Figure 2.2 North Richmond Bridge, 23 March 2021 (after peak). View is towards the southwest (Source: Hawkesbury Flood Statistics Unit Facebook page; Retrieved from (Infrastructure NSW, 2021))

Figure 2.3 North Richmond Bridge during March 2022 flood (Retrieved from Hawkesbury Gazette)

Figure 2.4 Terrace Road near Redbank Creek crossing, North Richmond, 5 July 2022 (Courtesy of a community member)

2.3 Relevant policies, legislation and guidance

2.3.1 National provisions

2.3.1.1 Australian Rainfall and Runoff, 2019

Australian Rainfall and Runoff (ARR) is a national guideline document, data and software suite that is used for the estimation of design flood characteristics in Australia. This is the 4th edition of ARR after the 1st edition was released by Engineers Australia in 1958. This edition is published and supported by the Commonwealth of Australia and is an update to the ARR 2016. Geoscience Australia supports ARR as part of its role to provide authoritative, independent information and advice to the Australian Government and other stakeholders to support risk mitigation and community resilience.

ARR is pivotal to the safety and sustainability of Australian infrastructure, communities and the environment. It is an important component in the provision of reliable and robust estimates of flood risk. Consistent use of ARR together with sound land use planning ensures that development does not occur in high-risk areas and that infrastructure is appropriately designed.

2.3.1.2 National Construction Code 2022

The 2022 edition of the National Construction Code (NCC) introduced new requirements related to building in Flood Hazard Areas (FHAs), which provide a minimum construction standard across Australia for specified building classifications in FHAs up to the Defined Flood Event (DFE).

The DFE is analogous to the planning flood event and is most commonly the 1% AEP flood. FHAs are defined in the BCA as encompassing land lower than the flood hazard level (FHL), which in turn is defined as 'the flood level used to determine the height of floors in a building and represents the DFE plus the 'freeboard'. Therefore, FHAs would typically be defined as those areas falling within the flood planning area.

Volume One, B1P4, specify the Performance Requirements for the construction of buildings in FHAs. B1P4 only applies to:

- a Class 2 or 3 building or a Class 4 part of a building; and
- a Class 9a health-care building; and
- a Class 9c building.

A building in a ***flood hazard area***, must be designed and constructed, to the degree necessary, to resist flotation, collapse or significant permanent movement resulting from the action of hydrostatic, hydrodynamic, erosion and scour, wind and other actions during the ***defined flood event*** (DFE).

The actions and requirements to be considered to satisfy this performance requirement include but are not limited to:

- Flood actions;
- Elevation requirements;

- Foundation and footing requirements;
- Requirements for enclosures below the flood hazard level;
- Requirements for structural connections;
- Material requirements;
- Requirements for utilities; and
- Requirements for occupant egress.

The Deemed-to-Satisfy (DTS) provisions of Volume One, B1D6, require buildings classified as a Class 2 or 3 building, Class 9a health-care building, Class 9c building or a Class 4 part of a building and located in a flood hazard area must comply with the ABCB Standard for Construction of Buildings in Flood Hazard Areas published in 2012.

The ABCB Standard specifies detailed requirements for the construction of buildings to which the NCC requirements apply, including:

- Resistance in the DFE to flood actions including hydrostatic actions, hydrodynamic actions, debris actions, wave action and erosion and scour
- Floor height requirements, for example that the finished floor level of habitable rooms must be above the FHL
- The design of footing systems to prevent flotation, collapse or significant permanent movement
- The provision in any enclosures or openings to allow for automatic entry and exit of floodwater for all floods up to the FHL
- Ensuring that any attachments to the building are structurally adequate and do not reduce the structural capacity of the building during the DFE
- The use of flood-compatible structural materials below the FHL
- The siting of electrical switches above the FHL, and flood proofing of electrical conduits and cables installed below the FHL
- The design of balconies etc. to allow a person in the building to be rescued by emergency services personnel, if rescue during a flood event up to the DFE is required.

Building Circular BS13-004 (NSW Department of Planning and Infrastructure, 2013) summarises the scope of the BCA and how it relates to NSW planning arrangements. The scope of the ABCB Standard does not include parts of FHA that are subject to flow velocities exceeding 1.5 m/s or are subject to mudslide or landslide during periods of rainfall and runoff or are subject to storm surge or coastal wave action.

It is particularly noted that the Standard applies only up to the DFE, which typically will correspond to the level of the 1% AEP flood plus 0.5 m freeboard. The Building Circular emphasises that because of the possibility of rarer floods, the BCA provisions do not fully mitigate the risk to life from flooding.

The ABCB has also prepared an Information Handbook for the Construction of Buildings in Flood Hazard Areas. This Handbook provides additional information relating to the construction of buildings in FHA but is not mandatory or regulatory in nature.

In the NSW planning system, the BCA takes on importance for complying development on flood control lots under the State Environmental Planning Policy (Exempt and Complying Development Codes) 2008.

2.3.2 State provisions

2.3.2.1 Environmental Planning and Assessment Act, 1979

General

The NSW Environmental Planning and Assessment Act 1979 (EP&A Act) creates the mechanism for development assessment and determination by providing a legislative framework for development and protection of the environment from adverse impacts arising from development. The EP&A Act outlines the level of assessment required under State, regional and local planning legislation and identifies the responsible assessing authority.

Prior to development taking place in NSW a formal assessment and determination must be made of the proposed activity to ensure it complies with relevant planning controls and, according to its nature and scale, conforms with the principles of environmentally sustainable development.

