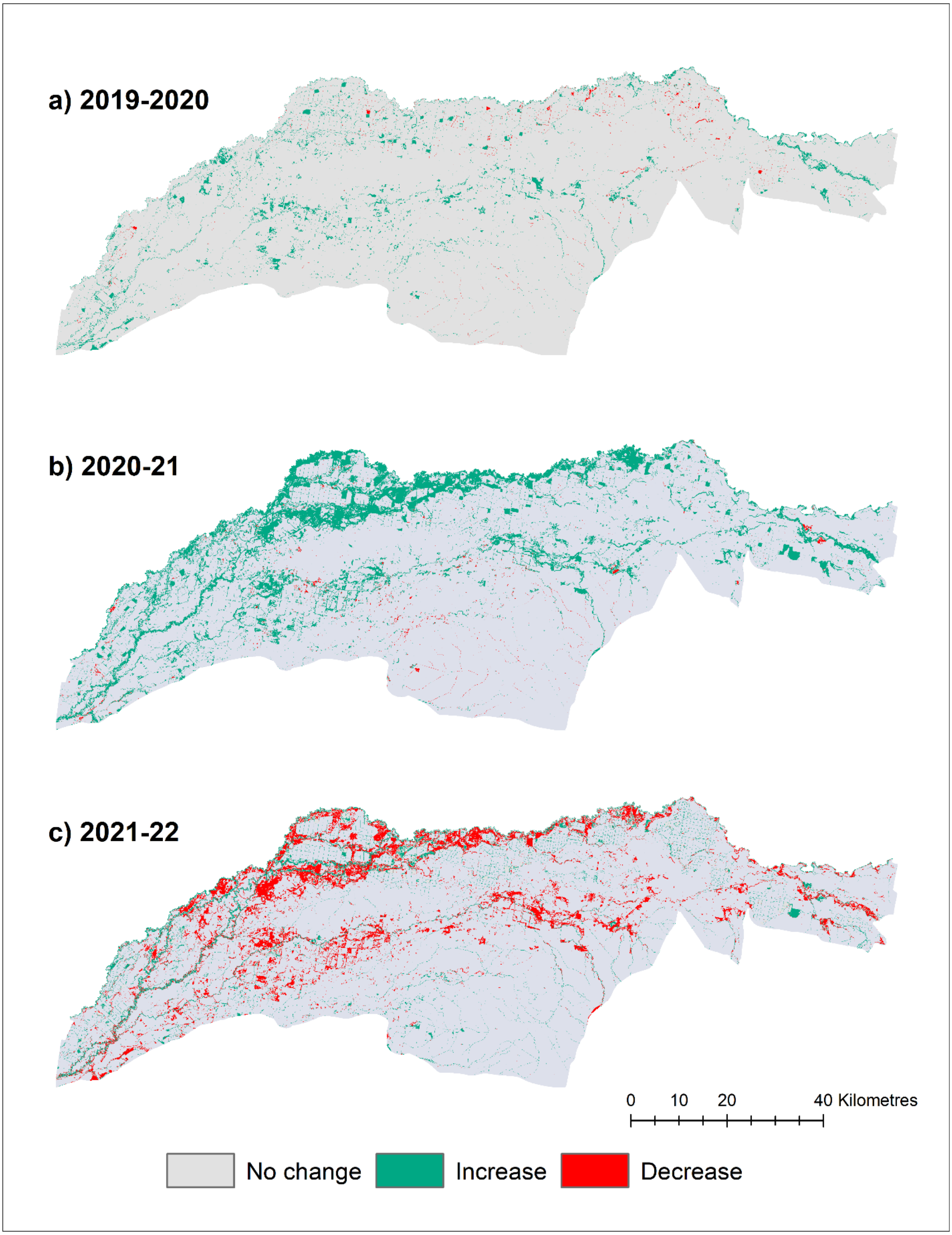

Figure 6. Change in inundation frequency across the Border Rivers floodplain from **a)**2019 to 2020, **b)** 2020 to 2021, and **c)** 2021 to 2022.

Conclusions

Our preliminary analysis suggests the following key findings:

- We assessed the suitability of a number of datasets, water indices and thresholds for mapping inundation extent across the northern Murray-Darling basin. We found that a multi-index method similar to that described in Ticehurst et al. (2022) was most suitable. We modified this method to utilise higher resolution Sentinel-2 imagery and refined river zones based on Strahler stream order.
- Over 400 maps of inundation extent have been produced for each catchment in the northern Murray-Darling basin. These maps closely represent the extent of field-observed inundation.
- A case study within the Border Rivers shows the usefulness of inundation mapping to:
    - Track changes in a pool's surface water extent
    - Detect persistent water bodies smaller than those that are able to be detected with Landsat-derived imagery
    - Compare changes in annual inundation duration, and the spatial distribution of these changes.

Next steps

The next stage of this project will use the developed inundation maps to generate tailored products to inform other projects within the EOMRP. These may include outputs such as a shapefile of persistent waterbodies, timeseries information of floodplain pool surface area, and inundation history information across areas of the floodplain with woody vegetation.

