NSW Reconstruction Authority

Hawkesbury-Nepean River Flood Study

Overview

June 2024

Acknowledgement of Country

The NSW Reconstruction Authority acknowledges that Aboriginal and Torres Strait Islander peoples are the First Peoples and Traditional Custodians of Australia, and the oldest continuing culture in human history.

We pay respect to Elders past and present and commit to respecting the lands we walk on, and the communities we walk with. We acknowledge the Aboriginal and Torres Strait Islander people that contributed to the development of the Flood Study.

We celebrate the deep and enduring connection of Aboriginal and Torres Strait Islander peoples to Country and acknowledge their continuing custodianship of the land, seas, and sky.

We acknowledge the ongoing stewardship of Aboriginal and Torres Strait Islander peoples, and the important contribution they make to our communities and economies.

We reflect on the continuing impact of government policies and practices and recognise our responsibility to work together with and for Aboriginal and Torres Strait Islander peoples, families, and communities, towards improved economic, social and cultural outcomes.

Hawkesbury-Nepean River Flood Study Overview

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Flooding in the Hawkesbury region, March 2022 | Photo by Adam Hollingworth

Photos in publication

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From the CEO

The 2024 Hawkesbury-Nepean River Flood Study is one of the most comprehensive flood studies ever undertaken in NSW.

The Hawkesbury-Nepean Valley is an incredibly complex floodplain, recognised as having one of the highest flood risks in Australia. It is essential that we have up-to-date technical information for community safety, evacuation and emergency management, as well as land use planning and infrastructure investment prioritisation.

The 2024 Hawkesbury-Nepean River Flood Study is a leading example of best-practice scientific analysis. It uses the latest modelling techniques to provide high resolution flood level, depth and velocity data so we can better understand the impact of flood events, and has been informed by and tested against the recent floods that have impacted the area.

The document includes a main report, 12 technical volumes and a map book, and has been reviewed by leading hydrologists from the University of NSW and University of Queensland as well as local councils in the Valley and relevant NSW Government agencies. The results of the study, including technical data, has been provided to local councils and other agencies as the most up-to-date and reliable source of flood information.

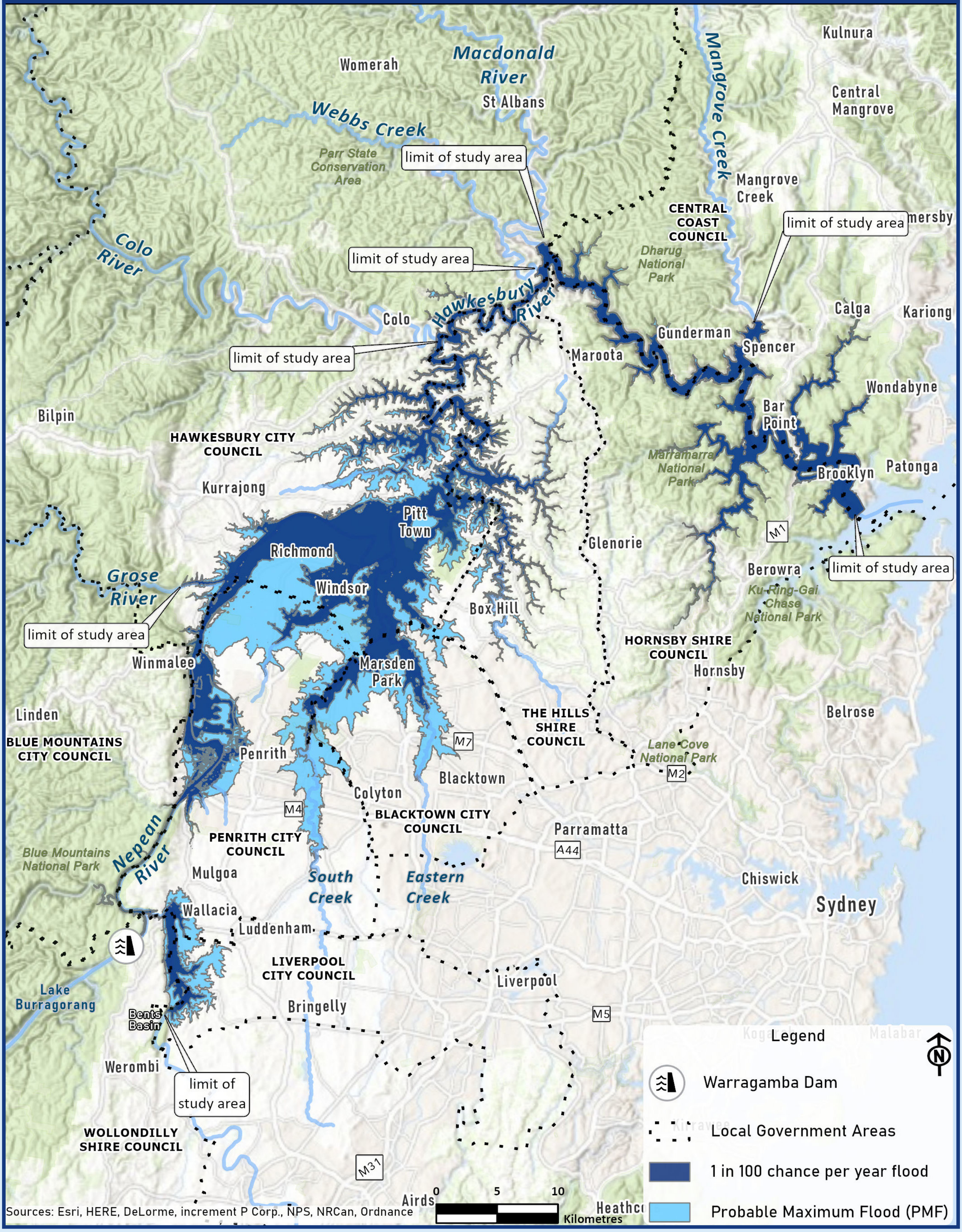
The Flood Study also provides valuable data to support one of the first regional Disaster Adaptation Plans (or DAPs) being developed by the NSW Reconstruction Authority, focusing on flood risk in the Hawkesbury-Nepean Valley (the Valley). It will inform a suite of risk reduction measures as guided by the State Disaster Mitigation Plan (2024).

This work is essential to ensure we understand flood risk and protect lives and properties in our high-risk catchments.

Mal Lanyon APM

CEO, NSW Reconstruction Authority
June 2024

Figure 1: Study area



Flooding in the Hawkesbury-Nepean Valley

The Hawkesbury-Nepean River (called Dyarubbin by the first Australians) has a long history of flooding.

After nearly three decades without serious floods, the floods in 2020, 2021 and 2022 are a reminder of the risk of damaging floods in the Valley.

Documented reports of flooding date back to 1789 - the longest flood record in Australia. The largest was in 1867, reaching 19.7 metres above sea level at Windsor - nearly six metres higher than the July 2022 flood. In 1867, floodwater in Penrith almost reached the corner of High and Woodriff Streets, and much of Emu Plains was under water.

Aboriginal peoples have lived along Dyarubbin for at least 50,000 years and have seen many floods. Reported oral traditions describe a flood at Windsor in around 1780 that was higher than the 1867 flood and swept away people taking refuge in tall trees.

Geological evidence also points to flooding much higher than the 1867 flood, prior to European settlement.

Floodplains adjacent to rivers are formed by flooding over thousands of years, as alluvial sediment is deposited when floodwater overtops riverbanks.

The NSW Government, through the NSW Reconstruction Authority, is committed to improving how NSW prepares and responds to natural hazards and making sure communities across the state recover from disasters faster. A vital requirement for planning for floods is accessible, contemporary flood risk information.

The 2024 Hawkesbury-Nepean River Flood Study draws on learnings from the recent floods and uses the latest flood modelling technologies and contemporary information to update and expand previous flood investigations.

This Study provides the most credible and up to date flood information for the Valley.

Hawkesbury-Nepean River Flood Study

The Hawkesbury-Nepean Valley has the highest flood risk in NSW, if not Australia. Having the best available flood information to understand and manage this risk is essential.

The Hawkesbury-Nepean River Flood Study (2024 Flood Study) identifies areas in the valley affected by flooding from this river and assesses the potential impacts of climate change.

The study accounts for flows from the entire 21,400 km^2 Hawkesbury-Nepean catchment, providing detailed flood information for the 190-km length of the Hawkesbury-Nepean River from Bents Basin near Wallacia through to Brooklyn. The study area falls mainly within the Penrith, Hawkesbury, Blacktown and The Hills Local Government Areas (LGAs). Other LGAs in this floodplain are Wollondilly, Liverpool, Hornsby and Central Coast (see Figure 1).

This overview describes how the 2024 Flood Study was developed, how it will be used, and some key findings.

What is a flood study?

A flood study is a technical investigation of the way floods behave within a river catchment. It is a vital input to the flood risk management process.

The aim of a flood study is to define flood behaviour, particularly the chance and severity of different sized floods.

The 2024 Flood Study builds on an extensive understanding of floods

The Hawkesbury-Nepean River Flood Study (2024 Flood Study) builds on the Hawkesbury-Nepean Valley Regional Flood Study published in 2019.

This 2019 Study laid groundwork for the 2024 Flood Study, especially developing a fast-running '1-dimensional' (1D) hydraulic model and using a 'Monte Carlo' approach to simulate nearly 20,000 modelled flood events.

The new Flood Study has involved the development of a new, detailed '2-dimensional' (2D) hydraulic model to produce highly granular flood information across the floodplain. It provides flood level, depth and velocity data at a 15m cell resolution across the river and floodplain.

As part of the 2024 Flood Study, the 1D model has been updated to better align with the 2D model. Parts of the Monte Carlo approach have also been updated to incorporate learnings from recent floods.

Around 60 events were selected from the 20,000 events modelled in the updated 1D model to run through the new 2D model.

The updated 1D model has been used to understand the variability of floods and to select some floods for detailed analysis.

The new 2D model has been used to generate detailed flood information for a wide range of purposes.

Important features of the 2024 Flood Study:

- Updated topography and surveys of river channels
- Refined hydrologic model
- New detailed 2-dimensional hydraulic model
- Calibration and validation of models using extensive observations from four recent floods as well as older floods
- 'Deep dives' into drivers of local flooding, especially the interaction of:
  - Warragamba and Nepean rivers impacting Wallacia
  - Hawkesbury and Colo rivers impacting the lower Hawkesbury River
  - Catchment and coastal flooding impacting the lower Hawkesbury.

The study uses best practice approaches and up-to-date flood guidelines:

- NSW Government's Flood Risk Management Manual, 2023, and associated guidance
- Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, Commonwealth of Australia, 2017
- Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia, 2019.