Section 7.11 Development Contributions

Section 7.11 (previously Section 94) of the EP&A Act enables councils to collect contributions from developers for the provision of infrastructure that is necessary as a consequence of development. This can include roads, drainage, open space and community facilities. Each council must develop a Section 94 Contributions Plan which demonstrates a quantifiable link between the development intensification and the need for the additional infrastructure as well as a detailed costing of such infrastructure and formulae to be used to determine contributions from each type of development.

Section 10.7 Planning Certificates

Planning certificates are a means of disclosing information about a parcel of land. Two types of information are provided in planning certificates: information under Section 10.7(2) and information under Section 10.7(5) of the EP&A Act. (Note that previously this clause was Section 149).

A planning certificate under Section 10.7(2) discloses matters relating to the land, including whether or not the land is affected by a policy that restricts the development of land. Those policies can be based on identified hazard risks (Environmental Planning and Assessment Regulation 2000, Clause 279 and Schedule 4 Clause 7), and whether development on the land is subject to flood-related development controls (EP&A Regulation, Schedule 4 Clause 7A). If no flood-related development controls apply to the land (such as for residential development in so-called ‘low’ risk areas above the FPL, unless ‘adequate justification’ has been satisfied), information describing the flood affectation of the land would not be indicated under Section 10.7(2). A lot that is a ‘flood control lot’ under the Codes SEPP is a prescribed matter for the purpose of a certificate under section 10.7(2).

A planning certificate may also include information under Section 10.7(5). This allows a council to provide advice on other relevant matters affecting land. This can include past, current or

future issues.

Inclusion of a planning certificate containing information prescribed under section 10.7(2) is a mandatory part of the property conveyancing process in NSW. The conveyancing process does not mandate the inclusion of information under section 10.7(5) but any purchaser may request such information be provided, pending payment of a fee to the issuing council.

2.3.2.2 State Environmental Planning Policies (SEPPs)

SEPPs are the highest level of planning instrument and generally prevail over Local Environmental Plans.

SEPP (Housing) 2021, Chapter 3, Part 5 (Housing for seniors and people with a disability)

The planning provisions for seniors housing were transferred from the State Environmental Planning Policy (Housing for Seniors or People with a Disability) 2004 (Seniors SEPP) (now repealed), to the State Environmental Planning Policy (Housing) 2021 (Housing SEPP).

State Environmental Planning Policy (Seniors Housing) 2021 aims to encourage the provision of housing (including residential care facilities) that will increase the supply of residences that meet the needs of seniors or people with a disability. This is achieved by setting aside local planning controls that would prevent such development.

Clause 5(6) and Schedule 1 indicate that the policy does not apply to land identified in another environmental planning instrument as being, amongst other descriptors, a floodway or high flooding hazard.

On 18 August 2023 the Housing SEPP was amended to clarify the calculation of gross floor area for proposed seniors housing development. This change was made to ensure the planning controls operate in the intended way. The definition of gross floor area for seniors housing development in the Housing SEPP now aligns with the definition of gross floor area under the Standard Instrument Local Environmental Plan, while retaining exclusions specific to seniors housing.

SEPP (Transport and Infrastructure) 2021, Chapter 2 (Infrastructure)

State Environmental Planning Policy (Infrastructure) 2007 aims to facilitate the effective delivery of infrastructure across the State by identifying development permissible without consent. SEPP (Infrastructure) 2007 allows Council to undertake stormwater and flood mitigation work without development consent.

SEPP (Exempt and Complying Development Codes) 2008, part 3, Division 2 (Clause 3.5 complying development on flood control lots)

A very important SEPP is State Environmental Planning Policy (Exempt and Complying Development Codes) 2008, which defines development which is exempt from obtaining development consent and other development which does not require development consent if it complies with certain criteria.

Clause 3.5 states that complying development is permitted on flood control lots where a Council or professional engineer can certify that the part of the lot proposed for development is not a flood storage area, floodway area, flow path, high hazard area or high-risk area. The

Codes SEPP specifies various controls in relation to floor levels, flood compatible materials, structural stability (up to the PMF if on-site refuge is proposed), flood affectation, safe evacuation, car parking and driveways.

In addition, Clause 1.18(1)(c) of the Codes SEPP indicates that complying development must meet the relevant provisions of the Building Code of Australia.

SEPP (Resilience and Hazards) 2021, Part 2, Division 1 and 3

SEPP (Resilience and Hazards) 2021 aims to promote an integrated and co-ordinated approach to land use planning in the coastal zone. For areas mapped as 'coastal wetlands and littoral rainforests area (Part 2, Division 1)' – including sizeable areas in the study area near the three lakes – development consent is required for the clearing of native vegetation, and for earthworks, construction of a levee, draining the land and environmental protection works, and for any other development. For areas mapped as 'coastal environment areas (Part 2, Division 3)' – covering much of the study area – development consent must not be granted unless the consent authority has considered whether the proposed development is likely to cause an adverse impact on "the integrity and resilience of the biophysical, hydrological (surface and groundwater) and ecological environment" amongst other factors. The development must be designed, sited and managed to either avoid, minimise or mitigate adverse impacts.