Additionally, the inundation maps can be used to investigate hydrological questions related to the floodplain. They can be used to identify flood pathways, critical pathways to ensure the inundation of environmental assets, and the impact of floodplain harvesting structures on extent of inundation across the floodplain.

Flood hydrology

Flood hydrology refers to the timing, frequency, magnitude and duration of river flow within the channel and as it breaks overbank and spreads onto the floodplain. Flood hydrology is the primary driver of floodplain inundation, along with localised rainfall. The flood hydrology project(s) will use flood inundation mapping to identify overbank flow paths and determine if these flow paths are impacted by artificial structures such as banks, dams, and on-property roads. The study will also seek to establish the extent of flooding in relation to nearby river gauge heights and in particular the gauge heights used as overbank environmental water requirements in the Long Term Water Plans.

Overbank Environmental Water Requirement validation project

Project team

Tim Haeusler, Daniel Coleman, Sara Shaeri Karimi, Lauren MacRae, Anna Helfensdorfer.

Project collaborators

This project is led by the department.

Introduction

A flow regime can be divided into flow types or categories such as cease-to-flows, low flows (or baseflows), freshes, bankfull flows and overbank flows (Figure 2). Each flow category can support or provide essential services to different species throughout their life cycle. An environmental water requirement (EWR) is the flow or inundation regime that a species, population or community needs to ensure its survival and persistence. For example, a fish may need a fresh in spring to enable it to travel to a breeding site, or a river red gum woodland may need 2 months of inundation every 2 years in spring.

Environmental watering requirements are based on best available scientific information on the target biota's biological and ecological needs to feed, breed, migrate and/or disperse. In the Murray-Darling basin environmental water requirements were developed for key species and communities by a panel of experts in each of the valleys during the production of Long Term Watering Plans. In each valley these descriptive environmental water requirements were converted to 'operational environmental water requirements'. These are flows at the most appropriate gauges in each valley.

These 'operational' environmental water requirements at a gauge are made up of a flow magnitude, duration, and a seasonal component. An example might be 750 ML/d at the Dubbo gauge for a minimum of 7 consecutive days between September and December for fish breeding purposes. Most environmental water requirements describe what flows need to be achieved while others may present flow conditions to avoid.

The environmental water requirements published in the Long Term Watering Plans as part of the Basin Plan process, provide a database of flow types which are related to specific environmental outcomes. There are also standard 'EWR tools' available which can easily calculate these environmental water requirements from a measured or modelled flow record in a consistent way. Environmental water requirements have been widely adopted by water managers. They are used to plan environmental water releases as well as measure the outcomes of environmental water programs.

Environmental water requirements associated with higher flows are an important tool to assess the frequency and duration of inundation and connectivity across the floodplain. They include bankfull flow, overbank flow, wetland inundation and anabranch connection flows. Bankfull flows provide fish breeding clues, move food supplies, provide greater habitat area and allow fish to move over barriers. Overbank and wetland flows connect habitats such as wetlands, billabongs and floodplains allowing aquatic animals to move.Tthey provide soil moisture and nutrients to riparian and floodplain vegetation, and provide habitat for fish, waterbirds, frogs and turtles to breed. Overbank flows also replenish groundwater supplies.

An assessment of environmental water requirement results was conducted through the Environment and Heritage Group of the Department of Planning and Environment's environmental water requirements dashboard (Wolfenden and Amos 2022). Results were input into the Murray Darling Basin Authority's Inundation History Tool in conjunction with Planet imagery to assess event inundation extents. Together, this data allows us to assess whether overbank environmental water requirements are having their intended effect on the floodplain. These analyses are currently ongoing as a component of projects in Water Dependent Fauna and Water Dependent Vegetation EOMRP reporting themes.

Project aims

We will use floodplain hydrology and flood inundation to answer the following:

Key project questions

- What is the extent of inundation across the floodplain when overbank environmental water requirements have been met?
- Are there any structures on the floodplain that alter natural flow paths and if so, does this impact any important floodplain habitats?

Link to water management activities

- Provide data for the ongoing monitoring and evaluation of the Basin Plan under Matter 8, Schedule 12, specifically the River Flows and Connectivity and, the Vegetation, themes in each of the Schedule J MER Plans for the northern basin water resource plans.
- Contribute to the monitoring and evaluation of the Floodplain Management Plans established under Section 50 of the NSW *Water Management Act 2000*, specifically to assess the performance indicator to assess the extent to which flood works have altered flood connectivity to flood-dependent ecological assets and values in the floodplain.

Method development

The methods used in this study are being developed through a case study and will be refined as final images from the Flood Inundation Mapping study are completed and further overbank environmental water requirements are assessed. The case study shows the typical results that can be achieved by comparing the inundation mapping of Gurleigh Lagoon in the Namoi catchment against the environmental water requirements based on river levels at the Namoi River at Mollee gauge (station number 419039).