How recent floods have informed the 2024 Flood Study

Extensive datasets were collected during and after recent Hawkesbury-Nepean River floods.

This work is briefly described in the March 2021 Flood Review and the March and July 2022 Floods Review, and detailed in Technical Volumes 8-10 of the 2024 Flood Study.

As the first serious Hawkesbury-Nepean River floods in around 30 years, this information has been vital to understanding how flooding behaviour may have changed.

The recent floods also provided an opportunity to calibrate and validate the flood models against contemporary, well-documented floods. This demonstrated that the models are replicating real floods. Importantly, there was a good match between the actual floods and the modelled floods, across the large study area.

Previous mapping of floods has been vital for community education | Photo by Adam Hollingworth

How will the 2024 Flood Study be used?

All of us living and working in the Hawkesbury-Nepean Valley need to understand the flood risk and actions we can take to protect ourselves and others in the event of a flood.

Information in the flood study supports:

- emergency management and evacuation planning including the **NSW State Emergency Service's Hawkesbury Nepean Flood Plan**
- local communities, providing information about their flood risk, including **flood maps with flood extents and depths**
- regional land use planning, particularly the development of a **regional risk-based planning approach**
- local council land use planning, including **local environmental plans, development control plans and other council policies**
- flood risk assessment by **organisations, companies, and insurers**
- the assessment and design of **flood mitigation infrastructure and evacuation roads.**

The 2024 Flood Study will also inform the Reconstruction Authority's Disaster Adaptation Plan for the Hawkesbury-Nepean Valley, currently being developed.

A large and complex floodplain

Warragamba Dam spilling, March 2021 | Photo by Adam Hollingworth

The 2024 Flood Study considers Hawkesbury-Nepean River flooding from Bents Basin near Wallacia through to Brooklyn. This is a large area and includes backwater flooding up tributaries.

The Hawkesbury-Nepean River is fed by several tributaries and their catchments including:

- Warragamba River (which although controlled by Warragamba Dam since 1960 remains the dominant source of floodwater)
- Nepean River
- Grose River
- South and Eastern creeks
- Colo River
- Macdonald River.

The geography of the Valley means that floodwaters from the catchment back up behind natural choke points created by narrow sandstone gorges (Figure 2). This 'bathtub' effect causes rapid, deep and widespread flooding.

The geography creates four distinctive floodplains in the study area (Figure 2):

- Wallacia
- Penrith/Emu Plains
- Richmond/Windsor, which also includes backwater flooding up Rickabys, South and Eastern creeks
- Lower Hawkesbury – narrow floodplains in the sandstone gorges between Cattai and Brooklyn.

Different types of flooding

The 2024 Flood Study focuses on flooding from the Hawkesbury-Nepean River, typically caused by three days of rain. It does not model localised, shorter duration flooding. Local councils undertake studies of local catchment and overland flooding.

Effects of Warragamba Dam on river flooding

Warragamba Dam is Australia's largest urban water supply dam. It is located in a narrow gorge on the lower section of the Warragamba River, 3.3km before it joins the Nepean River near Wallacia.

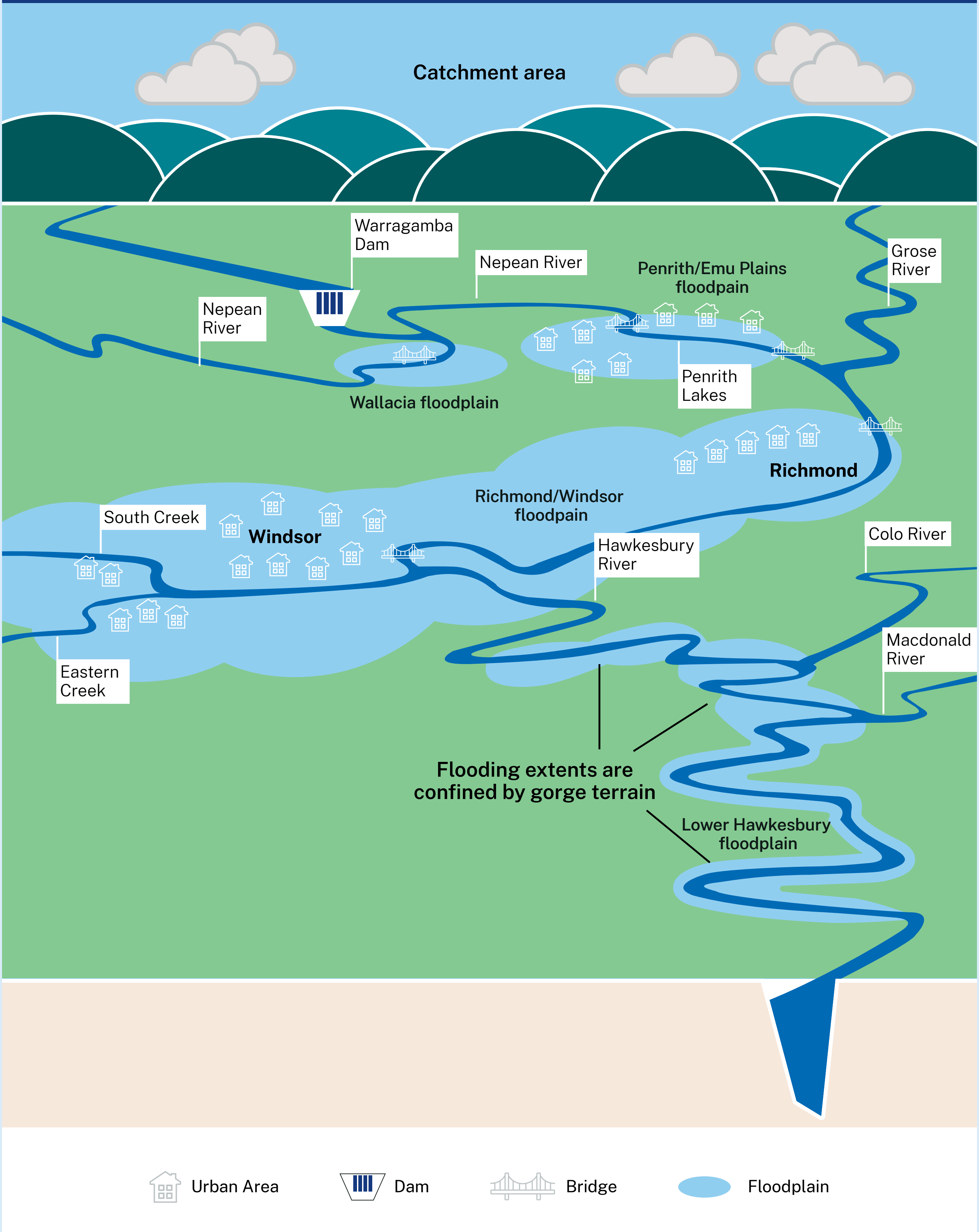
The catchment above Warragamba Dam makes up around 80% of the total catchment to Penrith and 70% to Windsor. Therefore, it has a major influence on flooding in the Valley, contributing the majority of flows during the largest floods.

If the storage level behind Warragamba Dam is very low at the start of a flood, it can help hold back the inflows during a flood. The dam was only at 43% capacity at the start of the February 2020 flood and captured all the inflows to the dam. Modelling shows that if the dam had been full, flood heights at Windsor would have been around 3m higher.

However, history shows that most of the large floods occur during wet periods when the dam is nearly full. When this happens, the dam cannot hold back the inflows. The floods in 2021 and 2022 are recent examples of this.

Variable dam starting levels have been taken into account in the flood study.

Figure 2: Hawkesbury-Nepean Valley landscape



Describing flood events

Floods are most often described in terms of the chance that floods of a certain size could happen, and the height floodwaters reach at specific locations.

Flood maps often use this information to show different types of floods. Knowing whether your property is flood affected can help you plan and consider what to do when flooding is predicted.

Chance of a flood happening

To work out how frequently an area might flood, we look at the chance of different sizes of flood. For example, the term '1 in 100 year flood' refers to a flood that has a 1 in 100 (or 1%) chance of happening (or being exceeded) in any given year. The technical term to describe this chance is Annual Exceedance Probability (AEP).

The Study estimates the 1 in 100 chance per year flood would reach 17.3m at Windsor, with flooding around 7m deep at Governor Phillip Park.

Expressed another way, it means that a person living to 80 years of age has more than a 55% chance of experiencing a flood this size during their lifetime.

Our understanding of flood chance typically evolves over time with a longer historical record and improved modelling tools. Changing environmental conditions can also change the flood height corresponding to the flood chance.

The largest flood possible is called the probable maximum flood or PMF. It is an extremely rare and unlikely flood, with roughly a 1 in 100,000 chance per year of happening in the Hawkesbury-Nepean Valley. However, a number of historical floods in Australia have approached the scale of a PMF. All properties within the footprint of a PMF are considered to be within the floodplain for that region, and need to be considered in evacuation planning.

The table below compares the chance of flooding in any year or over an 80-year lifetime, to the flood heights at Windsor.

	Chance of happening in any year		Chance of happening at least once in an 80-year lifetime	Flood height at Windsor PWD gauge (m AHD)
	AEP (1 in X)	AEP (%)		
	1 in 5	20%	> 99.9%	9.9
	1 in 20	5%	98.3%	13.8
	1 in 100	1%	55.3%	17.3
	1 in 500	0.2%	14.8%	20.2
PMF:	~ 1 in 100,000	~ .001%	< 0.1%	30.6

Height of floodwaters

Height is one indicator of how severe flooding may be. Flood heights are often measured as above Australian Height Datum (AHD), which is approximately equal to mean sea level.

In the Hawkesbury-Nepean Valley, river gauges from Windsor to the coast are set to 0m AHD. The July 2022 flood peaked at 13.9m on the Windsor gauge, or 13.9m AHD.

But upstream gauges use different datums. The March 2021 flood peaked at 10.0m on the Penrith gauge, or 24.1m AHD. At Wallacia Weir, the July 2022 flood peaked at 13.8m, or 40.4m AHD.

Flood warnings

During a flood, the Bureau of Meteorology may issue flood warnings for 'major', 'moderate' or 'minor' flooding. These classifications are based on predicted river heights and relate to the general consequences for local communities. Because the classifications are based on impacts, they are not aligned to the chance of floods. This is because a flood of the same chance may have different impacts at different locations.