2.3.2.3 NSW Flood Related Manuals

Flood Risk Management Manual, 2023

The Flood Risk Management Manual 2023 (the Manual) was gazetted on 30 June 2023 and relates to the management of flood liable land. It incorporates the NSW Flood Prone Land Policy, which aims to reduce the impacts of flooding and flood liability on individual owners and occupiers of flood prone property and to reduce private and public losses resulting from floods, using ecologically positive methods wherever possible. To implement this policy and achieve these objectives, the Manual espouses a merit approach for development decisions in the floodplain, taking into account social, economic, ecological and flooding considerations. The Manual confirms that responsibility for management of flood risk remains with local government. It assists councils in their management of the use and development of flood prone land by providing guidance in the development and implementation of local flood risk management plans.

2.3.2.4 NSW State Emergency Management Plan 2018

The plan provides for the emergency response to flood events, including evacuation. The State Emergency Management Plan (EMPLAN) describes the New South Wales approach to emergency management, the governance and coordination arrangements and roles and responsibilities of agencies. The Plan is supported by hazard specific sub plans and functional area supporting plans.

2.3.3 Local provision

In NSW, local government councils are responsible for managing flood risk within their LGAs. An LEP is used to establish what land uses are permissible and/or prohibited on land within the LGA and sets out high level flood planning objectives and requirements. A Development Control Plan (DCP) sets the standards, controls and regulations that apply when carrying out development or building work on land.

The below sections briefly describe and review the flood-related controls within the Hawkesbury council policies, with a view to flood behaviour in the North Richmond study area.

2.3.3.1 Hawkesbury Local Environmental Plan 2012

This Plan provides the planning controls for the Hawkesbury LGA including flood related controls. This Plan aims to make local environmental planning provisions for land in Hawkesbury LGA in accordance with the relevant standard environmental planning instrument under section 33A of the Act. The particular aims of this Plan are as follows:

- to provide the mechanism for the management, orderly and economic development and conservation of land in Hawkesbury;
- to provide appropriate land in area, location and quality for living, working and recreational activities and agricultural production;
- to protect attractive landscapes and preserve places of natural beauty, including wetlands and waterways;
- to protect and enhance the natural environment in Hawkesbury and to encourage ecologically sustainable development;
- to conserve and enhance buildings, structures and sites of recognised significance that are part of the heritage of Hawkesbury for future generations; and
- to provide opportunities for the provision of secure, appropriate and affordable housing in a variety of types and tenures for all income groups in Hawkesbury.

Clause 5.21 of Hawkesbury Local Environmental Plan 2012 aims to minimise flood risk, permit compatible development considering climate change, prevent adverse impacts on flood behaviour and the environment, and ensure safe occupation and efficient evacuation during floods. The consent authority must consider factors such as the impact on projected changes in flood behaviour due to climate change, the design and scale of buildings, measures to minimise risk and ensure safe evacuation, and the potential for modifying or relocating buildings impacted by flooding or coastal erosion.

2.3.3.2 Hawkesbury Flood Policy 2020 and Schedule of Flood Related Development Controls 2020

This draft Policy replaced the previous Policy and provided more comprehensive flood related development controls. The Flood Policy 2020 includes a Schedule of Flood Related Development Controls, which provides up-to-date, relevant, and best practice controls to meet the requirements of Clause 5.21 – Flood planning of Hawkesbury Local Environmental Plan 2012, and to clearly express how a proposed development's suitability is assessed in relation

to the impacts of flooding.

The controls within the Flood Policy 2020 are based on the Hazard Category in which a development will be situated, and provides appropriate controls dependent on whether the proposal is:

- new development, or
- is for the purposes of additions, alteration, intensification, rebuilding or redevelopment of an existing use, or
- if an existing use, whether or not it is within a compatible or incompatible Hazard Category.

2.3.3.3 Hawkesbury Nepean Flood Emergency Sub-Plan 2020

The Plan provides for the emergency response to flood events, including evacuation for the Hawkesbury Nepean Valley. This Plan is written and issued under the authority of the State Emergency and Rescue Management Act 1989 (NSW) ('SERM Act') and the NSW State Emergency Management Plan (EMPLAN). In addition to these instruments, the following Acts and Regulations apply to managing flooding in the Hawkesbury-Nepean Valley:

- State Emergency Service Act 1989 Link;
- Dams Safety Act 2015 Link;
- Dams Safety Regulation: 2019 Link;
- Water Act NSW 2014 Link; and
- Flood Risk management Manual 2023 (issued pursuant to Section 733 of the Local Government Act 1993).

This plan is a Sub Plan to the State Flood Plan 2018. It was approved by the Commissioner of the NSW State Emergency Service (NSW SES), which is the designated Combat Agency for floods, on 4 June 2020 and was endorsed by the NSW State Emergency Management Committee (SEMC) on 4 June 2020.

2.3.3.4 Hawkesbury-Nepean Valley Flood Risk Management

In 2017, the Resilient Valley, Resilient Communities – Hawkesbury-Nepean Valley Flood Risk Management Strategy (Flood Strategy) was released. The Flood Strategy is the result of years of investigation into the best ways to reduce impacts of flooding in the valley. It uses a regional approach as floods from the river system cover a wide area, with impacts felt in 10 local council areas. The NSW Reconstruction Authority (RA) is developing a high-priority regional Disaster Adaptation Plan (DAP) to address flood risk in the Hawkesbury-Nepean Valley which builds on the 2017 Flood Strategy. The DAP will include a suite of integrated measures to reduce the impact of floods.

2.3.3.5 Western City District Plan 2018

This Plan provides the vision for living within the Western City District. It also includes planning principles for development in the Hawkesbury Nepean floodplain. The Hawkesbury-Nepean Valley between Wallacia and Sackville, and parts of South Creek Valley have the greatest flood exposure of any valley in NSW. The District Plan addresses resilience to flooding and other hazards in more detail in Planning Priority W20.