Case study

Gurleigh Lagoon is a floodplain pool in the Namoi catchment located approximately 18 river kilometres downstream of the nearest gauge (Namoi River at Mollee (station number 419039)).

Three categories of overbank environmental water requirements are measured at this gauge: bankfull flow, small overbank flow and large overbank flow (Table 4). An initial assessment of flood hydrology was made through examination of the hydrograph (Figure 7). The Department of Planning and Environment - Environmental Heritage Group's environmental water requirements dashboard was then used for interrogation of the data for the combination of discharge, duration and frequency (Table 5). Environmental water requirement discharge thresholds and individual event dates were extracted from the dashboard and input into the Murray-Darling Basin Authority's Inundation History Tool.

The hydrograph for the study period was manually cross examined with dates of available imagery from Landsat and Sentinel satellite passes with preference given to satellite passes when flows were increasing. The tool produces an inundation extent for the region of interest which was then analysed in the ArcGIS geographic information system (Figure 8 & Figure 9). This large overbank flow (OB3) example demonstrates this sized flow event provides connectivity across the floodplain with inflows to Gurleigh Lagoon from Sheep Station Creek and overland flows downstream to the Namoi River.

Table 4: Overbank environmental water requirements for the Namoi River at Mollee (419039)

Flow category	EWR code	Flow rate (ML/d)	Timing	Duration	Frequency	Maximum inter-event period
Bankfull	**BK1**	>18,750	Oct – Apr	minimum 2 days, ideal > 10 days	4.5 years in 10	4 years
	BK2	>18,750	Sep – Feb (but can occur at any time)	minimum 5 days	3-5 years in 10	5 years
Small overbank	**OB1**	>21,750	Sep - Apr	minimum 2 days, ideal > 10 days	4-5 years in 10	4 years
	OB2	>21,750	Sep – Feb (but can occur at any time)	minimum 3 days	3-5 years in 10	5 years
Large overbank	**OB3**	>25,000	Aug – Feb (but can occur at any time)	minimum 2 days, 1-2 months inundation for regeneration, 5-7 months for maintenance	3-10 years in 10	5 years
	OB4	>40,000	Aug – Feb (but can occur at any time)	minimum 1 day, 1-4 months (habitat inundated)	3-5 years in 10	5 years