For more information visit: http://www.bom.gov.au/water/awid

Patterns of flooding

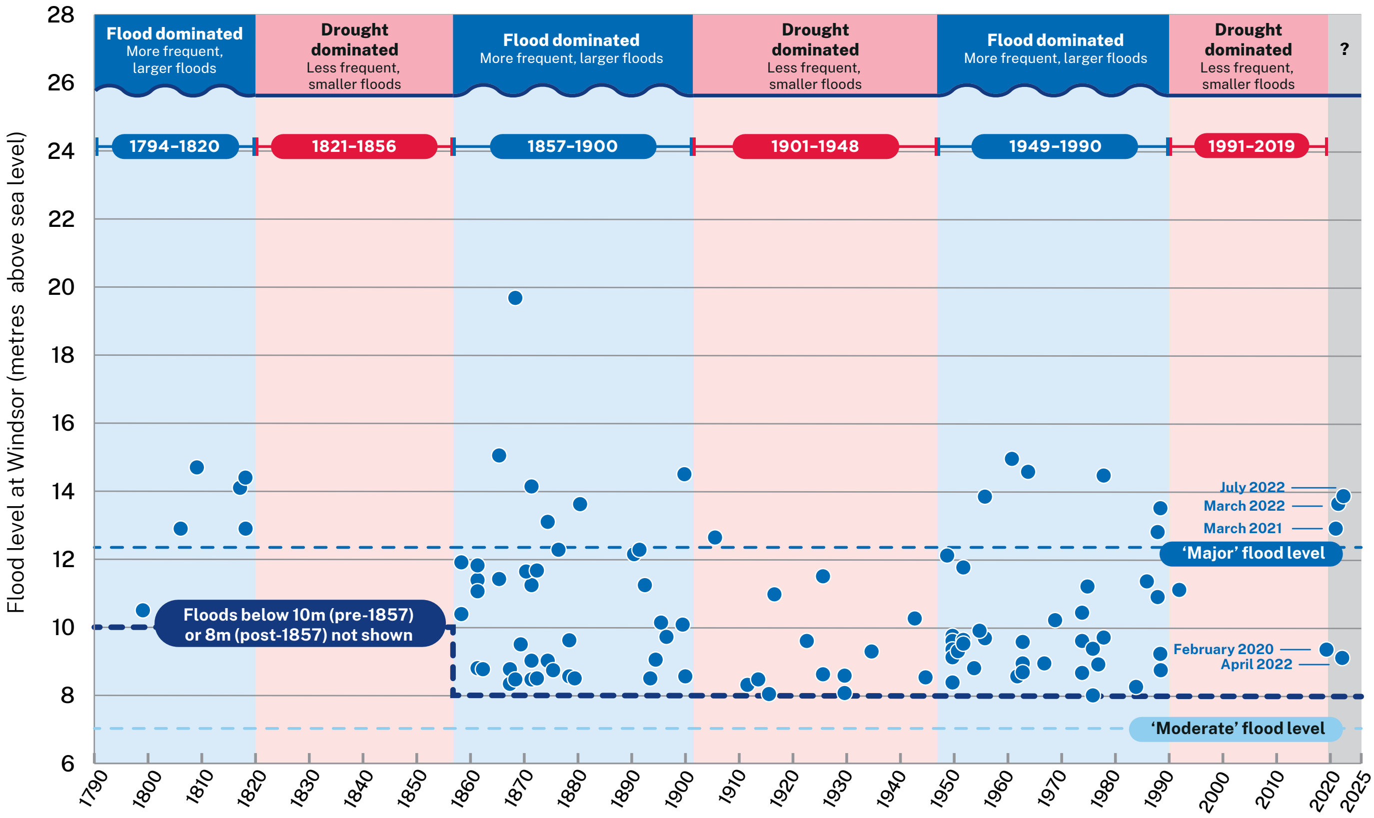
The flood history of the Valley suggests flood-rich periods, including higher floods, that last for decades. These can be followed by similar length periods of fewer and smaller floods. This pattern has been described as flood-dominated and drought-dominated regimes (see Figure 3).

On top of these underlying regimes are large annual variations in rainfall and runoff, in part aligned with the El Niño Southern Oscillation (ENSO) climate driver.

It's too early to know whether the cluster of floods from 2020 to 2022 signals the start of a new flood-dominated period – as indicated by the question mark on Figure 3.

Ultimately, floods are naturally occurring events. It's impossible to say when the next flood will come.

Figure 3: Hawkesbury River floods at Windsor 1791 to 2023



How this flood study was developed

Flood studies use flood modelling. A model is a mathematical representation of how a system works. In the case of flooding, the system relates to rainfall, runoff, river flows and the movement of water across a floodplain.

The NSW Government commissioned specialist Australian flood experts Rhelm Pty Ltd, in conjunction with Catchment Simulation Solutions Pty Ltd, to prepare the 2024 Flood Study. Components of the work were prepared by WMAwater Pty Ltd and Baird.

Local councils within the study area, together with the Hawkesbury-Nepean Valley Flood Risk Management Division within Infrastructure NSW then the NSW Reconstruction Authority, Department of Climate Change, Energy, the Environment and Water, Department of Planning, Housing and Infrastructure, NSW State Emergency Service, and the Bureau of Meteorology were members of a Technical Working Group that met over the development of the project.

The draft Flood Study was also reviewed by independent flood experts.

Steps taken to develop the 2024 Flood Study are outlined here.

STEP 1 | Data collection

In addition to the data collected for the 2019 Flood Study, a range of high-quality data was collected for the 2024 Flood Study including:

- detailed rainfall and river height information for the 2020, 2021 and 2022 floods. Some information was supplied by the community using the Social Pinpoint web platform.
- recent aerial imagery depicting catchment land uses and floodplain conditions
- recent topographic and river channel surveys
- surveys of bridges and other structures.

Surveying flood levels, March 2021 | Photo by Isabelle Testoni

STEP 2 | Hydrologic assessment

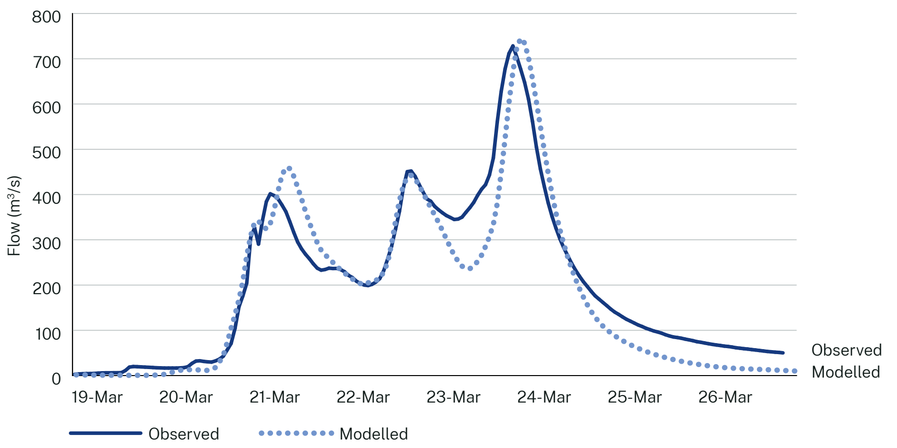
Hydrology is the study of how rainfall is converted into runoff from a catchment over time. It takes into account the rainfall and ground conditions in the catchment.

An existing **hydrologic model** (WBNM) of the Hawkesbury-Nepean catchment was refined and updated. This calculates the creek and river flows resulting from rainfall in the catchment.

The model was calibrated and validated using 11 historical floods (Jul 2022, Mar 2022, 2021, 2020, 1998, 1990, 1988, 1986, 1978, 1975, 1964).

A good match between observed and modelled river flows is evidence of a well calibrated model. Figure 4 shows an example on the Nepean River in the 2021 flood.

Figure 4: Observed and modelled flood flows, Nepean River at Maldon Weir, March 2021

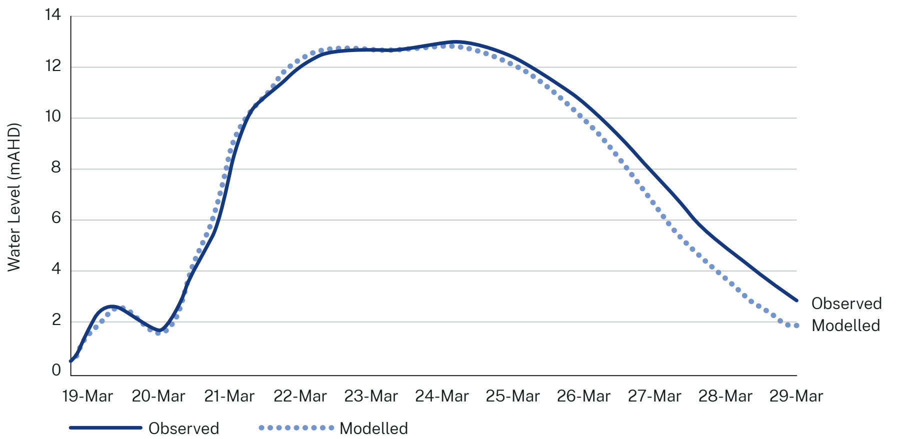


STEP 3 | Hydraulic assessment

Hydraulics is the study of the physical movement of water along rivers and over floodplains. Hydraulic modelling is used to determine:

- **flood levels**
- **flood extents**
- **flood depths**
- **flood velocities** (speed and direction)
- **flood hazard** – combinations of depths and velocities related to the stability of vehicles, people and buildings
- **flood function** – identification of floodways important for the conveyance of floodwater, and flood storage areas.