2.3.3.6 Local planning direction 4.3—Flooding

This Direction provides the requirements for applying development controls on Flood Prone Land. Planning proposals are required to be consistent with directions issued under section 9.1 of the EP&A Act. Local Planning Direction 4.3 - Flooding requires, among other matters, a planning proposal to be consistent with the principles of the Flood Risk Management Manual. The direction has been revised to remove the need to obtain exceptional circumstances to apply flood related residential development controls above the 1% Annual Exceedance Probability (AEP) flood event. It also ensures planning proposals consider the flood risks and do not permit residential accommodation in high hazard areas and other land uses on flood prone land where the development cannot effectively evacuate. The direction also makes provision for special flood considerations where councils have chosen to adopt the optional Special flood considerations clause in an LEP. The revised direction will apply to planning proposals that have not been issued with a gateway determination under section 3.34(2) of EP&A Act.

2.3.3.7 Flood Prone Land Package

The flood-prone land package provides advice to councils on considering flooding in land-use planning and commenced on 14 July 2021. The updated ministerial direction forms part of the package. The updated guidance supports:

- Better management of flood risk beyond the 1% AEP;
- Best management practices in managing and mitigating severe to extreme flood events; and
- Greater resilience built into communities in floodplains and reduces potential property damage and loss of life in recognition of increasing extreme flood events throughout NSW.

2.4 Land zoning

Land zoning in North Richmond and Redbank Creek is defined in the Hawkesbury Local Environmental Plan (LEP) 2012 and is shown in **Figure 2.5.** The majority of the township itself is zoned as either “R2 low density residential” or “R3 medium density residential”. There are smaller areas of “E4 general industrial”, “SP2 educational establishment”, and “RE1 public recreation” in the township. **Figure 2.5** shows that the area zoned as “R3 medium density residential” is located in the southeast of the North Richmond township and near the Hawkesbury River. Most of the Redbank Creek catchment is covered with area zoned as “RU1

primary production" or "RU4 primary production small lots". The area northwest of Redbank Creek catchment in Kurrajong is zoned as "R2 low density residential". The vegetated area downstream of Redbank Creek along the Hawkesbury River is zoned as "RU2 – rural landscape".

2.5 Demographic overview

Understanding the social characteristics of the study area can help ensure appropriate risk management practices are adopted and shape the methods used for community engagement. House tenure and age distribution data obtained from census data can indicate the community's experience with recent flood events, and hence an indication of community's flood awareness. As per the Bureau of Meteorology Flood Preparedness Manual, using the population census data and other information held by councils and state agencies can help to identify the potential number and location of people in an area with special needs or requiring additional support during floods (Australian Government (Attorney – General's Department), 2009). The relevant information has been extracted from the 2021 Census for the town of North Richmond (and surrounds) and tabulated in **Table 2.1**. As the study area is partially covered by Kurrajong, Grose Vale, and Kurmond townships, population census data and other information for these townships is tabulated in **Table 2.2**, **Table 2.3** and **Table 2.4**, respectively.

Table 2.1 North Richmond demographic overview based on the 2021 census

North Richmond Demographic Overview	
	
Source: https://www.abs.gov.au/census/find-census-data/quickstats/2021/SAL13012	
Population	6,358
Number of private dwellings	2,473 (either occupied or unoccupied)
Number of single-person householders	563 (23.9%)
Property tenure	Owned: 1,569 (66.6%, either outright or with a mortgage) Rented: 640 (27.2%)
Number of persons over the age of 75	693 (10.9%)
Number of single-parent families	332 (18.4%)
Language	English only is spoken at home: 5,660 (89%) A non-English language spoken at home: 215 (9.1%)
Average number of children per families with children	1.8
Average number of children per all households	0.8
Number of educated people aged 15 years and over	4,635 (90.3%)
Employed (including worked full-time, part-time and away from work)	2,932 (96.7%)
Number of dwellings without motor vehicles	86 (3.7%)

Table 2.2 Kurrajong demographic overview based on the 2021 census

Kurrajong Demographic Overview	
	
Source: https://abs.gov.au/census/find-census-data/quickstats/2021/SAL12226	
Population	3,113
Number of private dwellings	1,106 (either occupied or unoccupied)
Number of single-person householders	171 (16.4%)
Property tenure	Owned: 912 (87.2%, either outright or with a mortgage) Rented: 109 (10.4%)
Number of persons over the age of 75	264 (8.5%)
Number of single-parent families	332 (18.4%)
Language	English only is spoken at home: 2,854 (91.7%) A non-English language spoken at home: 98 (9.4%)
Average number of children per families with children	1.9
Average number of children per all households	0.8
Number of educated people aged 15 years and over	2,377 (92.2%)
Employed (including worked full-time, part-time and away from work)	1601 (97%)
Number of dwellings without motor vehicles	9 (0.9%)