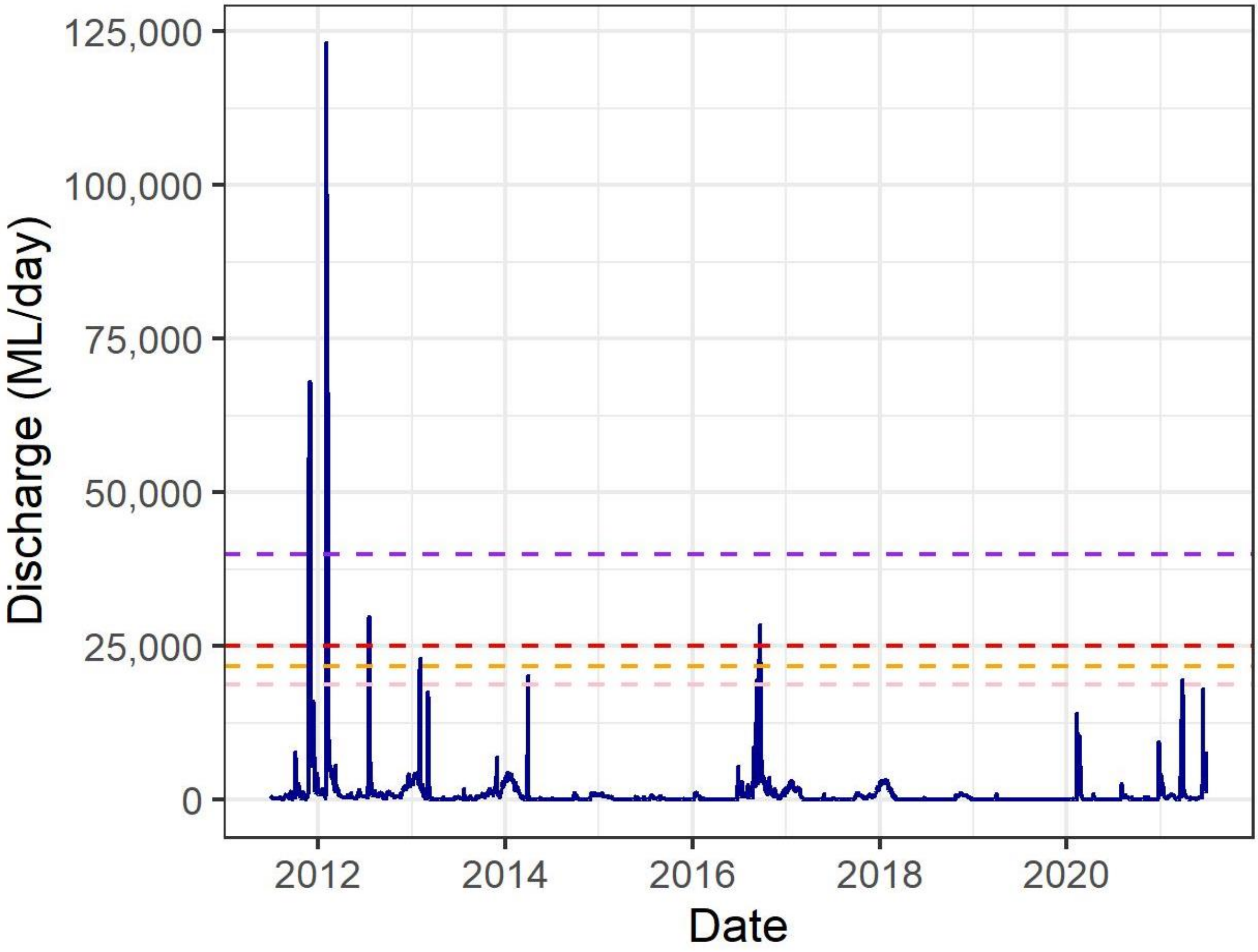

Figure 7. Namoi River at Mollee (419039) hydrograph for the last 10 water years showing the minimum discharge component of bankfull flow (pink dashed line), small overbank flow (orange dashed line), large overbank flow OB3 (red dashed line) and large overbank flow OB4 (purple dashed line) environmental water requirements.

Table 5: Number of times an overbank environmental water requirement has been met per water year over the last 10 water years at Namoi River at Mollee (419039, Planning Unit: Boggabri to Wee Waa). Not meeting frequency requirements (None/pink), meeting dry period frequency requirements (Dry/light blue), meeting wet period or long-term average frequency requirements (Wet/dark blue). The greater the number of EWRs met (light and dark blue – Wet/Dry) the better environmental outcomes are likely. Source: Department of Planning and Environment – Environment and Heritage Group's environmental water requirements dashboard .

EWR	BK1	BK2	OB1	OB2	OB3	OB4
Water Year						
2002-2003	0 (None)	0 (Dry)	0 (Wet)	0 (Wet)	0 (Dry)	0 (Dry)
2003-2004	0 (None)	0 (Dry)	0 (Wet)	0 (Wet)	0 (Dry)	0 (Dry)
2004-2005	1 (None)	0 (Dry)	1 (Wet)	1 (Wet)	1 (Wet)	1 (Wet)
2005-2006	0 (None)	0 (Dry)	0 (Wet)	1 (Wet)	1 (Wet)	0 (Wet)
2006-2007	0 (None)	0 (None)	0 (None)	0 (Wet)	0 (Wet)	0 (Dry)
2007-2008	0 (None)	0 (None)	0 (None)	0 (Wet)	0 (Dry)	0 (Dry)
2008-2009	2 (None)	0 (None)	1 (None)	1 (Wet)	1 (Dry)	0 (None)
2009-2010	1 (None)	0 (None)	1 (Wet)	1 (Wet)	1 (Wet)	0 (None)
2010-2011	1 (None)	1 (None)	1 (Wet)	1 (Wet)	1 (Wet)	3 (None)
2011-2012	2 (Wet)	2 (None)	2 (Wet)	2 (Wet)	2 (Wet)	2 (Dry)
2012-2013	1 (Wet)	0 (None)	0 (Wet)	1 (Wet)	1 (Wet)	0 (Dry)
2013-2014	0 (Wet)	0 (None)	0 (Wet)	0 (Wet)	0 (Wet)	0 (Dry)
2014-2015	0 (Wet)	0 (None)	0 (Wet)	0 (Wet)	0 (Wet)	0 (None)
2015-2016	0 (Wet)	0 (None)	0 (Wet)	0 (Wet)	0 (Wet)	0 (None)
2016-2017	0 (Wet)	1 (Dry)	1 (Wet)	1 (Wet)	1 (Wet)	0 (None)
2017-2018	0 (Wet)	0 (Dry)	0 (Wet)	0 (Wet)	0 (Wet)	0 (None)
2018-2019	0 (None)	0 (Dry)	0 (Wet)	0 (Wet)	0 (Wet)	0 (None)
2019-2020	0 (None)	0 (Dry)	0 (None)	0 (Wet)	0 (Dry)	0 (None)
2020-2021	1 (None)	0 (None)	0 (None)	0 (Dry)	0 (Dry)	0 (None)
2021-2022	3 (None)	2 (None)	2 (None)	2 (Dry)	2 (Dry)	2 (None)