Figure 5: Observed and modelled flood heights, Hawkesbury River at Windsor, March 2021

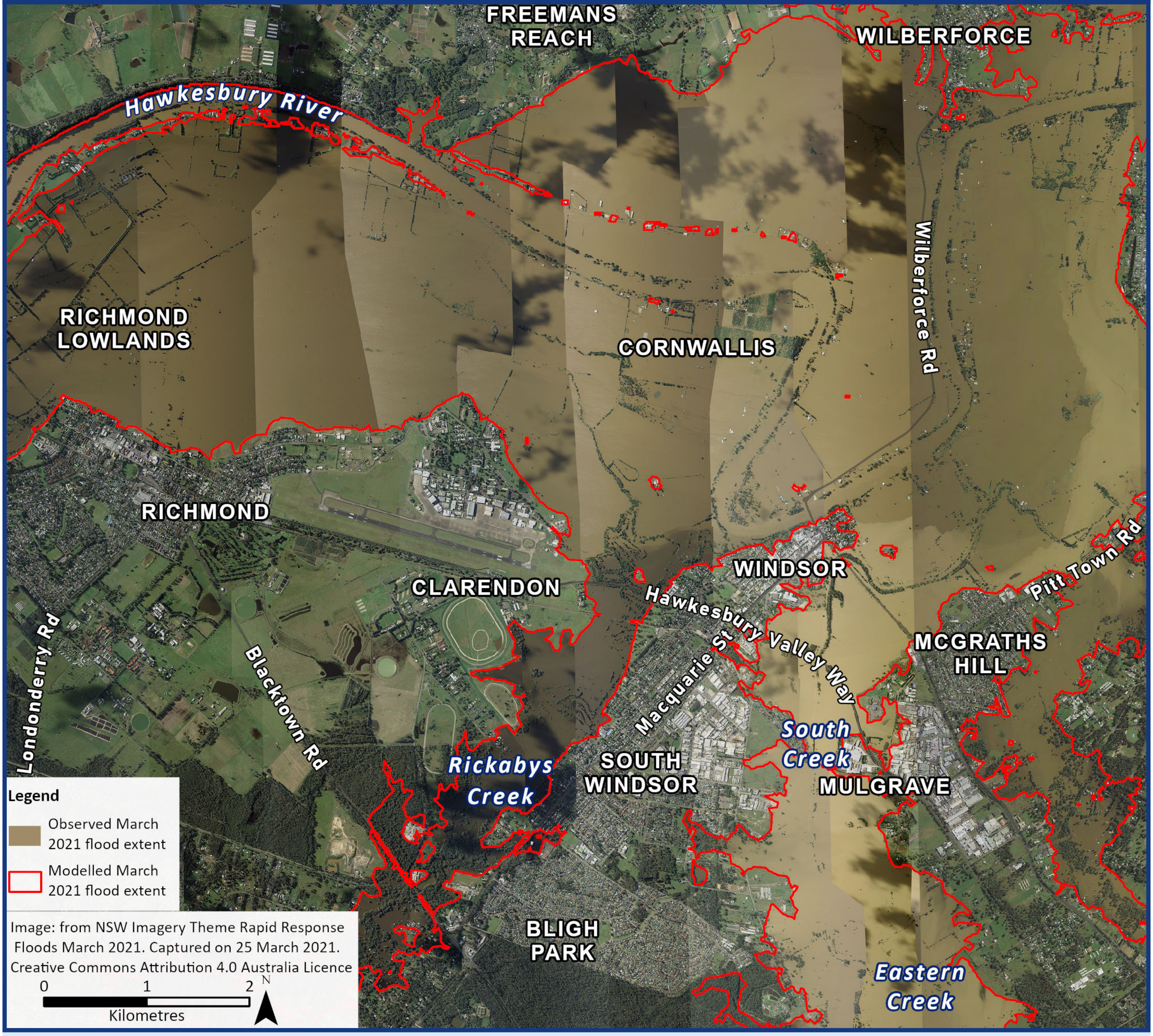


A new 2-dimensional **hydraulic model** (TUFLOW) covering an area of more than 1,500km^2 was developed. Flood flows from the hydrologic model were input to the 15m resolution hydraulic model.

The TUFLOW model was calibrated and validated using 11 historical floods (Jul 2022, Mar 2022, 2021, 2020, 1990, 1988, 1986, 1978, 1975, 1964, 1961).

A good match between observed and modelled river heights is evidence of a well calibrated model. Figures 5 and 6 compare continuous river heights over time, peak heights, and flood extents at Windsor for the 2021 flood. The very good match provides confidence in the robustness of the models.

Figure 6: Observed and modelled flood extents, Hawkesbury River near Windsor, March 2021



Flood models for this study have been calibrated and validated by comparing the modelled results with actual, recorded flood events. This is important to ensure the model outputs are as accurate as possible and best reflect the flooding behaviour in the valley.

STEP 4 | Monte Carlo modelling

Flooding over a large catchment like the Hawkesbury-Nepean is complex and depends on many variables:

- how much rain falls (intensity and duration)
- where the rain falls (spatial pattern)
- when the rain falls (temporal pattern)
- storm movement (this can affect the timing of tributary flows)
- catchment wetness at the start of the flood
- dam levels at the start of the flood
- tide levels.

The 'Monte Carlo' model set up for the 2019 Flood Study was updated for this study. This models thousands of flood scenarios by randomly combining a range of the inputs listed above.

The updates included:

- a flood frequency analysis of floods since 1860 used to better understand how floods from the Warragamba and Nepean rivers combine to impact Wallacia
- an analysis of floods on the Colo and Macdonald rivers since 1889, when compared to Hawkesbury-Nepean floods at Penrith and Windsor, used to better understand how these combine to impact the lower Hawkesbury River
- an analysis of the timing of catchment-driven flows and elevated coastal water levels to better understand how these interact
- rainfall spatial patterns of recent floods.

The refined hydrologic model (Step 2) was incorporated into the Monte Carlo model. The fast-running 1-dimensional hydraulic model developed for the 2019 Flood Study was recalibrated to match the results of the new 2-dimensional hydraulic model. Using these tools, close to 20,000 possible flood events were modelled, which represents approximately a 200,000-year flood record.

To validate the modelling of design events using the Monte Carlo model, flood frequency analyses were conducted at seven locations along the river. A flood frequency analysis is a technique using historical flood peaks to relate the magnitude of floods to their frequency of occurrence using probability distribution functions.

The validation found generally good matches between the peak flows or peak heights of floods using the Monte Carlo model and the flood frequency analyses, confirming the suitability of the approach.

STEP 5 | Design event modelling

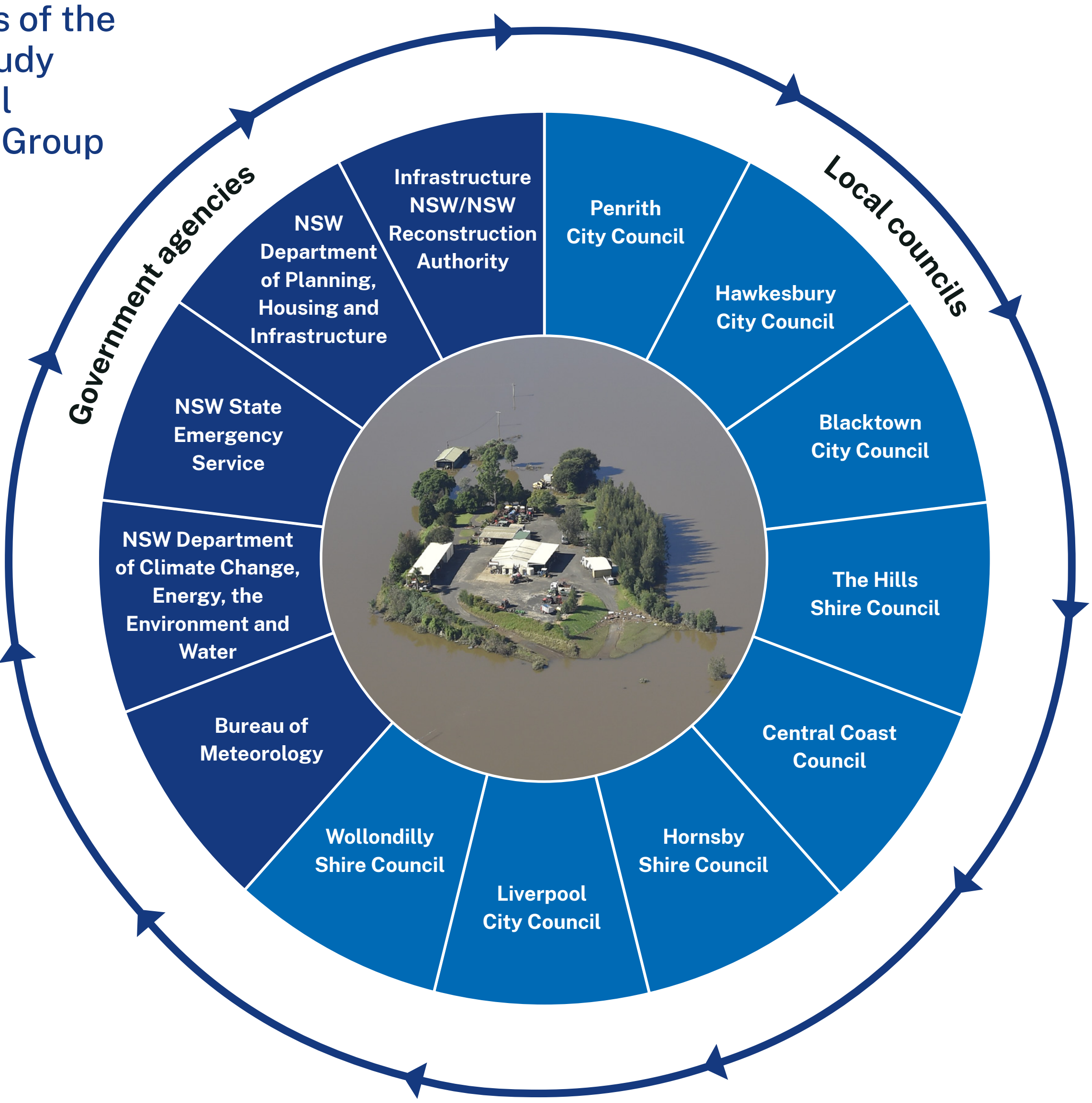
From the nearly 20,000 modelled floods, representative design events along the length of the river were selected for detailed modelling using the new 2-dimensional hydraulic model. In all, 12 flood scenarios were modelled: 1 in 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000 and 5000 chance per year (AEP) floods, plus the probable maximum flood (PMF). In addition, the potential effects of climate change on flooding were modelled for the 1 in 20, 100 and 500 chance per year floods.

STEP 6 | Expert review

The draft Flood Study was reviewed by Associate Professor Fiona Johnson from the Water Research Centre at the University of NSW, checking the validity and accuracy of the data, method and results. Emeritus Professor Colin Apelt from the University of Queensland also assessed the hydraulic modelling.

A Technical Working Group (TWG) including officers from the 8 local government areas in the floodplain met over 10 times to review and inform the work. Considerable effort was devoted to validating the results where changes from previous studies were observed.

Members of the Flood Study Technical Working Group



2024 Flood Study results

The 2024 Flood Study provides the most up-to-date regional information for Hawkesbury-Nepean flooding ranging from very frequent to very rare floods.