Table 2.3 Grose Vale demographic overview based on the 2021 census

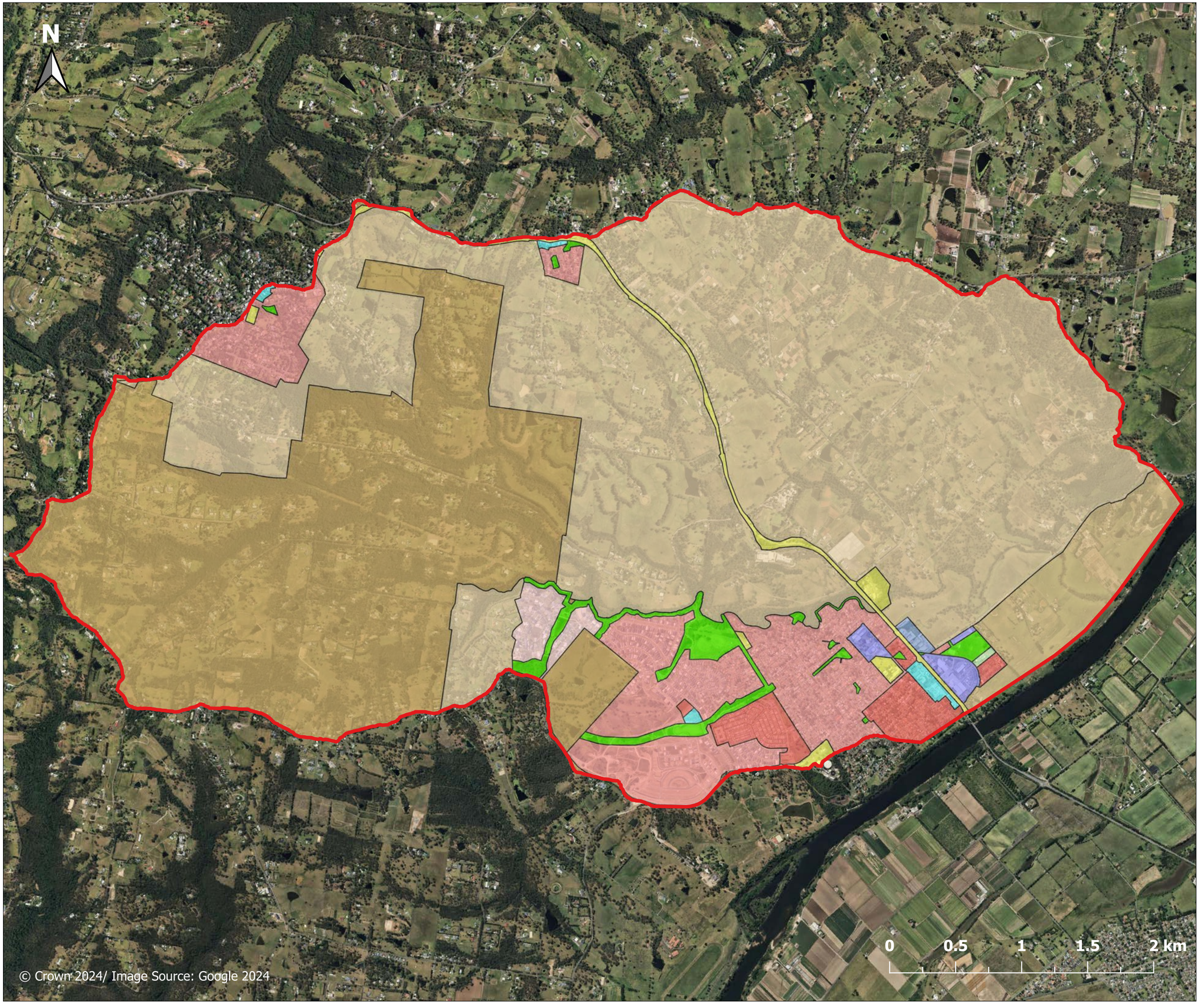
Grose Vale Demographic Overview	
	
Source: https://abs.gov.au/census/find-census-data/quickstats/2021/SAL11791	
Population	1,272
Number of private dwellings	414 (either occupied or unoccupied)
Number of single-person householders	53 (13.3%)
Property tenure	Owned: 361 (92.3%, either outright or with a mortgage) Rented: 28 (7.2%)
Number of persons over the age of 75	86 (6.8%)
Number of single-parent families	37 (10.1%)
Language	English only is spoken at home: 1,146 (90.1%) A non-English language spoken at home: 48 (12.3%)
Average number of children per families with children	1.9
Average number of children per all households	0.9
Number of educated people aged 15 years and over	993 (91.9%)
Employed (including worked full-time, part-time and away from work)	672 (96.6%)
Number of dwellings without motor vehicles	-

Table 2.4 Kurmond demographic overview based on the 2021 census

Kurmond Demographic Overview	
	
Source: https://abs.gov.au/census/find-census-data/quickstats/2021/SAL12223	
Population	850
Number of private dwellings	294 (either occupied or unoccupied)
Number of single-person householders	56 (19.8%)
Property tenure	Owned: 234 (83%, either outright or with a mortgage) Rented: 40 (14.2%)
Number of persons over the age of 75	83 (9.5%)
Number of single-parent families	31 (12.8%)
Language	English only is spoken at home: 763 (89.8%) A non-English language spoken at home: 32 (11.3%)
Average number of children per families with children	1.9
Average number of children per all households	0.8
Number of educated people aged 15 years and over	609 (90.9%)
Employed (including worked full-time, part-time and away from work)	419 (96.1%)
Number of dwellings without motor vehicles	5 (1.8%)

Figure 2.5

Land zoning



Legend

- Study area

Land zoning
LEP 2012

- E1 - Local Centre
- E3 - Productivity Support
- E4 - General Industrial
- C4 - Environmental Living
- R2 - Low Density Residential
- R3 - Medium Density Residential
- R5 - Large Lot Residential
- RE1 - Public Recreation
- RE2 - Private Recreation
- RU1 - Primary Production
- RU2 - Rural Landscape
- RU4 - Primary Production Small Lots
- SP2 - Infrastructure
- W1 - Natural Waterways

Report MHL3008

Redbank Creek Flood Study

NSW GOVERNMENT

Manly Hydraulics Laboratory

3 Previous studies

3.1 Hawkesbury Floodplain Risk Management Study and Plan, (Bewsher Consulting Pty Ltd , 2012)

The Hawkesbury Floodplain Risk Management Study and Plan was prepared for Hawkesbury City Council, by Bewsher Consulting Pty Ltd in July 2012 to build on the significant work done at the regional level, advancing local floodplain management initiatives including the provision of input to local planning instruments (Bewsher Consulting Pty Ltd , 2012).