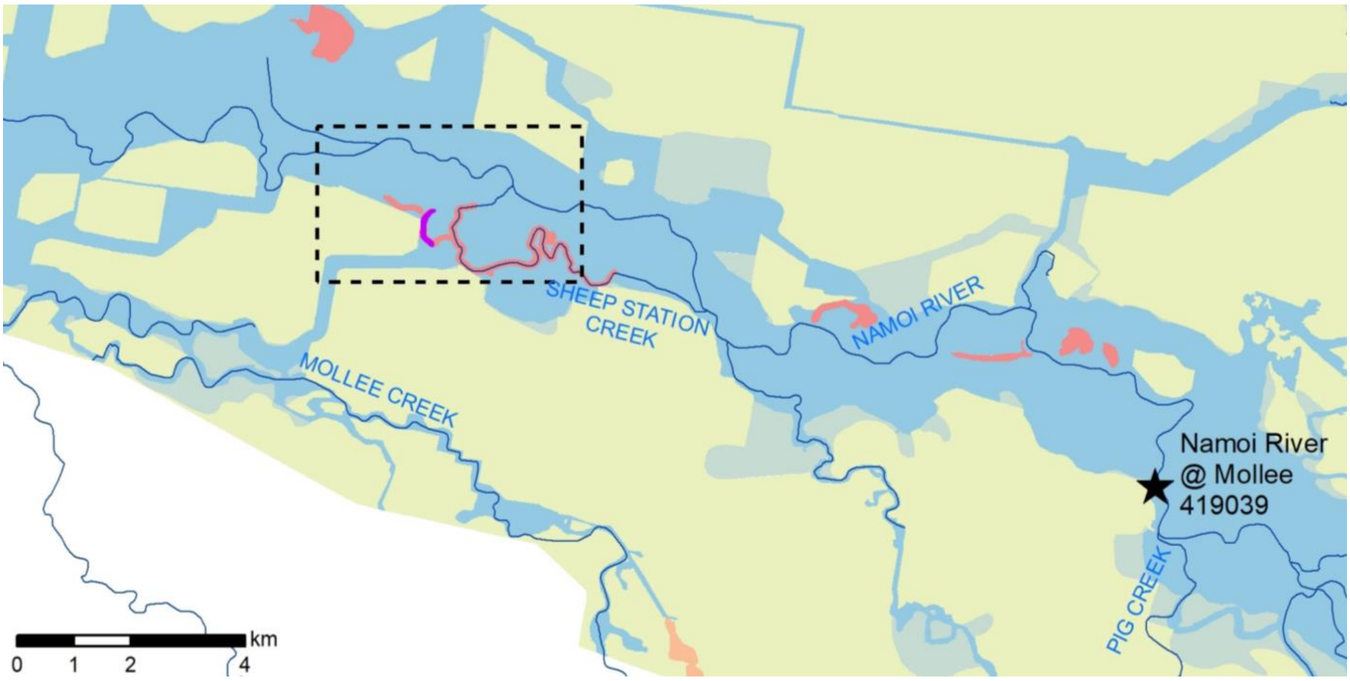

Figure 8. The Namoi River at Mollee (419039) gauge is approximately 18 river kilometres upstream of Gurleigh Lagoon (purple). The Lower Namoi Management Zones are derived from design floods with the primary overbank flow path shaded blue. The extent of Panel B is shown by the black dashed line.