The following are the key outputs of the 2024 Flood Study:

Hawkesbury-Nepean River Flood Study report is in three parts

Main report

Technical volumes

1. Data collection
2. Hydrologic model refinement and calibration
3. Hydraulic model development and calibration
4. Catchment/ocean joint probability analysis
5. Lower Hawkesbury analysis
6. Wallacia flood frequency analysis
7. Monte Carlo model updates
8. March 2021 flood validation
9. March 2022 flood validation
10. July 2022 flood validation
11. Design flood modelling
12. PMF modelling

Map book volumes

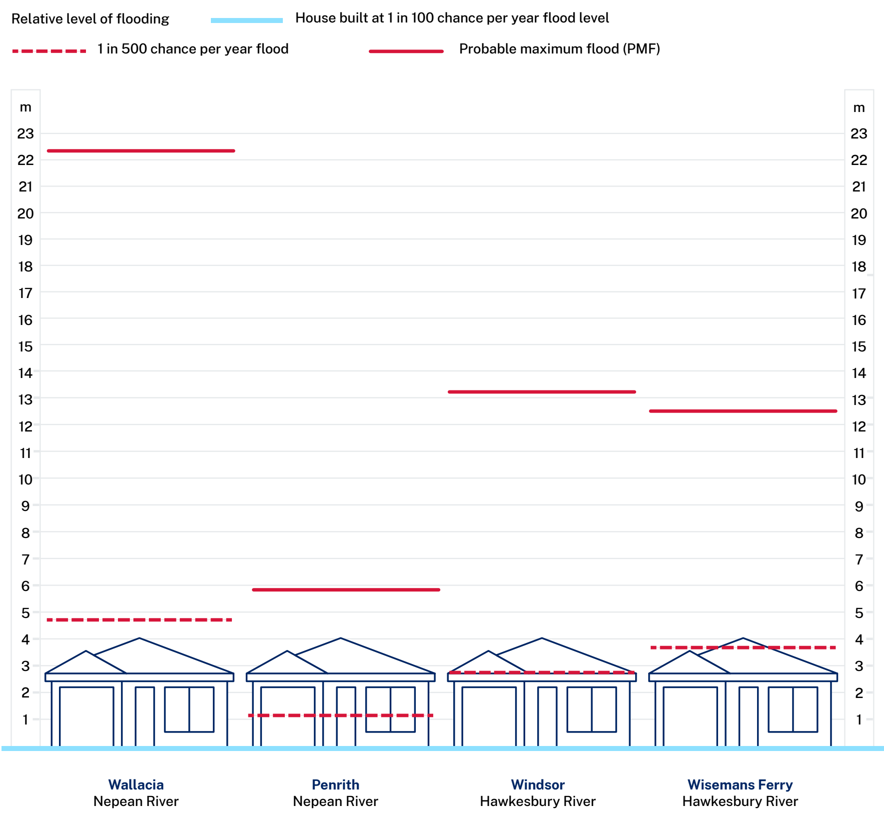
A. Flood extents/depths/levels

B. Flood hazard

C. Floodways, flood storage, flood fringe

Potential flood depths in the Hawkesbury-Nepean Valley

The new flood study has confirmed the extraordinary flood depths that can be reached in the Hawkesbury-Nepean Valley because of the distinct topography. A house at Windsor built at the 1 in 100 chance per year flood level would be inundated to its eaves in a 1 in 500 chance per year flood, or to a depth of over 13m in the PMF. The depths at Wallacia would be even greater.



The following sections summarise key findings and results for the four floodplains.

Wallacia

Floods are complex

Flooding at Wallacia is particularly complex. The Wallacia floodplain is located between Bents Basin and Wallacia Weir in its own 'bathtub', with the narrow sandstone gorges between Wallacia and Penrith forming a natural choke point. Floods may be driven by the Nepean River, Warragamba River, or, often, a combination of both, when flows spilling from Warragamba Dam join the Nepean River a few kilometres downstream and limit the speed with which Nepean River flows can escape Wallacia.

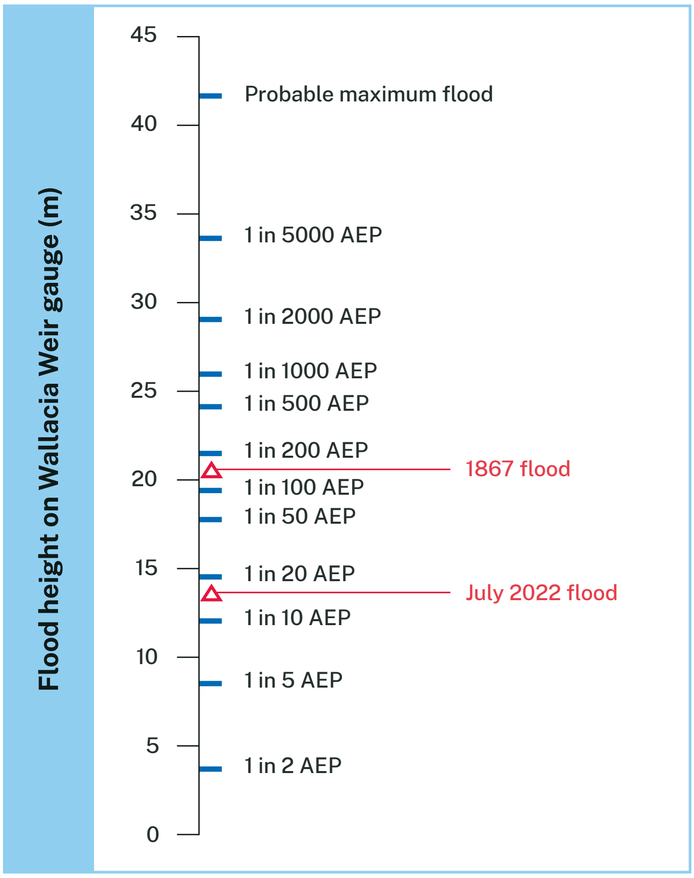
A detailed history of floods at Wallacia from 1860 was constructed. From this, the frequency and size of floods were analysed.

This work, plus the use of the updated Monte Carlo model and the 2-dimensional flood model, has led to refined estimates of flood heights compared to previous flood investigations.

The 1 in 100 chance per year flood height at Wallacia is 0.3-0.4m higher than that modelled in the 1995 Upper Nepean River Flood Study.

Nepean River at Silverdale Road Bridge, Wallacia, March 2022 | Photo by Adam Hollingworth

Nepean River (left to right) meeting the Warragamba River (top), March 2021 | Photo by Adam Hollingworth



Potential flood heights compared to 2 historical floods, Wallacia Weir

Results

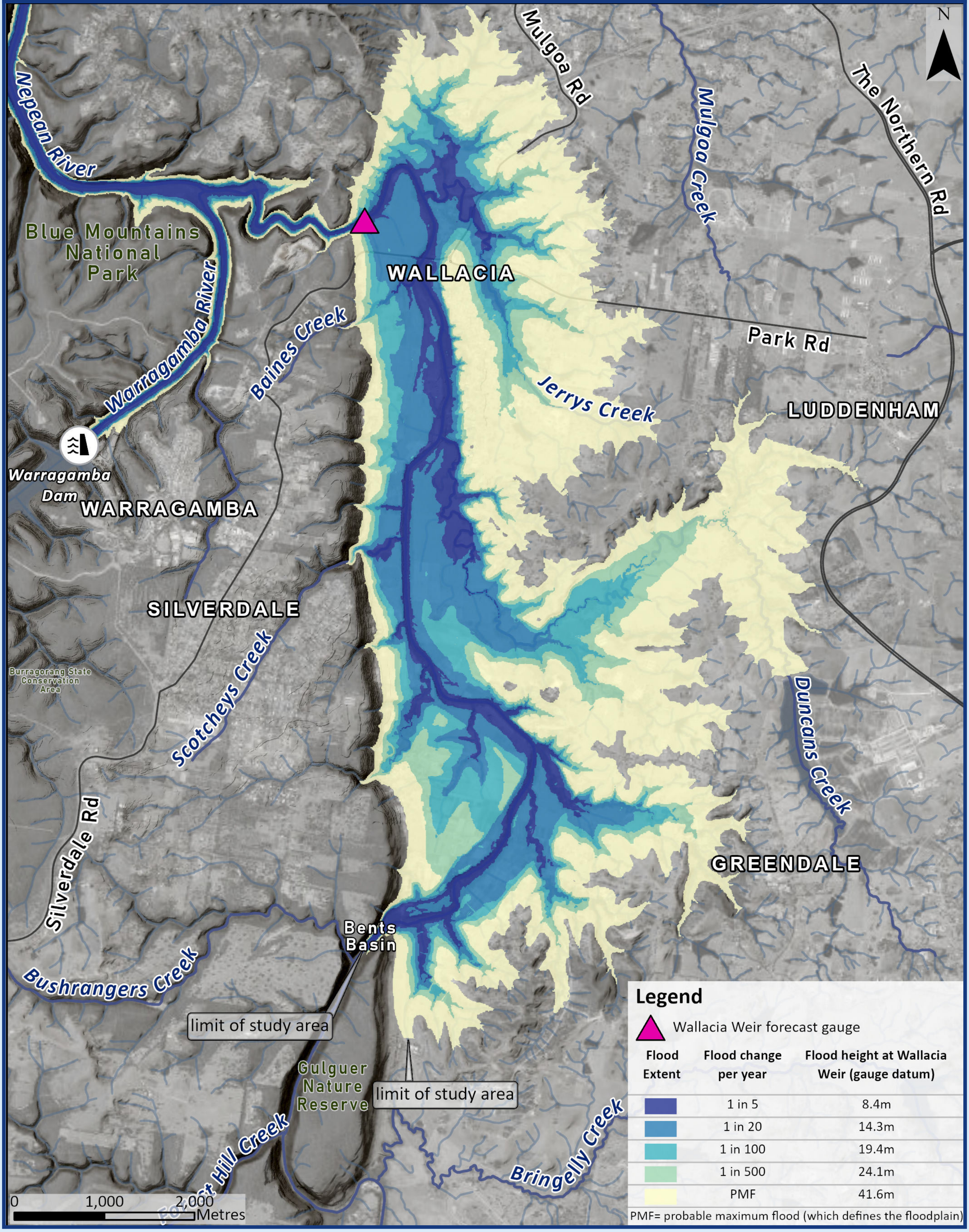
Flood extents are shown in Figure 7.

In a 1 in 5 chance per year flood (8.4m on Wallacia Weir gauge), Silverdale Road bridge is overtopped.

In a 1 in 20 chance per year flood (14.3m), the Park Road evacuation route is cut. This evacuation route was cut for a time in the smaller July 2022 flood (13.8m).

In the rarest and most unlikely flood (PMF) (41.6m), the village of Wallacia would be completely flooded. This is the deepest flooding that can occur in the study area as floodwaters from the Nepean and Warragamba rivers back up behind the downstream gorge and fill the Wallacia 'bathtub'.