The study area covers all of the Hawkesbury River and its immediate surroundings that fall within the Hawkesbury LGA. The study area extends from Agnes Banks / Yarramundi in the south to Wisemans Ferry in the north, representing approximately 83 km of the river stretch and an area of 220 km2 subject to inundation in the PMF event. Design flood behaviour in the study area was investigated in detail as part of the Warragamba Dam Auxiliary Spillway Environmental Impact Study (WMA Water, 1996). RORB and RUBICON modelling software were used by WMA Water (1996), which was subsequently converted to RMA-2 for inclusion in the Flood Hazard Definition Tool. Assuming all floor levels are approximately 0.3 m over the ground, an assessment was made of the number of buildings potentially flooded. About 350 houses would be inundated in 5% AEP flood, rising to 1600 houses in the 2% AEP, 3200 houses in the 1% AEP, and over 13000 in the PMF. An assessment of the potential cost of flooding to the residential sector was made and the annual average cost of flood damage to houses is calculated as about $18 million, whilst the value of damages over a 2% AEP is calculated as about $261 million. Design flood hydrographs for the Hawkesbury River at North Richmond is shown in **Figure 3.1**. This shows the floods peaking after about two days of the onset of flooding.

Although this study provides flood information and flood behaviour in the North Richmond area, a finer resolution flood study is required to delineate flood behaviour and risk in the Redbank Creek catchment. Moreover, while generally consistent, the flood levels defined in this study have been superseded by the recent studies described in the following sections.

3.2 North Richmond Township Flood Study and Options Assessment (J. Wyndham Prince, 2012)

The North Richmond Township flood study and options assessment was prepared for North Richmond Township in July 2012 to present a flood assessment of the hydraulic performance of the existing stormwater drainage infrastructure within the township of North Richmond and a preliminary investigation, identification and assessment of flood mitigation options (J. Wyndham Prince, 2012).

The study provides information on flood extents, and depths for design storm events, including 20% and 1% AEP events. An XP-RAFTS hydrologic model and a TUFLOW hydraulic model were used. The important parameters include initial losses (IL) and continuing losses (CL) for pervious and impervious areas. Impervious areas IL and CL are 1 mm and 0 mm/hr, respectively, and pervious area IL and CL are 20 mm and 2.5 mm/hr, respectively. Various Manning's Roughness coefficients were used within broader categories of buildings

(n = 3.000), open spaces (n = 0.030), road layer (n = 0.020), rural zoning (n = 0.055), and defaults (n = 0.035).

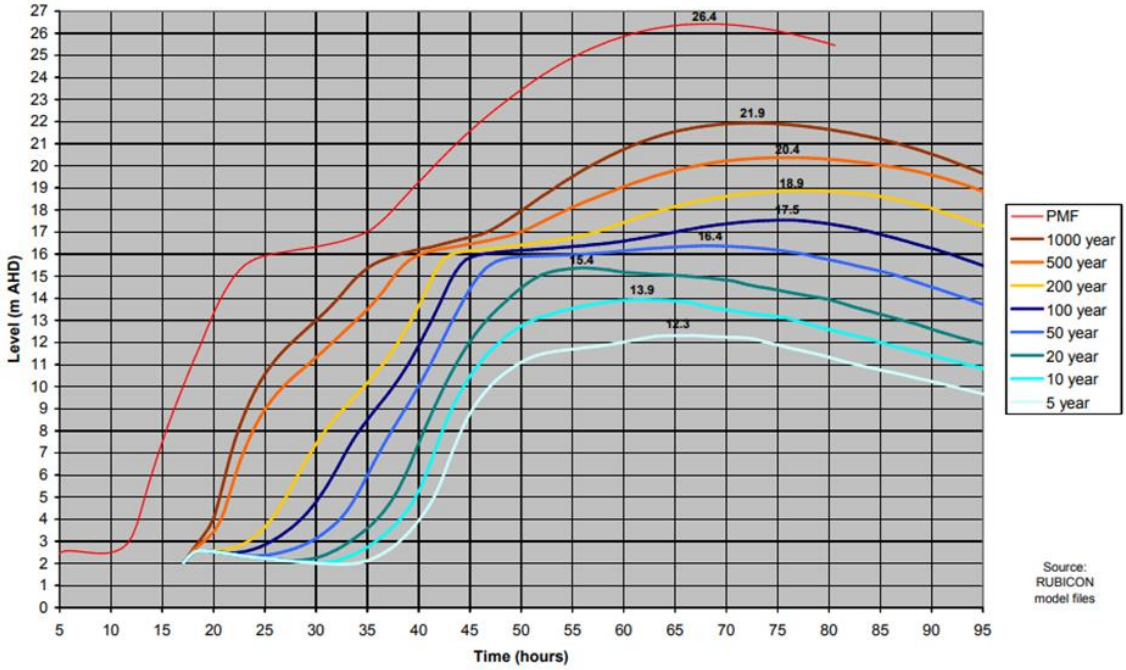


Figure 3.1 Design flood hydrographs for the Hawkesbury River at North Richmond Bridge (Source: WMA Water (1999) Rubicon model files; Retrieved from (Bewsher Consulting Pty Ltd , 2012)