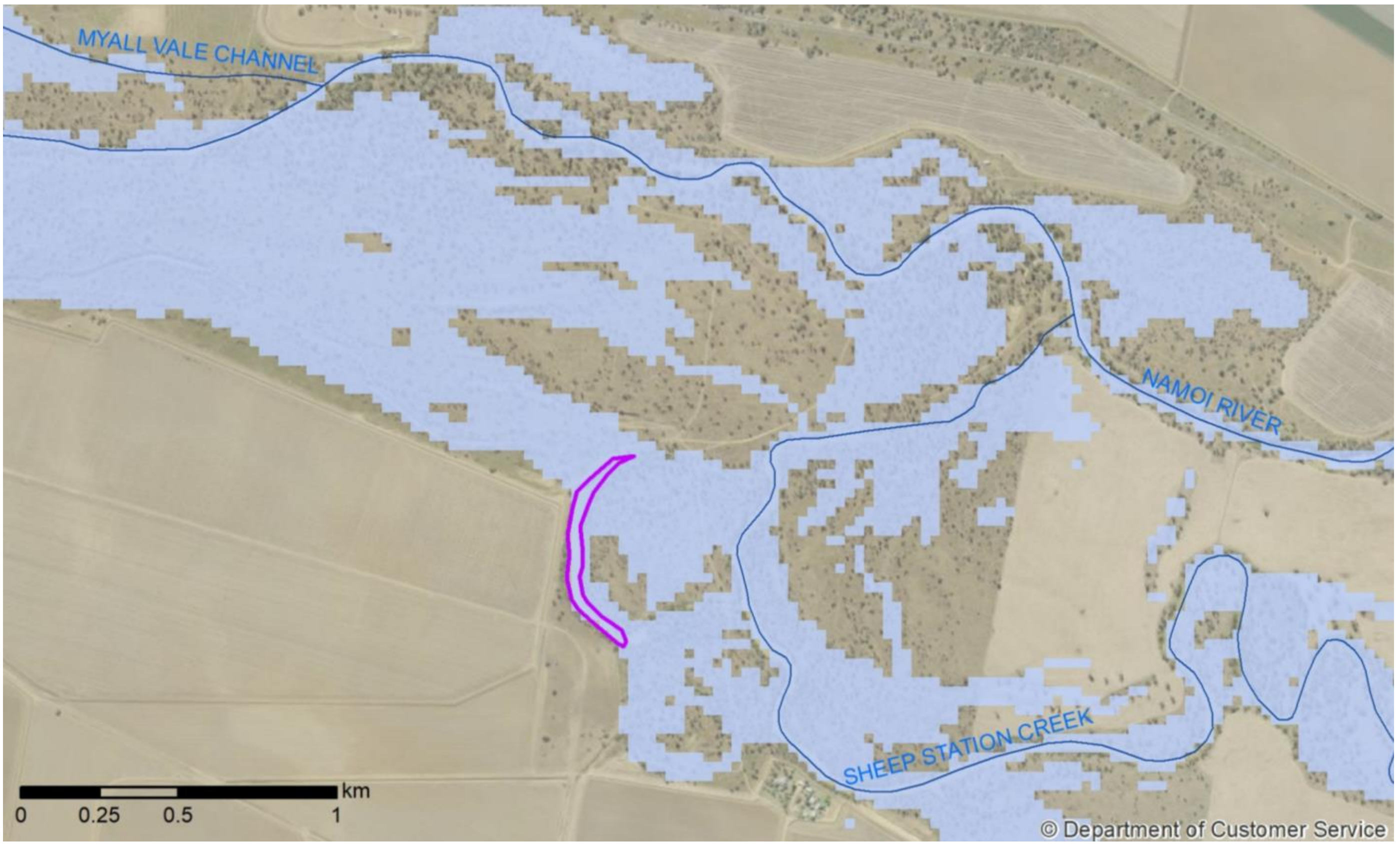

Figure 9 The oxbow Gurleigh Lagoon (purple) is located on the floodplain off Sheep Station Creek which drains into the Namoi River. The inundation extent derived from the Murray-Darling Basin Authority Inundation History Tool of a large overbank event (OB3) on the 12th December 2004 (blue shading). This event corresponds to a discharge at the Namoi River at Mollee gauge of 29,321 ML. An event of this magnitude provides connectivity across the floodplain with inflows to Gurleigh Lagoon from Sheep Station Creek and overland flows downstream to the Namoi River.

Conclusions

The case study of Gurleigh Lagoon shows that floodplain inundation maps can be used to assess the appropriateness of overbank environmental water requirements. Comparing inundation maps of floodplain pools and their surrounding landscape with environmental water requirements based on river levels allows validation that environmental water requirements are appropriately supporting the environmental assets they target.

Next steps

With the completion of further inundation maps from the floodplain inundation mapping project, the method developed in the case study of Gurleigh Lagoon can be applied to other areas across the floodplains of the northern Murray-Darling basin. This can be used to verify connectivity across the floodplain and the inundation of key environmental assets such as floodplain pools and lagoons and vegetation communities.

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Appendix 1 – detailed inundation mapping methods

This project uses the multi-index method developed by Ticehurst et al. (2022), modified to utilise the higher-resolution Sentinel-2 imagery instead of Landsat, and to apply more detailed boundaries for landscape zones. This method combines the strengths of different indices by applying them to the section of landscape to which they are most suited. Figure 10 illustrates the schematic overview of the automated workflow for floodplain inundation mapping using multi-index method.

Google Earth Engine, a cloud-based geospatial computing platform, was used to produce inundation maps based on three water indices across the area of interest. All analysis was performed on images from the atmospherically corrected surface reflectance Sentinel-2 L2A dataset with less than 35% cloud coverage.

Clouds and cloud shadows were masked using the method described in (Braaten 2020). The Sentinel-2 Cloud Probability dataset with a threshold of 65 was used to mask clouds. Shadows are searched within a range of 1000 m from cloud edges in the shadow direction. Potential cloud shadow pixels within this area were identified using a near-infrared reflectance value below 0.15. All identified clouds and shadows were buffered by 250 m to avoid border effects. To avoid confusion between clouds and bright non-cloud surface objects, the Cloud Displacement Index of less than -0.5 (Frantz et al. 2018) was also applied.

Images were mosaicked for each day and surface water was mapped for each mosaicked image using mNDWI with a threshold of -0.3, mNDWI with a threshold of 0, FWI with a threshold of 0.63 and TCW with a threshold of -0.035. TCW coefficients need to be adjusted for Sentinel-2 surface reflectance data, with two equations existing to achieve this (Shi and Xu 2019 & Henrich et al. 2012). We have used the equation developed by Henrich et al. (2012) as it has previously been used successfully in the northern Murray-Darling basin (Frazier et al. 2021). The resultant water maps were exported from Google Earth Engine for further processing.