Figure 7: Flood extents, Wallacia floodplain



Flood Extent	Flood change per year	Flood height at Wallacia Weir (gauge datum)
	1 in 5	8.4m
	1 in 20	14.3m
	1 in 100	19.4m
	1 in 500	24.1m
	PMF	41.6m

PMF= probable maximum flood (which defines the floodplain)

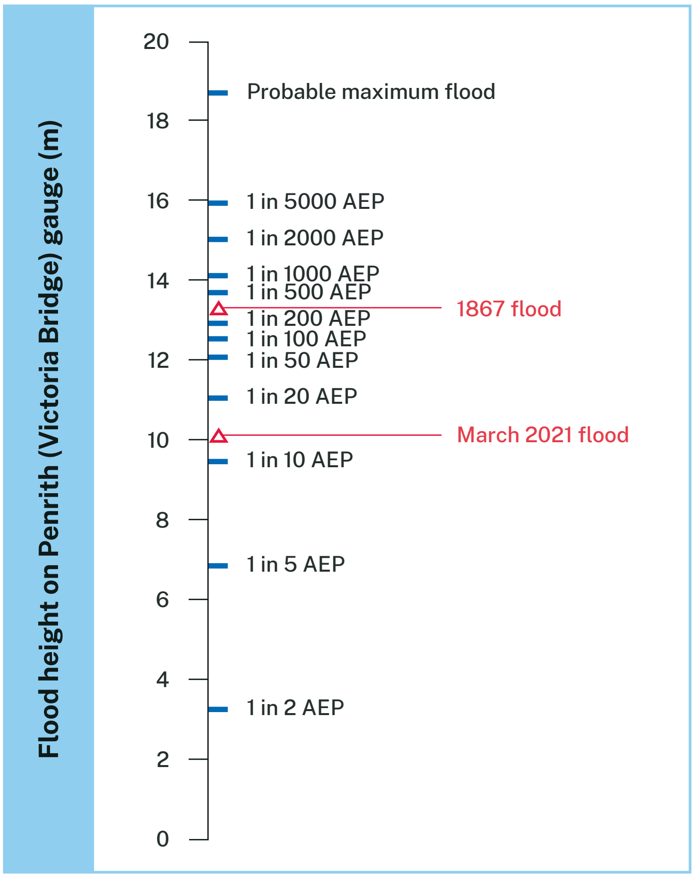
Penrith

Floods change over time

The March 2021 flood provided the opportunity to validate the flood models to a contemporary flood. Prior to 2021, the most recent similar-sized flood was in 1990.

Modelling of the 2021 flood showed that floods have changed. At Victoria Bridge, the 2021 flood was higher than the 1961 flood, despite having a much lower peak flow rate (the volume of water that passes each second). This change is attributed mainly to the recent growth of vegetation in the river channel and on the floodplain below Penrith Weir.

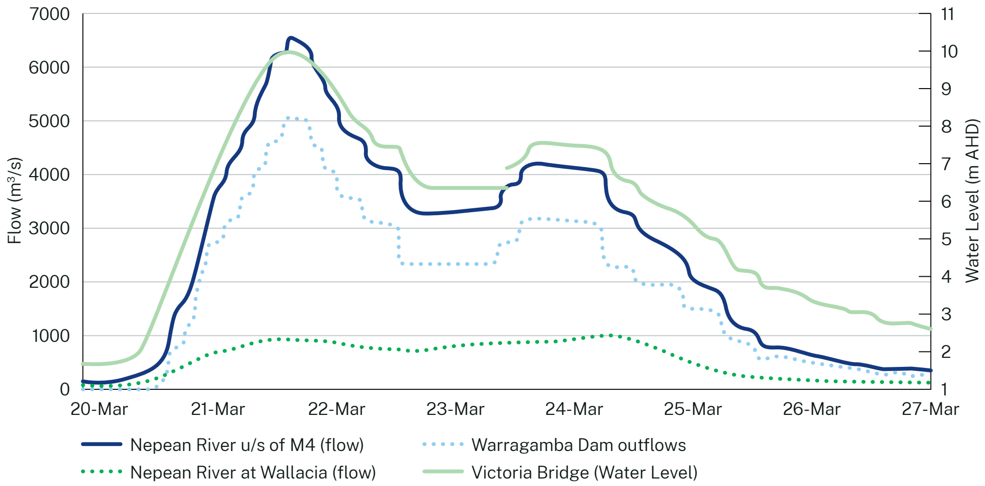
The 2024 Flood Study incorporates this change. As a result, the 1 in 100 chance per year flood height at Victoria Bridge is 0.5m higher than modelled in the 2018 Nepean River Flood Study.



Potential flood heights compared to 2 historical floods, Penrith

Dense vegetation, Nepean River below Penrith Weir, March 2021 | Photo by Rhys Thomson

Figure 8: Flow and water level hydrographs, March 2021



What drives flooding at Penrith?

Flooding in Penrith is driven largely by the capacity of the channel to convey floodwaters, with flood heights closely correlated to peak flows. This can be seen in hydrographs of the March 2021 flood (Figure 8). The high contribution from Warragamba Dam spills can also be seen.

Results

Flood extents are shown in Figure 9.

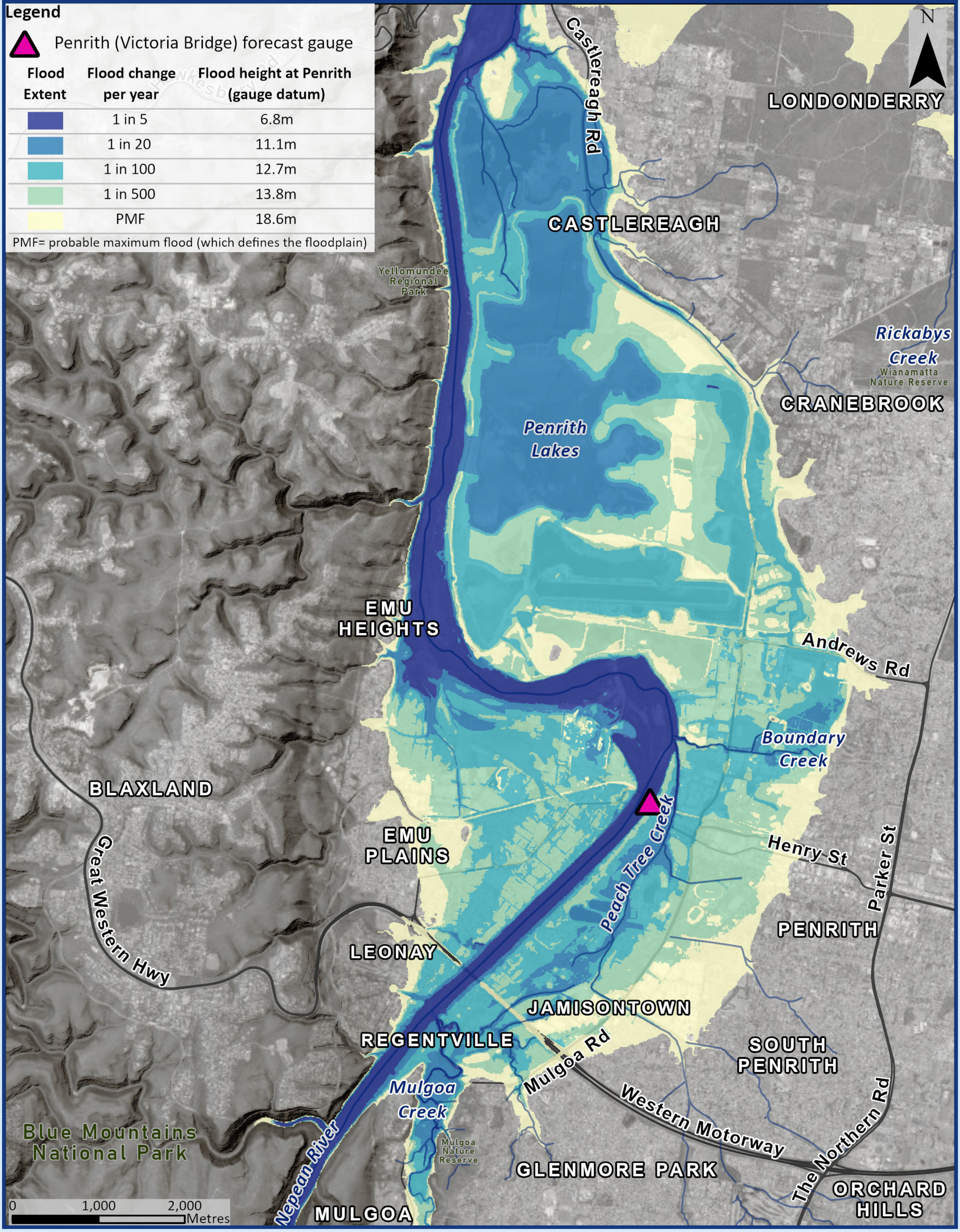
At Penrith, backwater flooding up Peach Tree Creek happens in relatively small floods like March 2021 (10.0m on Penrith gauge).

In the 1 in 100 chance per year flood (12.7m), considerable areas of Regentville, Jamisontown, Penrith, Leonay, Emu Plains and Emu Heights would be under water.

In the 1 in 500 chance per year flood (13.8m), much of Emu Plains would be inundated, and floodwaters would extend east of Woodriff Street in Penrith.

In the PMF (18.5m), flood depths are nearly 6m greater than in the 1 in 100 chance per year event, with a maximum width of flooding of over 5 km across the floodplain.

Figure 9: Flood extents, Penrith/Emu Plains floodplain



Richmond/Windsor

How a meandering outlet impacts the bathtub

The Richmond/Windsor floodplain is the most extensive 'bathtub' in the valley, extending many kilometres up Rickabys, South and Eastern creeks. It has five 'taps' (tributaries) flowing into the bathtub but just one outlet (the lower Hawkesbury River). Downstream of this floodplain is around 100km of meandering river constrained by sandstone gorges. The 'serpentine' shape of the lower Hawkesbury River limits the escape of floodwaters, pushing up flood heights - recognised by Governor John Hunter as early as 1796.

The effect of the pronounced meandering of the lower Hawkesbury River in holding back floodwaters in the Richmond/Windsor bathtub is confirmed by the study. The 2-dimensional flood model is a detailed model that represents the storage in the bathtub and the effect of the meanders in high resolution. It's why the 2024 Flood Study shows that in the Richmond/Windsor bathtub, the largest possible - though extremely rare - flood (PMF) could be several metres higher than previously understood. A PMF is the highest flood that the NSW SES needs to consider in its evacuation plans.

The 1 in 100 chance per year flood height at Windsor is unchanged (17.3m).