3.3 Penrith CBD Detailed Overland Flow Flood Study-Final Report (Cardno, 2015)

Penrith CBD Detailed Overland Flow Flood Study was prepared for Penrith City Council, in July 2015 to define the flood behaviour, the flood hazard, and to quantify flood damages under existing conditions (Cardno, 2015). The study area lies to the west of Sydney, east of Nepean River and north of the M4. It comprises the Penrith Central Business District (CBD) and the surrounding suburbs. This area is located on the southern side of the railway, and is bounded by Parker Street in the east, Jamison Road in the south, and Mulgoa Road in the west.

The study provides information on flood extents, levels, depths, and velocities for a full range of design storm events, including 1 EY, 50%, 20%, 10%, 5%, 2%, 1%, 1 in 200 AEP events and Probable Maximum Flood (PMF). An XP-RAFTS hydrologic model and a fully dynamic 1D/2D hydraulic TUFLOW model were used to assess flood behaviour in the Penrith CBD study. Impervious areas IL and CL are 1.5 mm and 0.0 mm/hr, respectively, and pervious area IL and CL are 10 mm and 2.5 mm/hr, respectively.

The hydraulic roughness map used in the “Overview Study” (Cardno Lawson Treloar, 2006) has been used for the 2D modelling (Table 3.1). As there is no standard reference that provides guidelines on estimating the hydraulic roughness for overland flow in 2D models in urban areas, the hydraulic roughness used in this study guided the determination of the roughness values in the current study.

Table 3.1 Roughness Values for 2D modelling used in (Cardno, 2015)

Classification	Adopted roughness values
Grass	0.03
Roads	0.015
Residential / Urban Areas	0.10
Forest / Bushland	0.10
Creeks / Waterways	0.03
Open Bushland/Shrubs	0.05
Fences (highly impermeable)	1.00

3.4 Hawkesbury - Nepean Valley Regional Flood Study (WMA Water, 2019)

Hawkesbury - Nepean Valley Regional Flood Study was prepared for Infrastructure NSW by WMA Water in July 2019 to assess flood behaviour for the Hawkesbury - Nepean River from Bents Basin near Wallacia downstream to Brooklyn Bridge (WMA Water, 2019). As part of this study, the previous flood frequency analysis was updated using the latest techniques at the time of modelling and using 22 years of additional rainfall and flow data used to calibrate the hydrologic model and to verify flow-frequency distribution derived from the Monte Carlo simulations. A RORB hydrologic model was developed to calculate flood flows resulting from rainfall events. A quasi-two-dimensional hydraulic model (RUBICON) was developed to calculate peak flood levels resulting from the flood flows. A Monte Carlo framework was established to better replicate the observed variability in actual flood events.

The Regional Flood Study calculated flood levels, extents, depths, provisional flood hazard and hydraulic categories for a series of defined design events. The design events included the 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500, 1 in 1,000, 1 in 2,000, 1 in 5,000 AEPs and Probable Maximum Flood (PMF) events. **Table 3.2** summarises the design flood levels at North Richmond Bridge. Comparing Hawkesbury Nepean Valley Regional Flood Study to previous regional flood studies from 1996 / 1997, this Regional Flood Study found that:

- The level of the 20% AEP event has decreased across the valley because the new study allows for the possibility that Warragamba Dam could be below its full water supply level at the beginning of the flood event and would be able to hold back inflows from smaller floods;
- Peak flood levels for the PMF event have increased at several sites because of new approaches to modelling this extreme event, and updated information.

While this study provides useful information on Hawkesbury-Nepean mainstream regional scale flood behaviour in North Richmond. It does not include local overland flooding or overland flow inundation. Therefore, a finer resolution flood study is required to delineate flood behaviour and risk in the Redbank Creek Catchment due to local overland flooding.

Table 3.2 Peak flood levels for design quantiles at North Richmond Bridge documents in the Hawkesbury Nepean Valley Regional Flood Study, (WMA Water, 2019)

Defined design events	Water Level at North Richmond Bridge (m AHD)
20% AEP	11.4
10% AEP	13.7
5% AEP	15.4
2% AEP	16.5
1% AEP	17.6
1 in 200 AEP	18.6
1 in 500 AEP	19.8
1 in 1,000 AEP	20.7
1 in 2,000 AEP	21.9
1 in 5,000 AEP	22.8
PMF	26.8

3.5 Hawkesbury-Nepean River March 2021 Flood Review (Infrastructure NSW, 2021)

The Hawkesbury-Nepean River March 2021 Flood Review was prepared by Infrastructure NSW in December 2021 to assess the causes, nature and impacts of the flood on the largest flood in the Hawkesbury-Nepean Valley for 30 years (Infrastructure NSW, 2021). This review commenced in response to the Hawkesbury-Nepean Valley Flood Risk Management Strategy's monitoring / evaluation / reporting / improvement framework (outcome 9), which requires evaluation after a significant flood. This report includes an assessment of the difference that various flood mitigation options would have made to this flood. The focus of the study was on flooding of the main river between Bents Basin near Wallacia and Brooklyn, plus backwater flooding. The flood had significant impacts on communities in Penrith, Hawkesbury, Blacktown, The Hills, Hornsby, and Central Coast local government areas. At North Richmond, the floodwaters from Warragamba caused a significant increase in the Hawkesbury River level on 20 and 21 March, peaking with major flooding at 14.91 m AHD at 4:30 pm on 21 March. While a lower, second peak was observed on Wednesday 24 March (13.94 m AHD), it was less pronounced compared to sites upstream. Information on flood behaviour at the North Richmond is shown in **Figure 3.2**. North Richmond and Windsor experienced flooding with an estimated magnitude of the 10% to 5% AEP events.