The landscape for the area of interest was divided into rivers, wetlands and other environments based on existing boundary datasets (Table 6). Applying the multi-index method, the most suitable index for each landscape zone was extracted from the Google Earth Engine water maps in R and combined to produce the final inundation map (Table 6). This process used mNDWI with a threshold of -0.3 to classify inundated pixels within river zones, and TCW with a threshold of -0.035 within the wetland zones. Inundated pixels outside of the rivers and wetlands zones were identified using the maximum water extent between FWI with a threshold of 0.63 and mNDWI with a threshold of 0.

Table 6: Landscape zones, boundary datasets, indices and thresholds used in the multi-index mapping method for the Northern Murray Darling Floodplains

Landscape Zone	Zone Boundary Dataset	Index Used	Threshold Used	Index Reference
Rivers **Rivers area and surrounding buffer**	NSW Spatial Services River layer with variable (15-50 m) buffer based on Strahler stream order	Modified Normalised Difference Water Index (mNDWI)	-0.3	Xu 2006
Wetlands **natural perennial and temporary lakes, billabongs and floodplains**	Australian National Aquatic Ecosystem (ANAE) wetlands layer (Brooks et al. 2013)	Tasseled Cap Wetness Index (TCW)	-0.035	Crist 1985
Other **Any area outside of river and wetlands zones**	Area outside of identified river and wetland zones	Fisher's Water Index (FWI) Modified Normalised Difference Water Index (mNDWI) (maximum extent)	0.63 0	Fisher et al. 2016 Xu 2006

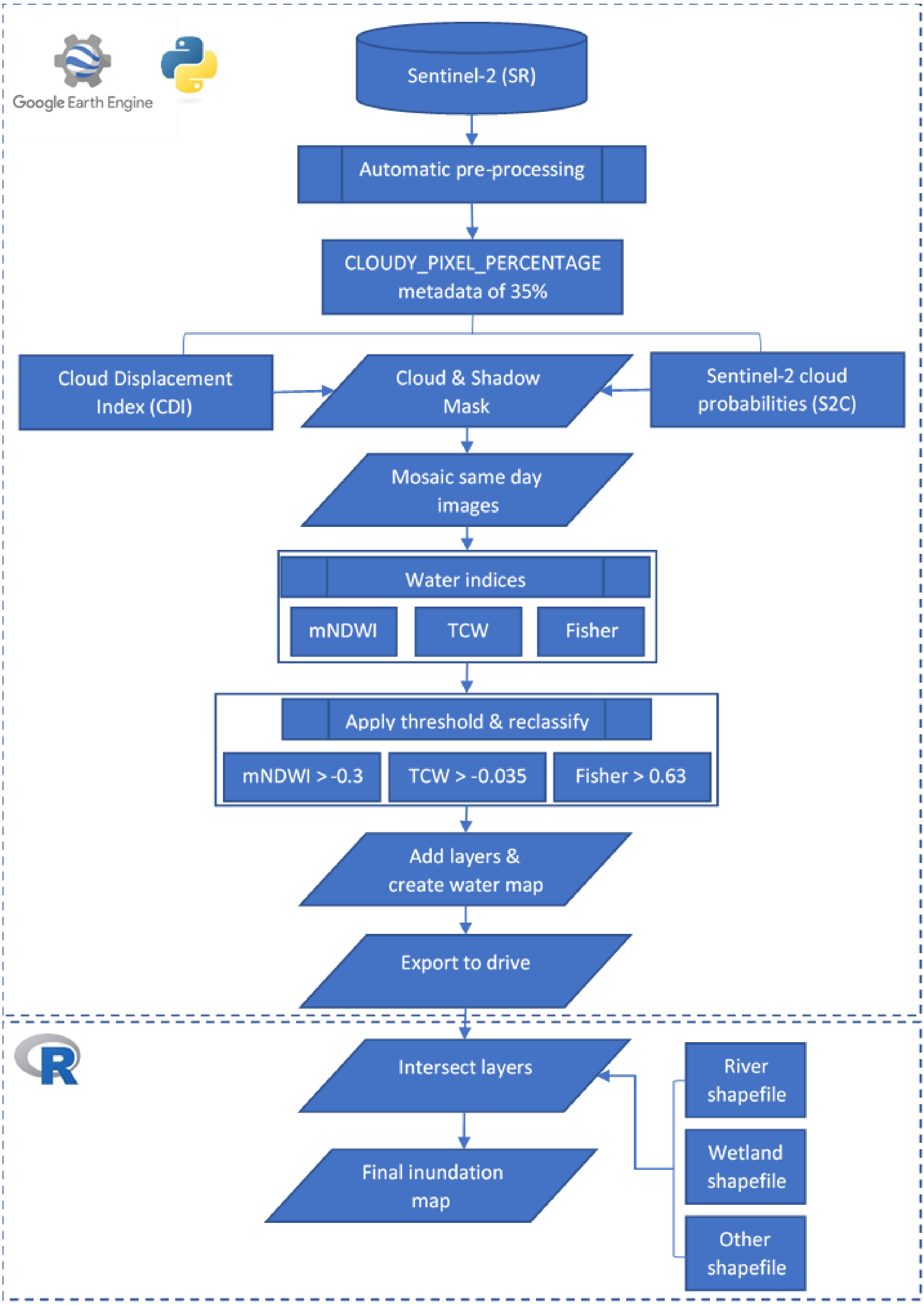

Figure 10. schematic workflow for automated floodplain inundation mapping from Sentinel-2 imagery.