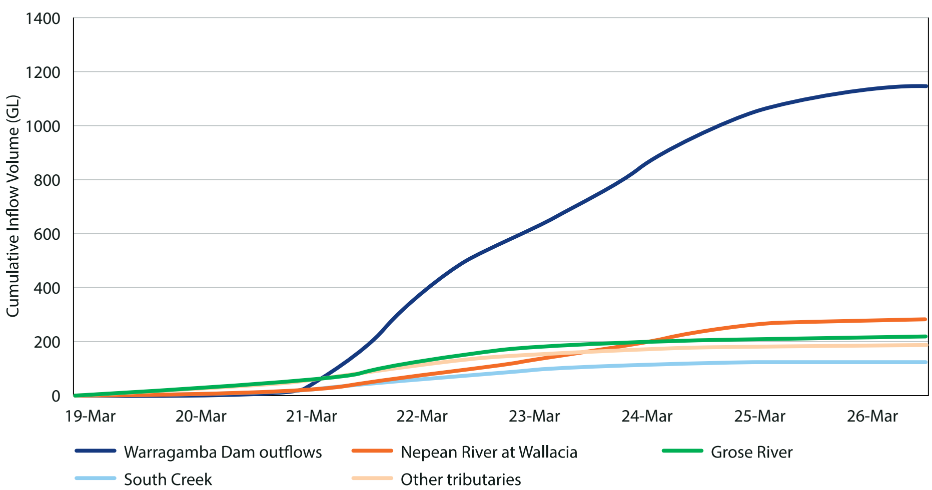
Tight meander bends in the lower Hawkesbury River, March 2021 | Photo by Adam Hollingworth

A long-recognised influence on flooding

'[T]he cause of the extraordinary Swellings of this River is clearly occasion'd by its Serpentine Shape and the Narrowness of its Bed ... the Stream downriver must be very much retarded in its progress to the Sea by the Short and Sudden bending of its various reaches, so that the torrents of water which after a heavy fall of rain must run down the sides of the Neighbouring Mountains, raises the Water within the Banks of the River ... so high as to overflow the banks & cover much of the Cultivated ground.'

Governor John Hunter to Sir Joseph Banks, 20 August 1796, Banks Papers, A1787, 14, cited in Karskens G (2020) People of the River: lost worlds of early Australia, Allen & Unwin, Sydney, p.260.

Figure 10: Cumulative inflows to Windsor, March 2021 flood



What drives flooding at Richmond/Windsor?

Flooding in the Richmond/ Windsor floodplain is driven largely by the volume of floodwaters entering the floodplain, rather than the peak flow. The Warragamba River tends to dominate this inflow volume for larger flood events, with smaller inflows from the Nepean River, Grose River and South Creek. An example for the March 2021 flood is shown in Figure 10.

Results

Flood extents are shown in Figure 11.

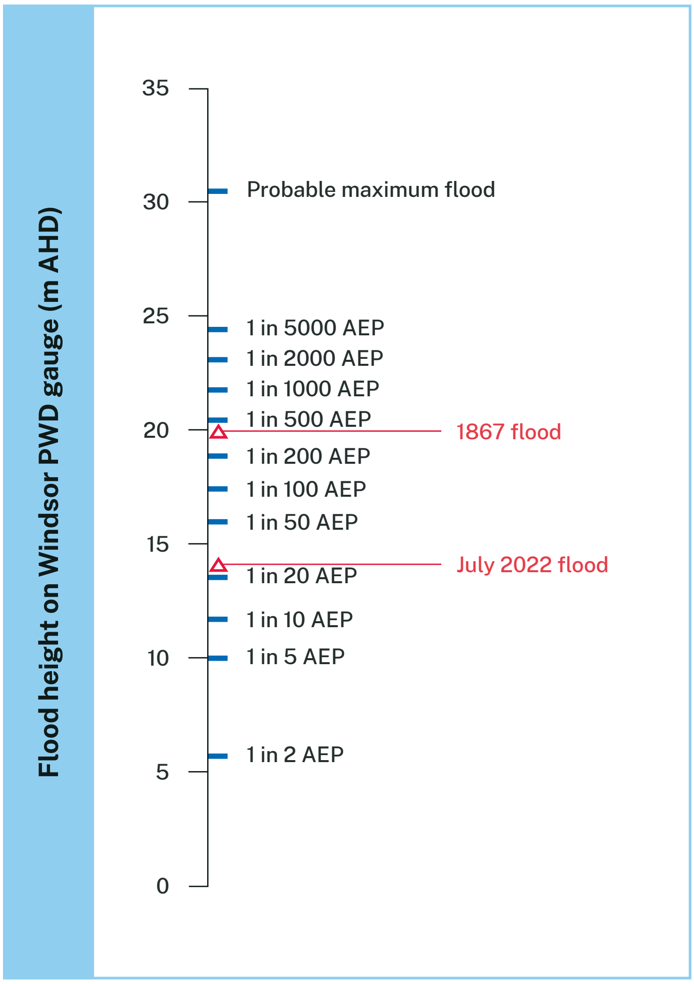
This floodplain is highly flood prone. Extensive flooding of low-lying river flats between Richmond and Pitt Town happens in a frequent 1 in 5 chance per year flood (9.9m at Windsor gauge).

In a 1 in 20 chance per year flood (13.8m), similar to the March and July 2022 floods, the McGraths Hill (Windsor Road) evacuation route is cut and significant areas are flooded. Backwater flooding extends up Rickabys Creek into Londonderry.

In a 1 in 100 chance per year flood (17.3m), McGraths Hill is completely submerged. Windsor becomes completely isolated as Jim Anderson Bridge is closed.

In a 1 in 500 chance per year flood (20.2m), similar to the record 1867 flood (19.7m), large areas of Richmond and Hobartville are flooded, and other parts of Richmond become a flood island. Large parts of Bligh Park are flooded too.

In an extremely rare PMF (30.6m), now estimated as over 13m higher than the 1 in 100 chance per year flood level, no land would be above floodwater between North Richmond and Oakville.



Potential flood heights compared to two historical floods, Windsor PWD gauge

McGraths Hill, March 2022 (13.8m) | Photo by Adam Hollingworth

South and Eastern creeks

As the 'bathtub' fills at Windsor, floodwaters back up tributaries including South and Eastern creeks causing flooding in adjacent suburbs.

In a 1 in 100 chance per year flood (17.3m at Windsor), backwater flooding extends to about Christie Street in St Marys (via South Creek), and to the northern edge of Colebee (via Eastern Creek). Suburbs with impacted properties include Windsor Downs, Berkshire Park, Shanes Park, Llandilo, Vineyard, Riverstone and Schofields.

Note that separate studies assess floods generated from the South and Eastern creeks local catchments (e.g. Wianamatta (South Creek) Catchment Flood Study). The current study includes inflows from each local catchment but only maps backwater flooding coming up each tributary from the main river.

Where a location is potentially impacted by both Hawkesbury-Nepean flooding and local catchment flooding, both flood studies should be consulted, where available.

Future development in the catchment may have a small impact on Hawkesbury-Nepean flooding

The community has expressed concern about the impact of development in Western Sydney on flooding of the Hawkesbury-Nepean River. Significant developments are planned and underway (especially in the South Creek catchment) including the South West Growth Area, Western Sydney International Airport, and the Aerotropolis. While these developments are largely beyond the reach of Hawkesbury-Nepean backwater flooding, changing the land cover in the catchment has the potential to increase flood heights.

To assess the potential impacts of future development, the hydrologic model was adjusted to incorporate increased imperviousness for major development footprints.

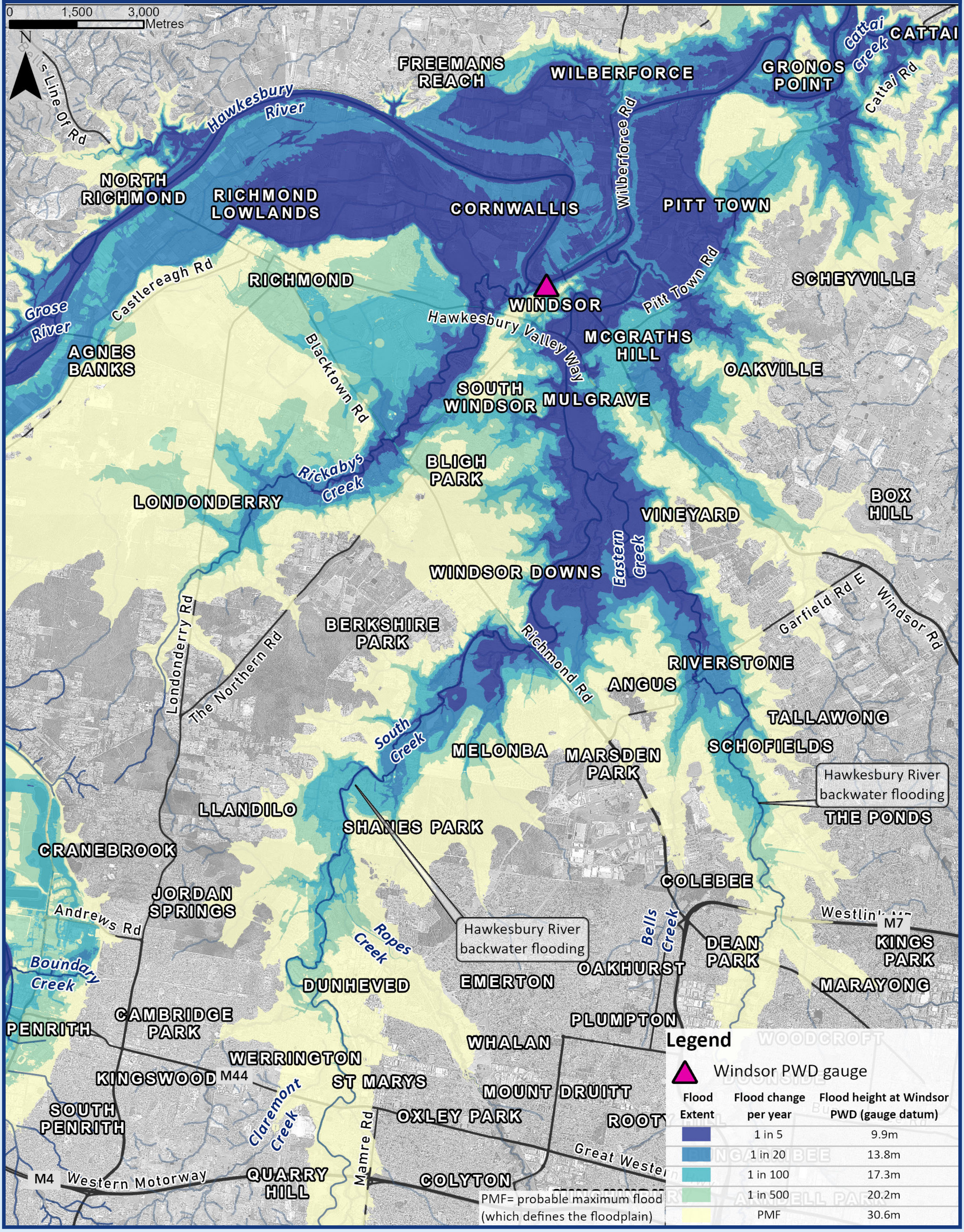
The models found that if no mitigation measures were applied, the 1 in 100 chance per year flood height at Windsor would increase by less than 0.05m. In the context of a 17.3m-high flood, this is a very small increase.