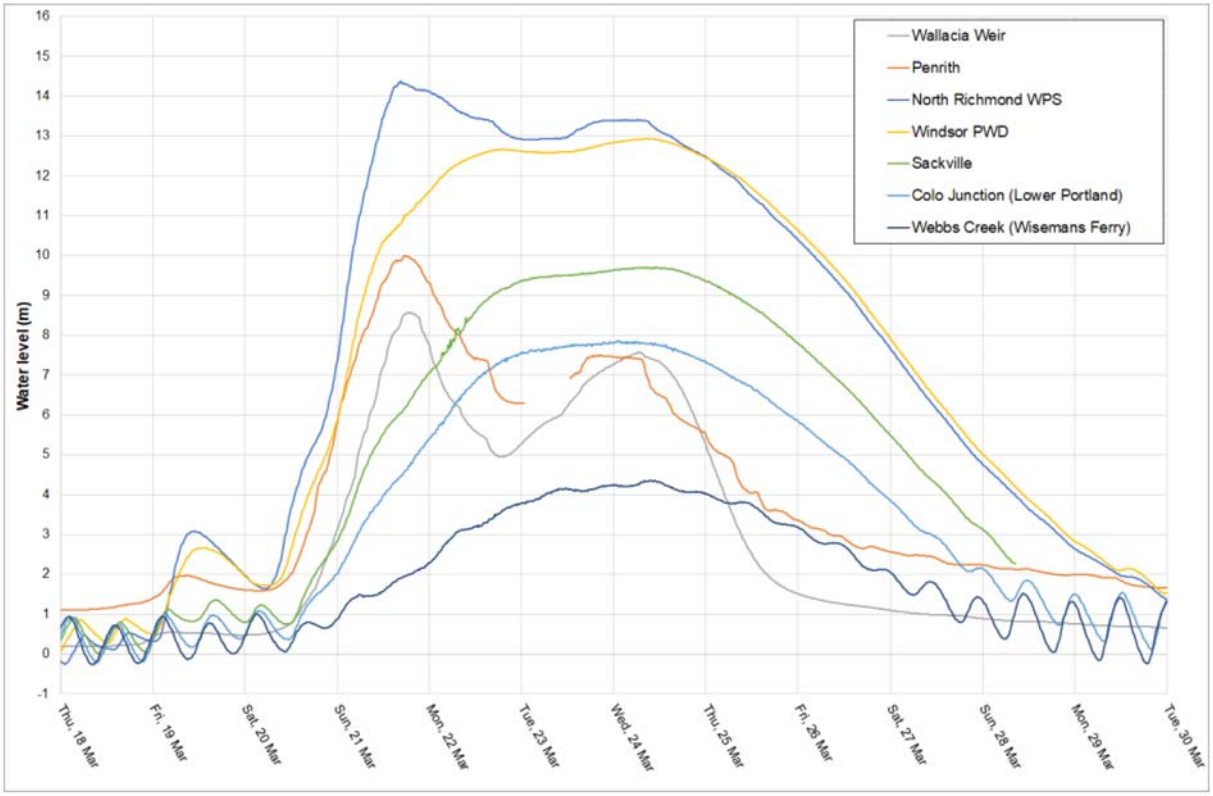


Figure 3.2 Flood hydrographs for selected Hawkesbury-Nepean flood warning gauges, 18 to 29 March 2021 (Retrieved from (Infrastructure NSW, 2021)). Note: The hydrographs are referenced to gauge datum, and when the gauge zero (0.529 m AHD) is applied, the values are expressed in m AHD.

3.6 Hawkesbury-Nepean River March and July 2022 Flood Review (Infrastructure NSW, 2023)

The Hawkesbury-Nepean River March and July 2022 Flood Review was prepared by Infrastructure NSW in February 2023 to assess the causes and nature of the flooding and the riverbank erosion that resulted from the flooding (Infrastructure NSW, 2023). The Hawkesbury-Nepean River system experienced four floods in March, April, July and October 2022. The two largest floods occurred in March and July and were documented in detail in this review (Infrastructure NSW, 2023).

The study area is located between Bents Basin near Wallacia and Brooklyn, including communities around Penrith and Windsor. The focus in this review was on flooding of the Nepean and Hawkesbury rivers downstream of Warragamba Dam, and backwater flooding up tributaries associated with flooding of the main river, such as South and Eastern creeks. In March 2022, the Hawkesbury-Nepean River were severely impacted by flooding. The March 2022 flood was a high-volume flood with two distinct peaks about five days apart. At North Richmond, the arrival of the floodwaters from Warragamba saw the Hawkesbury River rise steeply on 2 March, before initially peaking with major flooding at 13.59 m AHD at 3:15 pm 3 March. The second peak water level reached 14.66 m AHD at 12:15 am 9 March with an approximate likelihood of 1 in 5 to 10 chance per year (20% to 10% AEP events). North Richmond Bridge was flooded to the water level approaching 14.54 m AHD at the bridge, which