Appendix 2 – comparison of inundation frequency and yearly rainfall trends

The results seen in the Border Rivers percentage inundation change maps (Figure 6) were validated against yearly rainfall differences published by the Bureau of Meteorology (BOM 2020). The trends in seen in the inundation change maps were consistent with expectations based on changes in rainfall levels (Figure 11). A positive change in inundation frequency was seen between years where the change in rainfall was also positive. Similarly, when rainfall was lower a negative change in inundation frequency was observed.

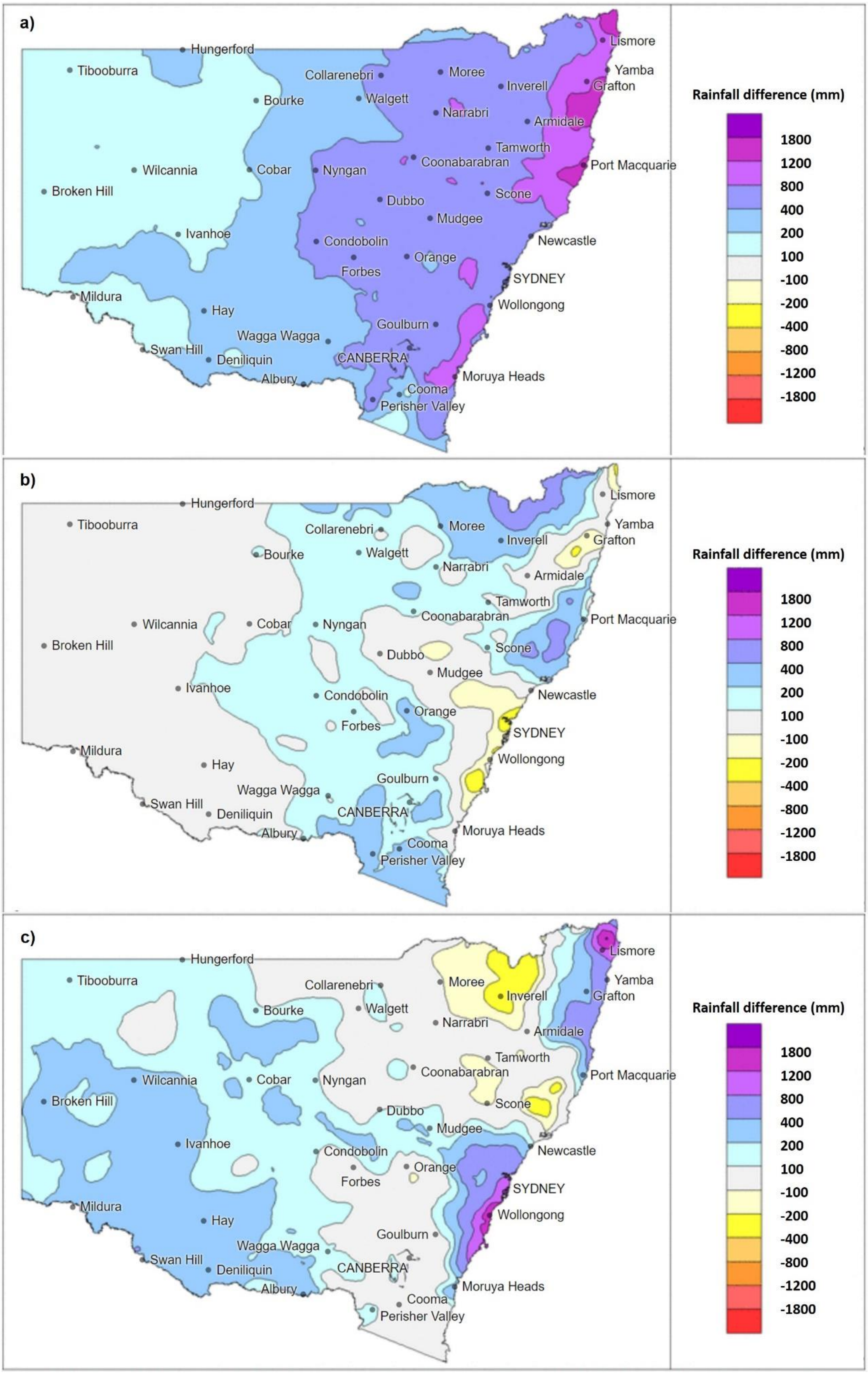

Figure 11. Annual rainfall difference for a) 12-months (Jan-Dec) 2020-2019, b) 12-months (Jan-Dec) 2021-2020, and c) 12 months (Jan-Dec) 2022-2021. Data source: the Bureaue of Meterology rainfall difference maps (http://www.bom.gov.au/).