The impacts would be slightly higher for small floods. The 1 in 5 chance per year flood height in the Windsor floodplain would increase by around 0.1m, which is a small increase in the context of a 9.9m-high flood.

The reason for the small impacts is the South Creek catchment makes up only 5% of the total catchment area to Windsor. The bulk of floodwaters to Windsor come from the Warragamba catchment, followed by the Nepean catchment.

Melonba with Hawkesbury River backwater flooding, March 2022 | Photo by Adam Hollingworth

Figure 11: Flood extents, Richmond/Windsor, plus South and Eastern creeks backwater



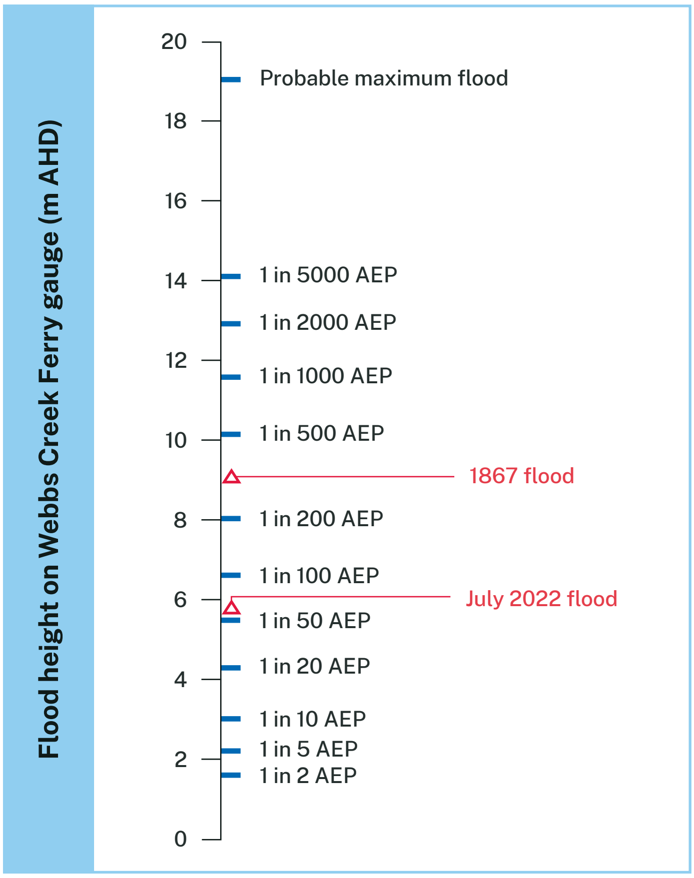
Lower Hawkesbury

The importance of tributary timing

The Colo River drains a large 4,630km² catchment, joining the Hawkesbury River at Lower Portland, over 40km downstream of Windsor. The size, relative timing and duration of inflows from the Colo River can make a significant difference to flooding in the lower Hawkesbury River at Lower Portland and downstream.

The new flood study includes a detailed investigation of historical flood patterns going back to 1889. Typically, the Colo peaks and gets away before the peak of the Hawkesbury arrives at the junction of the two rivers. Sometimes, including in the July 2022 flood, the Colo and Hawkesbury peaked at around the same time at the junction, pushing up flood heights in the lower Hawkesbury. This helps to explain why the July 2022 flood is approximately a 1 in 20 chance per year flood at Windsor but rarer than a 1 in 50 chance per year flood at Wisemans Ferry.

This historical analysis has informed the estimates of 'design' flood heights in the new flood study.



Potential flood heights compared to two historical floods, Wisemans Ferry

Wisemans Ferry, March 2022 | Photo by Top Notch

Results

Downstream of Cattai Creek near Ebenezer, the main Hawkesbury River enters gorge country which continues for around 100km to Brooklyn.

This narrow gorge limits flood extents. Figure 12 shows that most of the floodplain is flooded by the 1 in 20 chance per year event.

Rarer floods add considerable depth to floodwater, posing serious hazards to flood-prone developments along the river such as caravan parks.

The narrow floodplains also cause fast-moving floodwater. Flow speeds of more than 2 metres per second are common.

Tide levels have some minor impacts on flooding in the lower Hawkesbury, especially for smaller floods such as the 1 in 5 chance per year event, and with increasing influence downstream in areas like Spencer and Brooklyn.

Colo and Macdonald rivers, Webbs and Greens creeks

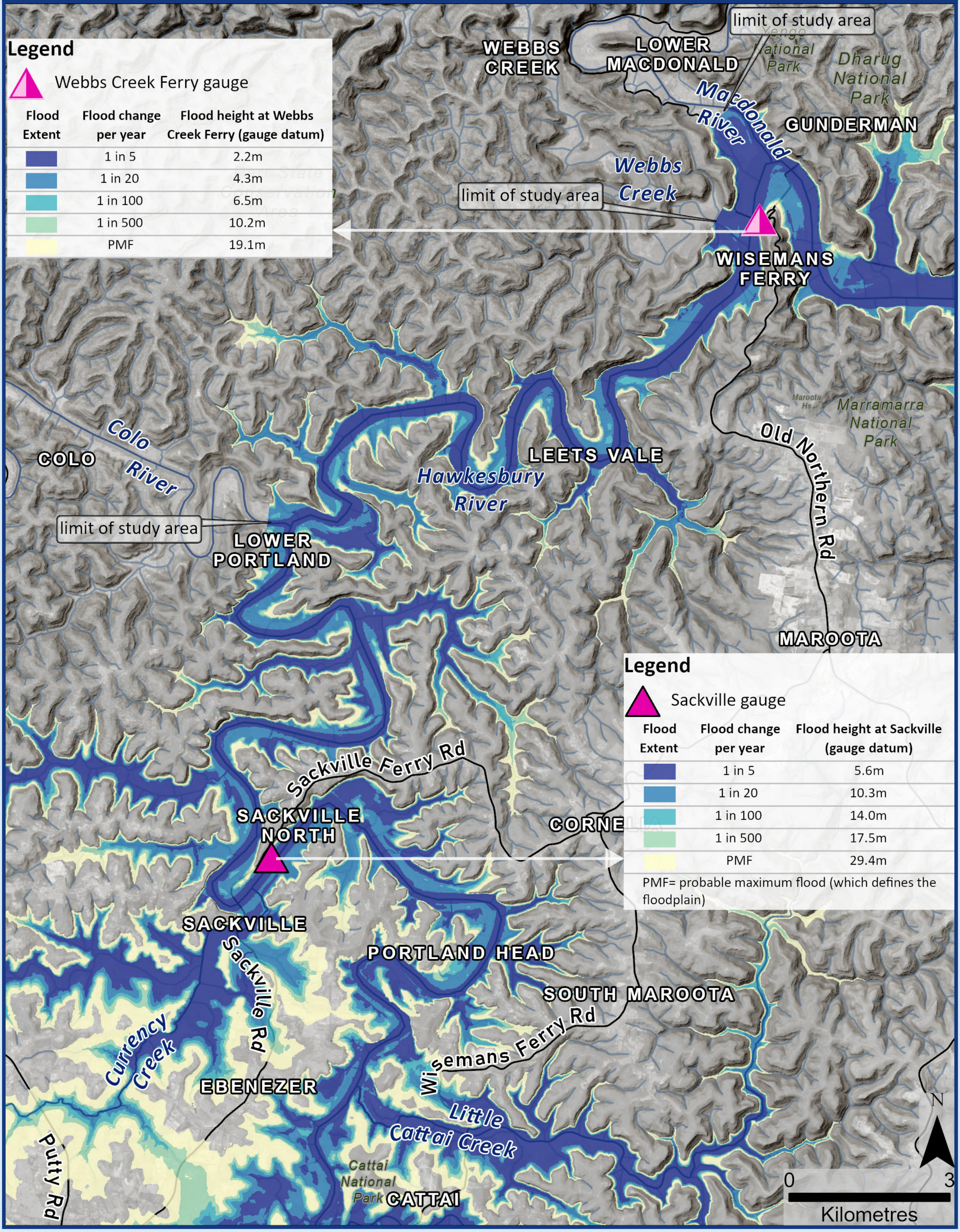
Hawkesbury City Council is in the process of developing a flood study for Colo River, Macdonald River, Webbs Creek and Greens Creek. Council's study will draw on information about Hawkesbury River flooding from this study.

The mapping presented in this study showing flooding of tributaries accounts for inflows from these catchments but maps only backwater flooding from the Hawkesbury River.

Where a location is potentially impacted by both Hawkesbury-Nepean flooding and local catchment flooding, both flood studies should be consulted, where available.

Colo River (bottom) joining the Hawkesbury River (right to left) at Lower Portland, March 2021 | Photo by Adam Hollingworth

Figure 12: Flood extents, lower Hawkesbury floodplain



Climate change is expected to increase Hawkesbury-Nepean flooding

There is strong evidence that increases in global temperatures will lead to an increase in the intensity of rare rainfall. Interim climate change factors published by Australian Rainfall and Runoff (2019) were used to assess the potential impacts of increased rainfall intensity on flooding in the Hawkesbury-Nepean River.

The unique topography of the Hawkesbury-Nepean Valley means the impacts of increased rainfall intensity are larger than in many other NSW catchments. At Windsor, the 1 in 100 chance per year flood height would increase by 0.9m with a 9.5% increase in rainfall intensity. The highest increase in the valley would be experienced at Wallacia (1.4m in this scenario).

The study also assessed the impacts of sea level rise, following guidance from the NSW Chief Scientist. The height of the 1 in 100 chance per year flood at Wisemans Ferry would increase by 0.1m and 0.3m for sea level rises of 0.4m and 0.9m, respectively. While the impact of sea level rise would extend further upstream in smaller floods, impacts at Windsor would be <0.1m.

1867 flood marker at Devlin Road, Castlereagh. The largest impact of climate change in the Hawkesbury-Nepean Valley is expected to result from increased rainfall | Photo by Adam Hollingworth

More information about the 2024 Flood Study

Contact: HNV@reconstruction.nsw.gov.au

More information about the NSW Reconstruction Authority

Visit: https://www.nsw.gov.au/emergency/nsw-reconstruction-authority

For information about flood preparedness

Visit: www.ses.nsw.gov.au/hawkesbury-nepean-floods

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